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The SAFFIE Project Report

Acknowledgements

Chapter 1 – Abstract

(Pages 1 – 6)

Sustainable Arable Farming For an Improved Environment

SAFFIE

Enhancing Biodiversity

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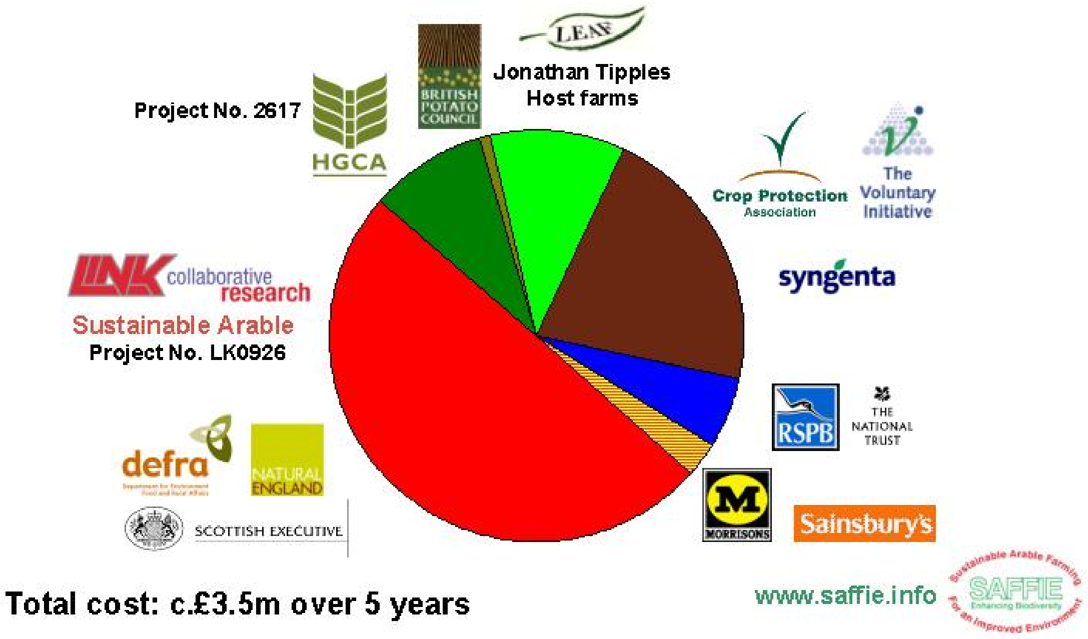

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1 ABSTRACT

The Sustainable Arable Farming For an Improved Environment (SAFFIE) project started in 2002 and experimental work continued until the end of 2006. When the project was conceived, arable farmers needed to optimise inputs and improve efficiency, and the UK was committed to increase biodiversity, especially for farmland birds. The SAFFIE project aimed to reconcile these pressures by developing new crop and margin management techniques for winter cereals and quantifying the associated costs and environmental benefits.

The SAFFIE project developed Skylark Plots, confirmed the benefits of adding wildflowers to grass margins, evaluated a range of in crop weed control programmes and tested two margin management techniques (graminicides and scarification) that had potential to create new habitats. The studies quantified: (a) the impact of these techniques on key species of grasses and flowering plants, beetles, bugs, flies, grasshoppers, soil invertebrates, spiders, bees, butterflies and birds; and (b) the costs of the techniques. Key findings included the following.

Plants

- Weed cover was increased by the use of selective herbicides and this benefited wider biodiversity. Selective herbicide applications in spring left more plant cover than application sequences, benefiting arthropod abundance. However, weed management must be site-specific and this approach is not appropriate where pernicious weeds are common or where there are herbicide resistant weeds.
- Plant species diversity in margins decreased over the five years, regardless of seed mix and treatment.
- Plots sown with a seed mix of fine grasses and wild flowers generally had the greatest abundance of reproductive resources (buds, flowers, seed/fruit) and plots sown with a grass seed mix generally had the lowest values.
- Compared with other margin management treatments, margins scarified in March/April had:
  - the greatest percentages of bare ground (21%, compared to 3% with cutting and 4% with graminicide),
  - enhanced plant species diversity at some sites,
  - plant diversities converging between margins sown with different seed mixes,
  - lower values of architectural complexity (especially of the dead litter, fine grass and legume components), and
  - reduced values of reproductive resources.
- In margins that had an application of a graminicide, plant communities included more sown wildflower species than margins that were scarified or cut.

Invertebrates

- The grass seed mix provided a good resource for those invertebrate species that are dependent on sward architectural complexity; however, it is a poor resource for phytophagous species, particularly where their host plants are wildflowers.
- A seed mix of tussocky grasses and wild flowers provided an architecturally complex sward and host plants vital for many invertebrate species.
- For a variety of invertebrate taxa there was evidence that abundance and species richness will reach a maximum 2–3 years after margin establishment.
- Sowing a diverse seed mixture of perennial wildflowers was the most effective means of creating foraging habitat for bees and butterflies on arable field

margins. Inclusion of forbs in the seed mixture resulted in increases in abundance and diversity of pollen and nectar resources, bumblebees and butterflies.

- Invertebrate species that required either an architecturally complex sward or dense grass responded poorly to scarification, e.g. planthoppers, spiders and Symphyta/ Lepidoptera larvae. In contrast, improved establishment of some wildflower species in response to scarification benefited some phytophagous invertebrates, e.g. weevils and leaf beetles.

- In scarified margins there were fewer species and lower abundances of isopods than in other margins. Species assemblages in the scarified plots consisted of species commonly associated with cropped or exposed habitats.

- Graminicide application is a practical option for enhancing the value of the large area of species-poor grass margins for pollinators.

Birds

- Creating bare ground and foraging access in wheat crops and field margins were the most important management treatments, and gave a significant (up to 4 fold) increase in bird densities and breeding territories for both field and boundary nesting species. Open ground can be achieved at relatively low cost by scarification in margins, and by creating undrilled patches in winter cereal crops.

- In wheat fields with undrilled patches, skylark territory densities were higher (particularly in the crucial late-season breeding period) and the number of skylark chicks reared was nearly 50% greater than in fields without undrilled patches.

- Wheat sown with wide-spaced rows provided some wildlife benefits (particularly for skylarks) but effects were smaller and less consistent than for crops with undrilled patches.

- For all species and species groups, bird densities and territories were consistently higher (1.3 - 2.8 times) in fields with margins and undrilled patches, than in fields with a conventional crop. This response was consistent also for Farmland Bird Index species and Biodiversity Action Plan species.

- In fields with undrilled patches and un-cropped field margins there were indications that skylarks experienced reduced breeding success and productivity compared with conventionally managed wheat. This was attributed to increased mammalian predator activity. It is recommended that wherever practical undrilled patches should not be situated within 50 m of a margin.

- For birds, margin sward content in terms of the grass/flower mix, was best managed to encourage beetles (especially Carabidae) and spiders (Arachnidae).

Costs

- Undrilled patches receiving Defra Entry Level Scheme (ELS) payments had a net benefit to farmers of £7.00 to £8.50 /ha, if made by lifting the drill and there was no additional weed control. If undrilled patches were made using an herbicide after crop emergence, and there was the unlikely need for additional weed control, the net cost to farmers would be £3.50 to £5.00 /ha.

- Field margins established with wild flowers in the seed mixes were ten times more expensive than grass-only seed mixes, and these costs are unlikely to be met by current agri-environment schemes. Higher wheat prices increase costs to the farmer because of greater production loss. Additional agri-environment scheme payments for floristic enhancement of margins are likely to be required if take-up is to be substantially improved.

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LINK collaborative research

The Voluntary Initiative

The SAFFIE Project Report

Chapter 2 – Executive Summary

(Pages 7 – 15)

Sustainable Arable Farming For an Improved Environment

SAFFIE

Enhancing Biodiversity

2 EXECUTIVE SUMMARY

2.1 INTRODUCTION AND OBJECTIVES

The Sustainable Arable Farming For an Improved Environment (SAFFIE) project started in 2002 and experimental work continued until the end of 2006. When the project was conceived there were competing economic and environmental pressures. Arable farmers had a need to optimise inputs and improve efficiency, and the UK had a commitment to increase biodiversity, especially farmland bird populations. The SAFFIE project aimed to reconcile these pressures by quantifying costs and environmental benefits of new techniques for farmers and policy-makers.

The SAFFIE project evaluated practical techniques to improve biodiversity in the cropping environment by quantifying: (a) the impact of the techniques on key species of birds, grasses and flowering plants, bees, butterflies, beetles, bugs, flies, grasshoppers, subsoil invertebrates and spiders; and (b) the costs of the techniques. Specific objectives of the SAFFIE project were:

1. Manipulate agronomy of wheat to increase biodiversity (see 2.2 and Chapters 4 and 5),
2. Manage margin vegetation to maximise biodiversity (see 2.3 and Chapter 6),
3. Assess the integrated effects of 'best' crop and margin management practices (see 2.4 and Chapter 7),
4. Conduct a cost: benefit analysis of the best practices (see 2.5 and Chapter 8), and
5. Interact with the farming community to focus the work and promote findings (see 2.6 and Chapter 9).

2.2 OBJECTIVE 1: MANIPULATE AGRONOMY OF WHEAT TO INCREASE BIODIVERSITY

2.2.1 Experiment 1.1 – Crop management to increase biodiversity (Chapter 4)

Wheat crops with normal row spacing, or with wide-spaced rows, or with undrilled patches (called Skylark Plots in ELS) and normal-spaced rows, were evaluated in winter wheat fields on 10 farms in 2002 and 2003, to determine effects on abundance and availability of food and nest sites for birds. Invertebrates, plants and birds were monitored during April-August, with emphasis on the breeding success of skylarks.

The treatments were:

CONV: The experimental control, conventional husbandry with normal row spacing and management.

UP: Undrilled Patches established at a density of 2 undrilled patches per ha; with the dimensions of each individual undrilled patch being approximately 4 m x 4 m.

WSR: Wide-spaced drill rows sown at double the normal width.

The experimental design aimed to locate the treatments within the same set of fields in both years of the study, with the location of individual treatment blocks randomly switched between years. Treatment blocks were then monitored for two years to provide data on agronomic implications of the treatments and their effects on various aspects of biodiversity, including arable plants, invertebrate taxa and birds (typified by a crop-nesting species: the skylark, *Alauda arvensis*).

At a local level within the UP treatments, differences in vegetation cover, structure and seed production were often marked, although there was variation between sites and years. Compared to the surrounding crop, the vegetation in undrilled patches was shorter, sparser and patchier, with higher weed cover including species important in the diet of birds, and a few invertebrate species or families were more abundant in the UP treatment. Although the UP treatment did not deliver consistent increases in bird-food abundance or biomass, the vegetative structure of undrilled patches was likely to have substantially increased access to the chick-food resources that were present. Probably as a result of this, in the UP treatment, skylark territory densities were higher (particularly in the crucial late-season breeding period) and the number of skylark chicks reared was nearly 50% greater than in the CONV treatment. The WSR treatment provided some wildlife benefits (particularly for skylarks) but effects were not as consistent or as pronounced as for the UP treatment and a yield decrease was noted on some sites.

The striking success of the UP treatment for skylarks suggests that, if widely adopted alongside other ‘skylark-friendly’ options (e.g. over wintered stubbles to provide the other resources needed for skylarks to complete their life-cycle), it could benefit skylark populations. In England (which has about 80% of the UK arable land with winter-sown rotations), this measure is now available as the ‘Skylark Plots’ option in the Environmental Stewardship Scheme, providing funding for farmers wishing to introduce Skylark Plots to their winter cereal fields. However, take-up so far has been low (<3% agreements at the end of 2006), as it does not accrue a high points total (compared with some other options) or have the familiarity of management associated with some other Stewardship options.

The successful development and experimental testing of the UP treatment, and subsequent, rapid integration into national agricultural policy, represents a rare example of a targeted and practicable conservation initiative that could protect the population of a widespread, but declining, species throughout much of its range. The development and deployment of such ‘smart’ research-based schemes, along with continued financial support of agri-environment schemes, represents a very practical way that the UK Government can reach its 2020 target to reverse farmland bird declines.

2.2.2 Experiment 1.2 – Weed management to increase beneficial weeds (Chapter 5)

Small-scale plot experiments were established at three sites in harvest years 2003, 2004 and 2005, to look at combinations of herbicide treatments, row spacing and hoeing, to maximise the diversity of plant species and associated insects within wheat crops, without compromising yield.

A factorial design combined row spacing and cultivation treatments with targeted herbicide programmes. Conventional row spacing was compared to wide-spaced rows (WSR) and WSR plus a cultivation between the rows in spring. Herbicide treatments included a range of selective and broad-spectrum herbicides that were applied individually and in combination. The study was conducted for three years at three sites with contrasting soil types. Herbicide treatments were different at one site reflecting the different weed spectrum.

Vegetation cover and arthropod abundance (sampled using a Dvac suction sampler) were recorded in mid June. Seed production was measured on a subset of treatments by pre-harvest seedhead and soil surface samples. Fertile tiller number, yield and grain quality were recorded. Data were analysed using a two factor analysis of variance for each site/year individually. Plant species were grouped according to their desirability with respect to both agronomic issues and biodiversity benefits. Arthropods were analysed by both taxonomic and functional groupings. Plant and arthropod communities were also analysed using multivariate techniques to investigate relationships between the two species assemblages.

Row spacing had a significant effect on fertile tiller number and yield at some sites and in some years, although crop cover was consistently lower under wide-spaced rows compared to conventional. Overall, the use of wide-spaced rows significantly reduced yield by 4% compared to conventional spacing. Using a spring cultivation with the wide-spaced rows significantly reduced yield by 4% over wide-spaced rows alone. Yields were significantly lower in untreated plots compared to those that received herbicides in five of the nine site and year combinations. However, differences between herbicide treatments were only recorded at one site in one year.

Weed and arthropod populations were different at each site and in each year, reflecting the different soil types, fields and climatic conditions. There were few effects of the spacing/cultivation treatments on either vegetation or arthropods; where differences were recorded, the effects were not consistent across sites or years.

Herbicide treatment had a significant effect on all individual weed species and groupings analysed, except where weed cover was very low (<0.5% on untreated plots). Highest weed cover and diversity were usually recorded on untreated plots. Generally, single product applications left more plant cover than sequences; different sequences controlled weeds equally effectively, except at Boxworth in 2004, where some species were not fully controlled in the absence of a pre-emergence herbicide. In most cases, of treatments receiving herbicide, a spring application of amidosulfuron allowed the most weeds to survive. Where desirable species remained, undesirable species were sometimes poorly controlled, but in cases where *Galium aparine* (cleavers) was the most important undesirable species, a spring application of amidosulfuron effectively controlled this species, but left appreciable cover of desirable species. Effects of herbicide on seed production were similar to those on weed cover.

There was variation in the degree to which arthropod groups were affected by differences in vegetation cover under differing herbicide regimes, but untreated plots usually supported greatest arthropod populations, and herbicide sequences the lowest. Of the single herbicide applications, arthropod abundance was generally highest where there was a spring application of amidosulfuron, benefiting a range of groups including nectar feeders, omnivores, Diptera, Heteroptera and species comprising skylark food items. This effect was pronounced at High Mowthorpe in 2005 and Boxworth in 2004.

Weed cover and arthropod abundance were only related where weed cover was relatively high (>25% on untreated plots), as were the species assemblages. The species composition of the weed assemblage was affected by herbicide application; most applications reduced the complexity of the weed spectrum. In contrast with the weed community, the species assemblage of the arthropods responded to row spacing and cultivation. At Gleadthorpe in 2003, wide-spaced, cultivated rows supported a greater proportion of beetles, bugs and spiders, which are all components of chick food.

The results of this study suggest that, in certain circumstances, it is possible to increase weed cover by the use of selective herbicides and this can result in positive benefits for wider biodiversity. However, management must be site specific and reactive and this approach is not appropriate where pernicious weeds are common or where herbicide resistance is present.

2.3 OBJECTIVE 2: MANAGE MARGIN VEGETATION TO MAXIMISE BIODIVERSITY

2.3.1 Experiment 2. – Margin management to maximise biodiversity (Chapter 6)

Three grass seed mixtures comprising a grass mix (CS, typical of countryside stewardship), a mixture of tussock grasses and flowers (TG, to increase ground-dwelling invertebrates), and a mixture of fine-leafed grasses and flowers (FG, to increase insect diversity, including pollen and nectar feeders), were sown as 6 m wide margins, at three sites in during October 2001–March 2002. Three different spring management treatments (cutting, scarification and a low rate of a selective graminicide) started in 2003, and were applied annually to each margin type, to manipulate the architecture of the vegetation. The resulting vegetation, invertebrates and birds were monitored until 2006.

2.3.1.1 Agronomic implications

There was no evidence that plants sown in the margin became weeds in the adjacent crop, and there was no increase in crop pest incidence adjacent to margins.

2.3.1.2 Plant biodiversity

Plant species diversity in margins decreased over the five years regardless of seed mix and treatment.

Values of coarse grain vegetation structure (based on height measurements) were highly variable with respect to treatment, site and year. Scarification, graminicide and the FG mix treatments were generally associated with the lowest values.

<u>Seed mix</u>

Distinct plant communities developed in the establishment year in relation to seed mix, but no effects on bare ground, litter cover and coarse grain vegetation structure were found. A greater species number and diversity resulted from sowing diverse seed mixes. Analysis across all sites revealed that plant diversity was lowest in plots sown with the CS mix in all years.

Plots sown with the CS mix generally had the lowest abundance of reproductive resources (buds, flowers, seed/fruit) and plots sown with the FG mix generally had the greatest values.

Analysis across all sites revealed that seed mix had no effect on values of coarse grain vegetation structure (vegetation height) recorded in June. In contrast, analysis across sites for September revealed that seed mix had a strong influence on coarse grain structure, with shorter vegetation in plots sown with the FG mix.

Key species depending on seed mix were determined for each site. At all sites, grasses were major determinants of sward composition, with *Festuca rubra* (red fescue) being strongly associated with plots sown with the FG mix. *Dactylis glomerata* (cock's foot), *Festuca pratensis* (meadow fescue) and *Phleum pratense* (timothy) were key grass species for the TG mix. The CS mix was mainly associated with unsown species, especially in 2003. These included, *Poa annua* (annual meadow-grass), *Poa trivialis* (rough meadow-grass), *Cirsium arvense* (creeping thistle) and *Tripleurospermum inodorum* (scentless mayweed), but responses were site specific. At Boxworth, *Leucanthemum vulgare* (ox-eye daisy) and *Dipsacus fullonum* (teasel) were key wildflower indicator species, while at Gleadthorpe, *L. vulgare*, *Lotus corniculatus* (bird's-foot trefoil) and *Achillea millefolium* (yarrow) were important species. At High Mowthorpe, *L. vulgare* was a key wildflower species during 2003 and 2004, but in 2006, *L. corniculatus*, *Plantago lanceolata* (ribwort plantain), *Ranunculus acris* (meadow buttercup) and *Galium mollugo* (hedge bedstaw) were an important determinant of community composition.

<u>Margin management</u>

Across all sites, diversity values were similar in 2003, with respect to management treatments, but in 2004 and 2006, there was greater diversity in scarified plots. Sward scarification in March (or April if applied late) had the following effects:

- it was associated with the greatest values of bare ground cover (compared with other treatments) in both June and September;
- it helped to maintain sown species in the sward and enhance plant species diversity, but this effect was site specific;
- it instigated a convergence in plant community composition between the different seed mixes, but the extent of this was site specific;
- it was generally associated with lower values of architectural complexity, especially of the dead litter, fine grass and legume components;
- it was associated with reduced values of reproductive resources, but tended to promote the resource abundance of the unsown components.

Graminicide application produced plant communities depicted by sown wildflower species.

Cutting was associated with greater values of tussock grass architectural complexity. Cutting was generally associated with greater values of reproductive resources, although in plots sown with the TG mix, values were greater in the graminicide treatment.

2.3.1.3 Invertebrate biodiversity

For a variety of invertebrate taxa there is evidence that abundance and species richness reached a maximum 2–3 years after margin establishment.

<u>Seed mix</u>

The CS seed mix provided a good resource for those invertebrate species that are dependent on sward architectural complexity; however, it can be a poor resource for phytophagous species, particularly where their host plants are wildflowers.

The TG seed mix provided an architecturally complex sward and wildflowers and grasses that are vital as hosts for many invertebrate species. When considered across a variety of non-pollinator invertebrates this was superior to both the CS and FG seed mix.

There was no significant effect of seed mix on the diversity of soil macrofauna.

The abundance and diversity of soil- and litter-feeders did not respond to seed mix.

Sowing a diverse seed mixture of perennial wildflowers was the most effective means of creating foraging habitat for bees and butterflies on arable field margins. Inclusion of wildflowers in the seed mixture resulted in the largest increases in abundance and diversity of pollen and nectar resources, bumblebees and butterflies. The rare bumblebee species, *Bombus ruderatus*, utilised the margins sown with wildflowers in all five years at the Boxworth site.

<u>Margin management</u>

The importance of margin management often showed strong contrasts between taxa. Species that required either an architecturally complex sward or dense grass vegetations responded poorly to scarification, e.g. planthoppers, spiders and Symphyta/ Lepidoptera larvae. In contrast improved establishment of some key floral species in response to scarification benefited some phytophagous invertebrates, e.g. the weevils and leaf beetles.

Isopods responded significantly to management: there were fewer species (typically 2 per m^2) in the scarified plots than in the cut and graminicide plots (typically 3 per m^2), and lower abundances in the scarified plots (about 20 per m^2) than in the other plots (90-110 per m^2). Assemblages in the scarified plots consisted of species commonly associated with cropped or exposed habitats.

The abundance and diversity of soil-feeders were significantly influenced by management treatment. The abundance of soil-feeders in the scarified plots in the spring was low (*c*150 individuals per m^2), but by autumn these then increased to levels equal to, or greater than, the other management treatments (>180 per m^2). Litter-dwelling species, with their requirement for surface residue to provide cover and food, also had low densities in the scarified plots (50 per m^2) in spring, though this increased to about 200 individuals per m^2 in the autumn.

For pollinating insects (bees and butterflies), margin management effects were secondary: soil disturbance by scarification increased diversity of flowering plants; graminicide application reduced competition from grasses, and increased flower abundance and species richness of bees. Graminicide application was a practical option for enhancing the value of the large area of species-poor grass margins for pollinators.

2.3.1.4 Birds

There was a shallow but positive response by birds to treatments that had higher prey densities (of ground beetles in particular; $r^2 = 0.06$) and greater vegetation density ($r^2 = 0.03$). However, bird densities were, on average, over twice as high in the scarification and graminicide treatments, compared with cutting.

Compared with margin management the response of birds to seed mix was weak but significant after five years, birds being more strongly associated with the tussock and fine grass mixes than the CS mix.

2.4 OBJECTIVE 3: ASSESS THE INTEGRATED EFFECTS OF 'BEST' CROP AND MARGIN MANAGEMENT PRACTICES

2.4.1 Experiment 3 – Integrated effects of 'best' crop and margin management (Chapter 7)

The best results from Experiments 1.1 and Experiment 2 were evaluated in winter wheat crops on 26 commercial farms in England and Scotland, starting in 2004. Undrilled patches were established on all sites as the best within-crop option from Experiment 1.1. Two margin types, tussock grasses + flowers (TG) and fine grasses + flowers (FG) were used on each site in equal lengths. The best margin management treatment from Experiment 2, scarification, was tested in the springs of 2005 and 2006.

The four treatments comprised: (1) conventional wheat and no margins; (2) wheat with undrilled patches and margins; (3) conventional wheat and margins; (4) wheat with undrilled patches and no margins.

The 26 field sites were located on typical arable farms in England and Scotland. The farms were located in five clusters, the most northern sites in East Lothian, Scotland and the most southern in south Essex. In the west there was a cluster of five farms in Herefordshire and Shropshire and in the east several sites in Suffolk and Essex. Experiment 3 covered a total area of 856 ha, located on predominantly clay-based soil types, with between 25 and 45 ha on each individual farm. Crop rotations were predominantly winter cropped (70%) with first and second wheat the most common crops. A range of break crops was grown including, winter oilseed rape, barley, peas, onions and potatoes, and set-aside was included in some rotations. All crops were managed by the host farmer, using typical management for the location and season.

In spring 2003, 28 km of margin were sown on the sites between 18 March and 26 May. Drilling was delayed in Scotland due to wet weather. Margins were 6 m wide and accounted for 4% of the field area in which they were drilled. After an establishment year, margins were scarified in spring 2004 by cultivation with a power harrow to a depth of 2.5 cm to achieve a target of 60% disturbance of the soil surface area.

There was no evidence of adverse effects on crop weed, pest or disease levels from incorporating margins and undrilled patches into a winter dominated arable rotation.

For all species and species groups, bird densities and territories were consistently higher (1.3 - 2.8 times) in fields with margins (4% of field area) and two undrilled patches per hectare than in fields with a conventional crop. This response was also consistent for Farmland Bird Index species and Biodiversity Action Plan species, for which farmland recovery is particularly desirable. Factors that affected these increases in density and population size included: (a) in margins, the combined elements of higher beetle and spider abundances, and more complex swards, and (b) in wheat crops, the presence of undrilled patches (large-scale open ground) and bare ground at a fine-scale and at foraging locations. In crops, there were only weak links to invertebrate abundance.

Creating bare ground and foraging access in dense crops and field margins was the single most important management treatment to give the 1.3 –2.8 times increase in bird densities and breeding territories for both field and boundary nesting species. Open ground can be achieved at relatively low cost by scarification in margins, and by creating undrilled patches in wheat crops. For birds, margin sward content in terms of the grass/flower mix, was best managed to encourage beetles (especially carabidae) and spiders (Arachnidae).

Overall the sown margins and UPs had relatively few effects on the numbers of invertebrates within the crop and, therefore, the abundance of food available to farmland birds. There was some evidence that invertebrates were remaining within the margins rather than dispersing into the adjacent crop. The low levels of weeds within the crop may also have limited colonisation by phytophagous invertebrates and their associated predators. Conversely, invertebrate predation may have been higher where margins and patches were present, so that the effects of the margins were obscured.

There were indications that where undrilled patches and margins were present in the same field, skylarks experienced reduced breeding success and productivity than in conventionally managed wheat. This was attributed to increased mammalian predator activity. It is recommended that undrilled patches should not be situated within 50 m of a margin.

2.5 OBJECTIVE 4: CONDUCT A COST:BENEFIT ANALYSIS OF THE BEST PRACTICES

The approach to the cost-benefit analysis (Chapter 8) was to estimate the additional costs to a farmer of providing the management system in question. These included costs of field operations, inputs (such as seed for margin establishment) and production loss where land was not cropped. These costs were related to possible income from current agri-environment schemes, and to biodiversity benefits by cross-referencing to results of the field studies. As financial values for costs varied between sites and years, they have been shown as ranges, rather than absolute values.

Undrilled patches receiving Department for Environment, Food and Rural Affairs (Defra) Entry Level Scheme (ELS) payments were generally regarded by farmers as easy to create and were beneficial to birds. They were found to have a net financial benefit to the farmer of £7.00 to £8.50 per ha if the undrilled patches were made by lifting the drill (rather than spraying after emergence) and no additional weed control was required. However, if the undrilled patches were made by knapsack application of an herbicide after crop emergence, and there was the unlikely need for additional weed control (by knapsack sprayer), the net cost to farmers would be £3.50 to £5.00 /ha.

In practice, in the SAFFIE experiments on 26 farms over 3 seasons, an application of an herbicide by knapsack sprayer was never required to control weeds in undrilled patches. Thus, in this work, undrilled patches were always profitable. However, undrilled patches may be unsuitable (for crops and biodiversity) in fields where herbicide-resistant weeds are a known agronomic problem.

Despite the potential of undrilled patches to deliver a cheap but effective solution for skylarks, take-up in ELS has been poor. Farmers perceived that undrilled patches may require additional management (localised weed control using a knapsack sprayer), which could be time-consuming and costly, relative to the ELS points awarded for this ELS option. It is likely that undrilled patches will need to be further incentivised in future agri-environment scheme reviews to attain a level of take-up that may be beneficial at the population level.

Weed control strategies using a single application of amidosulfuron in the spring, indicated that, in some fields with low populations of pernicious weeds, there might be scope to reduce herbicide use (and thus input costs) without either significantly decreasing yields or increasing non-desirable weeds.

Field margins established with a component of wild flowers in the seed mixes were ten times more expensive than grass-only seed mixes, commonly used in agri-environment schemes such as Countryside Stewardship and ELS. However, the biodiversity benefits, measured at the plant community level, of including wildflowers in the seed mixes were large.

The costs of creating margins using the seed mixes that contain wild flowers, as used in SAFFIE experiments, are unlikely to be met by current agri-environment scheme payments. Simplification of seed mixes, via the removal of species that rarely established, could reduce the cost of establishing wildflower margins while retaining the biodiversity benefits. However, the cost calculations are highly sensitive to the price of wheat. For a farmer to break even (without covering overheads), at a wheat price of £85/tonne, £25 to £170 per ha of margin (depending on establishment and management costs) would be available for seed. At £95/tonne the greater value of lost production would result in a loss of £255 to £400, plus the seed cost. However, at £65/tonne (similar to the wheat price early in the SAFFIE project), £880 to £1,025 would be available to cover seed costs (assuming no overheads or profit). These calculations assume the benefit of current ELS payments. To put these values into context, costs of the seed mixtures used in the SAFFIE project ranged from £124 (for a grass mix) to £1,302 per ha of margin.

Additional agri-environment scheme payments for floristic enhancement of margins are likely to be required if take-up is to be substantially improved.

The three margin management techniques incurred similar costs, which were small compared to the costs of the seed mixes. The novel treatments (scarification and selective graminicide) had considerably greater biodiversity benefits than cutting, which is the method currently prescribed to manage margin swards in most agri-environment schemes.

2.6 OBJECTIVE 5: INTERACT WITH THE FARMING COMMUNITY TO FOCUS THE WORK AND PROMOTE FINDINGS

Communication activities (Chapter 9) have included publication of refereed scientific papers, conference presentations and papers, trade and popular press articles, meetings and workshops with farmers and policy makers, field demonstrations and open days, a project web site, and publication of best practice guides.

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The SAFFIE Project Report

Chapter 3 – Introduction

(Pages 16 – 20)

Sustainable Arable Farming

SAFFIE

Enhancing Biodiversity

For an Improved Environment

3 INTRODUCTION

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Chapter 3 contents

3.1 BACKGROUND

There is now widespread consensus that agricultural intensification is, directly or indirectly, the main cause of widespread biodiversity loss observed on lowland farmland in the UK and over much of Europe during the last 30-40 years (e.g. Pain & Pienkowski 1997, Krebs et al. 1999, Robinson & Sutherland 2002, Newton 2004). 'Intensification' is diverse and difficult to define precisely, and differs between arable and pastoral systems. Changes in arable crop varieties, husbandry, nutrition, pest and disease control, harvesting methods, and the subsidies available for these activities, are all likely to have contributed to a simplification of arable crop structure and diversity and, consequently, the associated biodiversity (Fuller 2000).

During this period, population declines have been well documented for many farmland birds (e.g. Donald et al. 2001, 2006, Newton 2004), including many species of conservation concern, such as the skylark, *Alauda arvensis*, for which a substantial proportion of the population breed and feed in cropped habitats (Donald 2004). Agricultural habitats now support more bird species of European conservation concern than any other broad habitat type (Tucker & Evans 1997). These declines have not only affected birds; although not as well-documented, declines in the abundance and species diversity of mammals (Flowerdew 1997), arthropods and flowering plants (Sotherton & Self 2000, McCracken et al. 2004) on farmland have also been severe. Many of these taxa are important as bird food resources (Wilson et al. 1999, Holland et al. 2006).

In response to these declines, the UK government now regards birds as a primary quality of life indicator (with a suite of 19 farmland species contributing to the indictor) and is committed to several Biodiversity Action Plan (BAP) targets. Specifically, the Department for Environment, Food and Rural Affairs (Defra) has a public service agreement to reverse the long-term decline in a suite of farmland bird species (including skylark, grey partridge, yellowhammer, corn bunting and reed bunting) by 2020 (Gregory et al. 2004). Defra is also committed to a number of BAP targets for individual farmland bird species, and a BAP target to increase the area of cereal field margin under conservation management to 15,000 ha by 2010. Although the BAP target for the area of margins has already been achieved, the diversity of wild plants is still in decline in fields and margins, so it is important to consider the quality of an environmental measure as well as the quantity (Vickery et al. 2004).

While seeking to deliver biodiversity and quality-of-life targets, the UK government, environmental non-governmental organisations (NGOs) and other interested parties acknowledge that there are strong economic pressures on UK cereal growers and that an economically viable farming industry is essential to deliver sustainable agricultural systems in which biodiversity can flourish. Hence, proposals to deliver biodiversity are most likely to succeed if they are easy to implement at a minimal cost to the farmer or, if the cost is remunerable, e.g. through agri-environment payments.

The Entry Level Scheme (ELS) component of the new Environmental Stewardship Scheme was launched in the spring of 2005, giving all farmers in England the opportunity to help to redress the balance of wildlife and cropping on their farms. Many arable farmers are now managing the environment as part of their farming businesses, through agri-environment schemes. This revenue will increase in importance as Single Payment Scheme funds are gradually diverted into the agri-environment schemes through the CAP reform measures (Barnett 2007). Thus, selecting the best environmental options for the farm will become as important as choosing, for example, the best variety of a crop species.

3.2 THE SAFFIE PROJECT

The Sustainable Arable Farming For an Improved Environment (SAFFIE) project started in 2002 and experimental work continued until the end of 2006. When the project was conceived there were competing economic and environmental pressures. Arable farmers had a need to optimise inputs and improve efficiency, and the UK had a commitment to increase biodiversity, especially farmland bird populations. The SAFFIE project aimed to reconcile these pressures by quantifying costs and environmental benefits of new techniques for farmers and policy-makers.

3.2.1 Objectives

The SAFFIE project evaluated practical techniques to improve biodiversity in the cropping environment by quantifying: (a) the impact of the techniques on key species of birds, grasses and flowering plants, bees, butterflies, beetles, bugs, flies, grasshoppers, subsoil invertebrates and spiders; and (b) the costs of the techniques. Specific aims of the SAFFIE project were:

1. Manipulate agronomy of wheat to increase biodiversity (see Chapters 4 and 5),
2. Manage margin vegetation to maximise biodiversity (see Chapter 6),
3. Assess the integrated effects of ‘best’ crop and margin management practices (see Chapter 7),
4. Conduct a cost:benefit analysis of the best practices (see Chapter 8), and
5. Interact with the farming community to focus the work and promote findings (see Chapter 9).

3.2.2 Approaches

3.2.2.1 Field experiments

<u>Experiment 1.1 – Crop management to increase biodiversity (Chapter 4)</u>
Wheat crops with normal row spacing, or with wide-spaced rows, or with undrilled patches (called Skylark Plots in ELS) and normal-spaced rows, were evaluated in winter wheat fields on 10 farms in 2002 and 2003, to determine effects on abundance

and availability of food and nest sites for birds. Invertebrates, plants and birds were monitored, with emphasis on the breeding success of skylarks.

Experiment 1.2 – Weed management to increase beneficial weeds (Chapter 5)
Small-scale plot experiments were established at three sites in harvest years 2003, 2004 and 2005, to look at combinations of herbicide treatments, row spacing and hoeing, to maximise the diversity of plant species and associated insects within wheat crops, without compromising yield.

Experiment 2. – Margin management to maximise biodiversity (Chapter 6)
Three grass seed mixtures comprising a typical Countryside Stewardship grass mix, a mixture of tussock grasses and flowers (to increase ground-dwelling invertebrates), and a mixture of fine-leafed grasses and flowers (to increase insect diversity, including pollen and nectar feeders), were sown as 6 m wide margins, at three sites in during October 2001 – March 2002. Three different spring management treatments (cutting, scarification and a low rate of a selective graminicide) started in 2003, and were applied annually to each margin type, to manipulate the architecture of the vegetation. The resulting vegetation, epigeal invertebrates, bees, butterflies and birds were monitored until 2006.

Experiment 3 – Integrated effects of ‘best’ crop and margin management (Chapter 7)
Results from the studies above were evaluated in winter wheat crops on 26 commercial farms in England and Scotland, starting in 2004. Undrilled patches were established on all sites as the best within-crop option from Experiment 1.1. Two margin types, tussock grasses + flowers and fine grasses + flowers were used on each site in equal lengths. The best margin management treatment from Experiment 2, scarification, was tested in the springs of 2005 and 2006. The four treatments comprised: (1) conventional wheat and no margins; (2) wheat with undrilled patches and margins; (3) conventional wheat and margins; (4) wheat with undrilled patches and no margins.

3.2.2.2 Cost-benefit analysis

The approach to the cost-benefit analysis (Chapter 8) was to estimate the additional costs to a farmer of providing the management system in question. These included costs of field operations, inputs (such as seed for margin establishment) and production loss where land was not cropped. These costs were related to possible income from current agri-environment schemes and to biodiversity benefits by cross-referencing to results of the field studies.

3.2.2.3 Communication activities

Communication activities (Chapter 9) have included publication of refereed scientific papers, conference presentations and papers, trade and popular press articles, meetings and workshops with farmers and policy makers, field demonstrations and open days, a project web site, and publication of best practice guides.

3.2.3 Application

Despite the development of agri-environment schemes over the life of the SAFFIE project, there are still competing economic and environmental pressures on farmers and government. The outputs of the SAFFIE project presented in this report remain very relevant to future interactions between farmers and government in agri-environment policy development and implementation. This report provides a detailed record of SAFFIE project activities and findings as a resource to help future decision making.

3.3 REFERENCES

Barnett, A. (2007) Agri-environment policy: a European overview. *Aspects of Applied Biology* **81**, 1-6.

Donald, P.F. (2004) *The skylark*. Poyser, London.

Donald, P.D., Sanderson, F.J., Burfield, I.J. & van Bommel, F.P.J. (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds 1990-2000. *Agriculture Ecosystems and Environment* **116**, 189-196.

Donald, P.F., Green, R.E. & Heath, M.F. (2001) Agricultural intensification and the collapse of Europe's farmland bird populations. *Proceedings of the Royal Society of London, Biological Sciences* **268**, 25–29.

Flowerdew, J.R. (1997) Mammal biodiversity in agricultural habitats. In: Kirkwood, R.C. (Ed) *Biodiversity and Conservation in Agriculture*, 25–40. BCPC Symposium 69. British Crop Protection Council, Farnham.

Fuller, R.J. (2000) Relationships between recent changes in lowland British agriculture and farmland bird populations: an overview. In: Aebischer, N.J., Evans, A.D., Grice, P.V. & Vickery, J.A. (Eds) *Ecology and Conservation of Lowland Farmland Birds*, 5–16. British Ornithologists' Union, Tring.

Gregory, R.D., Noble, D.G. & Custance, J. (2004) The state of play of farmland birds: population trends and conservation status of lowland farmland birds in the United Kingdom. *Ibis* **146**, 1–13.

Holland, J.M., Hutchison, M.A.S., Smith, B. & Aebischer, N.J. (2006) A review of invertebrates and seed-bearing plants as food for farmland birds in Europe *Annals of Applied Biology* **148**, 49–71.

Krebs, J.R., Wilson, J.D., Bradbury, R.B. & Siriwardena, G.M. (1999) The second silent spring? *Nature* **400**, 611–612.

Newton, I. (2004) The recent declines of farmland bird populations in Britain. An appraisal of causal factors and conservation actions. *Ibis* **146**, 579–600.

Pain, D.J. & Pienkowski, M.W. (Eds) (1997) *Farming and Birds in Europ*e. *The Common Agricultural Policy and its Implications for Bird Conservatio*n. Academic Press, London.

Robinson, R.A. & Sutherland, W.J. (2002) Post-war changes in arable farming and biodiversity in Great Britain. *Journal of Animal Ecology* **39**, 157–176.

Sotherton, N.W. & Self, M.J. (2000) Changes in plant and arthropod biodiversity on lowland farmland: an overview. In: Aebischer, N.J., Evans, A.D., Grice, P.V. & Vickery, J.A. (Eds) *Ecology and Conservation of Lowland Farmland Birds,* 26–35. British Ornithologists' Union, Tring.

McCracken, D.I., Bignal, E.M., Blake, S. & Foster, G.N. (2004) Productivity and profitability: the effects of farming practices on the prey of insectivorous birds. In: van Emden, H.F. & Rothschild, M. (Eds) *Insects and bird interactions*, 75–87. Intercept, Andover.

Tucker, G.M. & Evans, M.I. (1997) *Habitats for Birds in Europe. A Conservation Strategy for the Wider Environment*. BirdLife International, Cambridge.

Vickery, J.A., Bradbury, R.B., Henderson, I.G., Eaton, M.A. & Grice, P.V. (2004) The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England. *Biol. Cons.* **119**, 19–39.

Wilson, J.D., Morris, A.J., Arroyo, B.E., Clark, S.C. & Bradbury, R.B. (1999) A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. *Agriculture, Ecosystems and Environment* **75**, 13–30.

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Chapter 4 – Experiment 1.1 – Manipulate within crop agronomy to increase biodiversity: Crop architecture

(Pages 21 – 107)

Sustainable Arable Farming For an Improved Environment

SAFFIE

Enhancing Biodiversity

4 EXPERIMENT 1.1 - MANIPULATE WITHIN CROP AGRONOMY TO INCREASE BIODIVERSITY: CROP ARCHITECTURE

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Chapter 4 contents

4.1 SUMMARY

This experiment investigated the impacts of novel habitat management on the in-crop biodiversity of winter-sown wheat crops. Field trials were carried out during April-August 2002 and 2003, on 10 sites in each year with a representative range of soil types. On each site, wheat crops were established with three treatments:

CONV: The experimental control, conventional husbandry with normal row spacing and management.

UP: Undrilled Patches established at a density of two undrilled patches per ha; with the dimensions of each individual undrilled patch (PA) being approximately 4 m x 4 m.

WSR: Wide-spaced drill rows sown at double the normal width.

The experimental design aimed to locate the treatments within the same set of fields in both years of the study, with the location of individual treatment blocks randomly switched between years. Treatment blocks were then monitored in both summers to provide data on agronomic implications of the treatments and their effects on various aspects of biodiversity, including arable plants, invertebrate taxa and birds (typified by a crop-nesting species: the skylark, *Alauda arvensis*).

Results indicated that the experimental treatments mostly failed to deliver consistent increases in bird-food abundance or biomass, although a few invertebrate species or families were more abundant in the UP treatment. At the field-scale, treatments also had few effects on vegetation. However, at a local level within the UP treatments, differences in vegetation cover, structure and seed production were often marked, although there was variation between sites and years. Compared to the surrounding crop, the vegetation in PAs was shorter, sparser and patchier, with higher weed cover including species important in the diet of birds. The vegetative structure of PAs was likely to have substantially increased access to the chick-food resources that were present. Probably as a result of this, in the UP treatment, skylark territory densities were higher (particularly in the crucial late-season breeding period) and the number of skylark chicks reared was nearly 50% greater than in the CONV treatment. The WSR treatment provided some wildlife benefits (particularly for skylarks) but effects were not as consistent or as pronounced as for the UP treatment and a yield decrease was noted on some sites.

The striking success of the UP treatment for skylarks suggests that, if widely adopted alongside other ‘skylark-friendly’ options (e.g. overwintered stubbles to provide the other resources needed for skylarks to complete their life-cycle), it could benefit skylark populations. In England (which has most of the UK arable land with winter-sown rotations), this measure is now available as the ‘Skylark Plots’ option in the Environmental Stewardship Scheme, providing funding for farmers wishing to introduce Skylark Plots to their winter cereal fields. However, take-up so far has been low (<3% agreements at the end of 2006), as it does not accrue a high point total or have the familiarity of management associated with some Stewardship options.

The successful development and experimental testing of the UP treatment, and subsequent, rapid integration into national agricultural policy, represents a rare example of a targeted and practicable conservation initiative which could protect the population of a widespread, but declining, species throughout much of its range. The development and deployment of such ‘smart’ research-based schemes, along with continued financial support of agri-environment schemes, represents the only practical way that the UK Government can reach its 2020 target to reverse farmland bird declines.

4.2 INTRODUCTION

4.2.1 Background

An example of the potential conflict between maintaining biodiversity and profitable arable farming is provided by the trend to sow more cereal crops in the autumn (‘winter-sowing’) rather than in the spring. This trend, brought about by a variety of mechanisms, including the development of new grass herbicides, cultivation techniques and plant breeding, accelerated rapidly from the late 1960s. In England and Wales, 80% of tilled land was spring-sown in the early 1960s but this had been reduced to 20% by 2000. In some areas, e.g. Cambridgeshire, where heavy-soil conditions mean that spring cultivation is regarded as high risk, winter wheat accounts for nearly 90% of all cereals, just 4% of which are now spring sown (Shrubb 2003, Anon 2004a). It has long been postulated that the switch from spring-sown to winter-sown cereals has been associated with a decline in farmland biodiversity (O’Connor & Shrubb 1986, Fuller 2000). The taller and denser structure of modern winter wheat crops makes them unsuitable for ground-nesting birds, such as lapwing, *Vanellus vanellus*, and skylark, *Alauda arvensis* (Hudson et al. 1994, Donald et al. 2001a). Moreover, non-crop flora that encourages invertebrates is subject to increased competition from crop plants that mature earlier, and to associated herbicide regimes. These effects compound the loss of over-winter stubble fields, which are now ploughed in autumn, prior to the establishment of a new crop, with the consequent loss of winter refugia and food (Evans et al. 2004). Although some attempt has been made to redress the loss of spring-sown cereals through the provision of agri-environment funding (e.g. Department for Environment, Food and Rural Affairs (Defra) Entry Level Scheme (ELS) Option EG1), such prescriptions are relatively expensive to the taxpayer and are still deemed unfavourable in certain crop rotations and soil conditions. Thus, they are unlikely to be taken up on a sufficiently large scale to benefit widely dispersed species.

However, it may not be necessary to depend on reversing the original causes of declines to encourage biodiversity or population recovery in target species. To this end, SAFFIE experiment 1.1 sought to address a clear scientific challenge: how to adjust the agronomy of winter wheat production to make it sustainable in terms of biodiversity while minimising impact on crop husbandry and profitability.

4.2.2 Objective of SAFFIE Experiment 1.1

‘To enhance farmland biodiversity by integrating novel habitat management approaches within the crop’.

Previous arable farming system studies suggested that input reductions help protect existing biodiversity, but produce relatively small improvements on their own (Holland et al. 1998, Young et al. 2001). Nor did these studies (e.g. LINK Integrated Farming Systems, MAFF-funded SCARAB and TALISMAN projects) focus on the combined objectives of delivering increased biodiversity and profitable production.

To address these issues, SAFFIE Experiment 1.1 adopted an alternative novel approach to enhance biodiversity in the farmed landscape through solely manipulating the crop structure (also known as vegetation architecture[1]). This enabled a study of the potential interaction with associated invertebrates and taxa higher up the food chain, coupled with a sound agronomic evaluation of the most practical and cost-effective techniques. The aim was to show how low cost changes in sowing and physical management of the crop could affect the vegetation architecture of winter-sown cereals, bestowing similar advantages to wildlife to those expected from spring cropping. The experiment therefore required an innovative approach to the manipulation of vegetation structure, comparing the impact of 'normal-practice' wheat (CONV), the experimental control, to two novel options: creating undrilled, also known as 'skylark scrapes' or 'skylark plots' within the crop patches (we use the abbreviations UP for this treatment, and PA for an undrilled patch within the experiment fields), and establishing the crop with wide-row spacing (WSR). Previous research has indicated that canopy closure is later in crops with WSR than in a conventionally sown wheat crop.

The hypothesis was that:

- manipulating vegetation architecture in the crop areas (i.e. providing PAs and WSR) would create a diverse sward, thus increasing farmland biodiversity in general and, by enhancing the diversity, abundance and availability of arable plant and invertebrate food, and the provision of nesting habitats, would benefit farmland birds.

4.3 MATERIALS AND METHODS

4.3.1 Field Sites

Field trials were carried out in April-August 2002 and 2003, on 10 sites in each year. Nine sites were constant between years, the other being replaced due to repeated vandalism of the experimental layout in 2002. All sites were winter-sown, wheat-based cropping systems, covering a representative range of soil types. Participating sites are listed in Table 4.1. Further details of each site are available in Appendix 1.

[1] Vegetation architecture refers to the three-dimensional structure of vegetation and is relevant at scales from individual plants to the entire crop sward. Key components of farmland biodiversity, including resources for birds, are influenced by vegetation architecture (Lawton 1983, Morris 2000, Wilson et al. 2005; Butler & Gillings 2004). The patchiness (including bare ground), height, structural and species diversity of the vegetation are all components of vegetation architecture. These features vary both seasonally and spatially.

Table 4.1. Experiment 1.1 sites.

Farm Code	**Location**	**Notes**
HM	North Yorkshire	
GD/LD	Oxfordshire	UP sprayed out in 2003
LE	Oxfordshire	
WP	Cambridgeshire	
PH	Norfolk	
PX	East Yorkshire,	
GK	Cambridgeshire	
SL	Wiltshire	No WSR in 2003
WF	Wiltshire	Bird data only from 2003
WH	Suffolk	2002 only
BX	Cambridgeshire	2003 only

The sites were sown with winter wheat in both years of the study, giving a total of 20 replicates (site / year pairings). Fields adjacent to the treatments were sown with a variety of crops; including other cereals, oilseed rape, sugar beet, potatoes, field vegetables, pulses and grass.

4.3.2 Treatments

On each site, winter-sown wheat crops were established with three treatments:

CONV: The experimental control, conventional husbandry with normal row spacing and management.

UP: Undrilled Patches established at a density of 2 undrilled patches per ha; with the dimensions of each individual undrilled patch (PA) being approximately 4 m x 4 m.

WSR: Wide-spaced drill rows sown at double the normal width.

Treatment areas were selected with characteristics likely to maximise densities of crop-dwelling organisms key to this study, notably skylark (Wilson et al. 1997). Thus, each treatment area was >5 ha and had a relatively open aspect, with minimal influence from surrounding tall hedges, tree lines and woodland.

The experimental design aimed to locate the treatments within the same set of fields in both years of the study, with the location of individual treatment blocks randomly switched between years. However, on three sites, soil condition in autumn 2002 meant that it was not possible to establish a second winter-sown wheat crop on the original treatment areas, and consequently, the 2003 treatments were moved to the nearest available area of winter-sown wheat, matching the above criteria. In addition, one site had to be replaced completely between years (see 4.3.1) and, in 2003, one site was unable to drill WSR, while the UP treatment at another site was established by spraying with glyphosate.

Due to constraints on the availability of the correct crop rotations with suitable associated habitat requirements within the same farm, treatments could be either whole or split fields. In four replicates, all three treatments were in a single large field; in two replicates, the treatments were in three separate fields; in the remaining 14 replicates, the three treatments were in two fields (one whole and one split). In all but two sites (WP, both years; PX, 2003 only), the treatments were adjacent to each other. For details of crop establishment and management, see 4*.3.3.2.*

4.3.3 Methods of data collection

4.3.3.1 *General habitat information*

Using information supplied to ADAS by the landowner/tenants, and mapping visits by RSPB staff, the following data were recorded for all treatments:

- Size (ha) and crop present in each treatment.

- A boundary-height index was calculated for each treatment. These were used to calculate the degree of enclose; a factor known to influence field occupancy by skylarks (Wilson et al. 1997) and which may have a bearing on dispersal into the crop by other taxa (e.g. arable plants and invertebrates). Each boundary segment was categorised by visual observation as belonging to one class of a 5-level factor, adapted from the classification of Wilson et al. (1997): 1 = no structure; 2 = low hedge ≤2 m; 3 = tall hedge >2 m; 4 = line of trees; 5 = tall habitat block e.g. woodland edge or buildings. Normally, a single boundary segment equated to one side of a field. However, two or more separate segment scores per side were made if the nature of the boundary changed dramatically along the same side of a field. Each boundary segment was then assigned an individual score, based on its physical structure multiplied by its length. Individual scores for all boundary segments bordering a treatment were then summed and divided by the total length of the treatment perimeter to give the ‘boundary index’ for that treatment.

- Crop-types, or other habitats, present in all areas adjacent to each treatment. These were used to calculate ‘adjacent habitat scores’ by assigning a score to each individual habitat block adjacent to a treatment. The scores were based on the habitat suitability scores for skylarks given by Browne et al. (2000), multiplied by the length of the treatment perimeter adjacent to the block. The individual scores for all adjacent habitat blocks were then summed and divided by the total length of the treatment perimeter to give the ‘adjacent habitat score’ for that treatment. Values greater than 1.05 (Browne’s score for winter cereals) indicated that the surrounding habitat was relatively better for skylarks than in the treatment (usually because there was a high percentage of spring-sown crops surrounding it). Values less than 1.05 indicated the surrounding habitat was less suitable than in the treatment (often because there was a high percentage of tall, dense crops, such as oilseed rape or intensively managed grassland).

4.3.3.2 Agronomy

All treatments on the same site were drilled with the same variety of winter wheat, and managed identically (cultivations, crop protection etc.), to the prevailing best Integrated Crop Management (ICM) practice (Anon 2002). They were either 1st year winter wheat or ‘2nd wheats’ (winter wheat following a crop of winter wheat). Details are given in Appendix 1.

WSR treatments were sown at double the normal seed-drill width (c. 25 cm row spacing), at the normal seed rate (i.e. double rate in each row) by blocking off alternate drill coulters.

During 2001, RSPB ran a pilot project on a limited number of sites, testing UP against CONV wheat crops. This pilot helped refine the design but UP still required full evaluation on further farms and comparison with WSR as an alternative solution. In SAFFIE Experiment 1.1, patches were created by turning off or lifting up the seed drill temporarily during sowing to leave an unsown area (Anon, 2004b). Most patches measured c. 4 m x 4 m, although there was local variability, due to differences in type and operation of seed-drills. To account for this variation, the dimensions of all PAs were individually measured. On all sites, PAs were established at a density of two per ha, within an otherwise conventional row spacing and husbandry (i.e. the PAs received the same chemical inputs as the rest of the crop).

The following measures of pre-sowing conditions, and crop establishment, management and agronomic performance, were also taken for each treatment:

- Soil type and series. Details are given in Appendix 1.
- Straw disposal method.
- Pre-sowing cultivations.
- Drill date. Details are given in Appendix 1.
- Seed rate.
- All pesticide and fertilisers applications (dates and application rates). A summary is given in Appendix 1.
- Plant population (March), in 20 lengths of row, 0.5 m each, per treatment.
- Row width (March) in each treatment, by measurement in the field to confirm drill width.
- Pest monitoring (March and early July). If pests were observed to be present, 25 stems per plot were taken when the assessment was a count or percentage area infested, or 50 tillers or plants per plot, when the assessment was on a presence/absence basis.
- Visual assessment of weed levels (March and early July). Two tramlines were walked in each treatment with 25 stops. Weed levels were noted at each stop.
- Number of fertile tillers (early July). An assessment of the number of fertile tillers in 20 lengths of row of 0.5 m each, or 20 quadrats of 0.1 m^2 each, per treatment.
- Disease monitoring was done in early July. Two tramlines were walked in each treatment with 25 stops. Assessments were made of percentage infection by each recorded disease, identified and recorded on leaves 1, 2 and 3 (numbered from the flag leaf down) separately. Green leaf area was estimated for each of leaves 1-4 at five stops per plot. The percentages of crop affected by lodging and leaning were assessed by visual assessment in each treatment prior to harvest.
- Crop yield (August/September), measured with the help of the farmer using the farm combine. Yields were measured using the farm weighbridge, or by total weight taken by haulier from the field, divided by field area.

4.3.3.3 *Vegetation*

Plant species composition, reproductive status and structure were assessed in the cropped areas of each treatment and also within PA. Flexicanes were used to mark specific locations where both vegetation monitoring and vacuum sampling took place. Vegetation was assessed on two occasions in mid-May and early-July. Twenty-four quadrats, each 0.25 m^2 (0.5 m x 0.5 m), were sampled from each treatment, plus an additional 24 PA quadrats in UP. Quadrats were placed in eight groups of three, with approximately 1 m between quadrats within a group. Two groups were randomly located adjacent to each of four randomly-chosen tramlines. Similarly, two PAs were randomly selected from the vicinity of each of four randomly-chosen tramlines.

Percentage cover of each plant species was recorded, plus crop, bare ground (viewed from below the canopy) and litter. Cover was recorded in the following categories, with the midpoint value used for analysis: 0-1%, >1-2%, >2-5%, >5-10%, >10-20% and then in 10% bands up to >90-100%. Total plant cover could sum to more than 100% because vegetation was present at different heights in the canopy, causing overlap.

As vegetation structure may be an important factor in the use of cropped areas by other organisms such as invertebrates and birds, a graduated board method was used to assess the overall vegetation structure. Estimates of the proportion of the board obscured by crop and weeds were made at different heights in order to build up a profile of vegetation density. Assessments were made in mid-May and early-July in the three treatments and separately for PAs, for eight quadrats per treatment (one quadrat from each group of three). A graduated board (1 m x 0.25 m) was placed vertically, perpendicular to the crop rows, with a crop row in the centre of the board. The board was divided into 10 sections, each 10 cm high, and the proportion of each section obscured was estimated by viewing the board horizontally from a distance of 1 m. The board was placed 25 cm from the quadrat and viewed through the quadrat with 25 cm in front and behind.

To obtain an estimate of potential seed availability as a food source over the autumn and winter, seed production was assessed pre-harvest in late July/early August. All weed vegetation was removed from eight quadrats per plot (with one from each group of three used to assess vegetation structure) and recently shed seeds were sampled from the soil surface using a portable vacuum collector. In the laboratory, seeds were separated from vegetative matter by hand, then identified and counted. Seeds were extracted from the soil surface sample by washing the soil through a 500 µm mesh sieve to remove the fine soil particles followed by floating off the organic matter using a saturated solution of $CaCl_2$. Seeds were then removed from other organic matter by hand under ×2 magnification, identified and counted. Seed numbers of both mature seed (assumed to be viable) and immature seed were assessed. Because sampling was carried out before harvest, some of the immature seed would have become viable before the crop was harvested. Also, immature seed may still form a potential food source for other species.

This assessment of seed production will not represent total seed production through the season. Some seed shed before sampling would have become incorporated into the soil and some would already have been taken by granivorous species. However, this approach provided a comparison between treatments and indicated the potential food source available to other species after harvest.

4.3.3.4 *Invertebrates*

The main objective of the in-crop invertebrate sampling was to determine levels of key invertebrate bird food through implementation of WSR and UP treatments. Three collection methods were employed to sample all the key invertebrate groups (vacuum sampling, sweep netting and pitfall trapping) and these methods were largely complementary in terms of target groups collected. Sampling was mid-field, avoiding headland (minimum of 30 m from nearest field boundary) in all three treatments and also within the undrilled patches. The methods used were: (1) vacuum sampling (2) sweep netting and (3) pitfall traps. The sampling regime was seasonal, based upon the main breeding period for skylarks, the availability of invertebrates as potential food sources for birds and the key periods of abundance of each group (Table 4.2). Groups were identified to the taxonomic level given in Table 4.3.

For vacuum sampling, a Dvac suction sampler was used (Dietrick 1961). This device was chosen because it is the only type capable of sampling a mature cereal crop, it causes minimal crop damage (the same location has to be sampled on three occasions) and a relatively large area is sampled (invertebrates occur at lower densities within crops compared to non-crop habitats). Insect sampling was conducted at exactly the same locations as the vegetation recording (see 4.3.3.3).

Sweep netting was conducted on only the CONV and WSR treatments. Nets were standard D-frame kite net (Watkins and Doncaster E679). The sampling approach provided two samples per plot (labelled 1 and 2) by:

1. randomly selecting two tramlines and randomly selecting one location along each of these;

2. at each location, two sweep net samples of 20 sweeps were taken and the contents of sweep net placed in one bag.

Pitfall trapping was conducted using a 6 cm diameter, white plastic pitfall trap, half filled with 50% ethylene glycol (antifreeze) and unscented detergent, supplied by A W Gregory & Co Ltd. (product: No. 8 white). Semi-permanent sleeves were in place during each sampling season to facilitate setting and collection of traps and were removed from the appropriate plots prior to harvest.

Table 4.2. Methods of invertebrate sampling.

Technique	Sampling time	Rationale
Vacuum	early May (weeks 2-3), June (weeks 2-3), early July (weeks 1-2)	Method which collects the widest range of key groups fed to nestlings. Sampling period encompasses nesting period of skylarks.
Sweep	early-May, mid-June	Collects a similar range of groups as vacuum sampling but on the standing vegetation only; particularly larger insects such as sawfly and lepidopteran larvae, which are most abundant during May and June.
Pitfall	mid-June	Estimates activity/density of ground-active invertebrates which peak during June.

Table 4.3. Invertebrate groups, sampling method and taxonomic approach.

Group	Common name	Sampling method	Taxonomic level
Araneae	Spiders	Vacuum + pitfall	Family
Opiliones	Harvestmen	Vacuum + pitfall	Order
Hemiptera	Bugs	Vacuum + sweep	Family
Heteroptera	True bugs	Vacuum + sweep	Family
Auchenorrhynca	Hoppers	Vacuum + sweep	Family (not nymphs)
Sternorrhyncha	Aphids	Vacuum + sweep	Family
Diptera	Flies	Vacuum + sweep	Family
Orthoptera	Grasshoppers	Sweep	Order
Hymenoptera	Bees, wasps, ants	Sweep + vacuum	Order
Lepidoptera	Butterflies, moths	Sweep	Order (larvae)
Neuroptera	Lacewings	Sweep + vacuum	Order
Coleoptera	Beetles	Vacuum + pitfall	Family
Chrysomelidae	Leaf beetles	Vacuum	Species (if abundant) to family (otherwise)
Curculionidae	Weevils	Vacuum	Species (if abundant) to family (otherwise))
Carabidae	Ground beetles	Vacuum and pitfall	Species
Staphylinidae	Rove beetles	Vacuum and pitfall	Species

For each treatment block, samples were taken from the eight locations used for Dvac sampling. Two pitfall traps were installed at each location in line with vegetation quadrats 1 & 3 (see 4.3.3.3). Data from the two traps at each location were pooled for analysis. Each trap was left open for 7 days. This provided eight samples per plot (labelled 1 to 8).

The sampling approach for UP was to randomly select eight PA per UP treatment block. Within each selected PA, two pitfall traps were installed, 3 m apart and at least 1 m from the edge of the patch. Each trap was again left open for 7 days.

This provided a total of 16 pooled samples per UP treatment; eight from the crop and 8 PA samples. A summary of the sample sizes is given in Table 4.4.

Table 4.4. Total number of invertebrate samples by method, for each treatment, site, sampling occasion and year.

Method	No. per plot	No. per site	No. per occasion	No. per year
Vacuum	8 (16 where UP)	32	320	960
Sweep	2	4	40	80
Pitfall	8 (16 where UP)	32	320	320

4.3.3.5 *Birds*

Assessments focused on a ground-nesting species, skylark, which occurred in sufficient numbers on all sites to permit adequate data collection. Collection of all bird data was carried out by fieldworkers trained in the relevant techniques.

Standardised Area Watches (SAWs) were used to assess the density of territorial birds present at different times in the breeding season. This method was modified from that of Vickery et al. (1992). 5 ha plots were measured out using pedometers or land measuring wheels, and then delimited with flexicanes. Each area was watched for 30 min weekly throughout the breeding season (early April to early August). On each visit, birds seen during a 30 min observation period were mapped using standard Common Birds Census activity codes to give an indication of the number of birds present and proportion of birds actively holding territory. Birds were deemed to be holding territory if they were engaged in song flights, prolonged territorial disputes, or if there was an indication of an active nest (carrying of nest material or chick-food). An estimate of territory density was obtained, based on methods for analysing mapped data (Marchant et al. 1990). All observations were conducted during the morning in dry, still weather conditions.

During these watches, indications of breeding behaviour in and around the SAW plots were also noted. If such activities were observed, supplementary searching was then used to locate the nests. Nest visits were made in good weather conditions at two to four day intervals, to allow for effective monitoring of the contents without causing excessive disturbance. On each visit, nest contents were recorded according to the criteria below.

- Nest under construction, containing no eggs or nestlings.
- Eggs – clutch size. It was possible to determine a known clutch size if the nest contained the same number of eggs on more than one date or if the maximum observed clutch size ≥4, the usual maximum reported for arable crops in England (although around 2% of nests in this and similar studies contained five eggs; Donald 2004). Where these criteria were not met, an estimated clutch size was recorded, based on the maximum number of eggs or nestlings observed.
- Nestlings – brood size. A known brood size was recorded for nests where the maximum number of nestlings equalled the maximum number of eggs or, if not found until after hatching, if the brood size was ≥4 (the usual maximum reported brood size). Otherwise, an estimated brood size was recorded, based on the maximum number of nestlings observed.
- Fledged – empty nests previously known to have contained one or more nestlings, which would subsequently have been old enough (≥7 days) to have successfully left the nest. In such cases, the area around the nest was then

searched to obtain evidence that mobile, but unfledged, juveniles were present (e.g. fresh faecal sacs or feather scales present around the entrance to nest, with a well-flattened and undisturbed nest-lining, or adults carrying food or giving alarm calls nearby)

- Predated – failed nests, with evidence of the entire clutch or brood having been taken by a predator. Most predations were accompanied by visible damage to the structure of the nest and, sometimes, remains of eggshells or chicks, allowing confident diagnosis of nest failure. In cases where the nest was found to be empty more than one day before the normal nestling leaving dates, predation was assumed, unless there was evidence to the contrary.

- Abandoned – failed nests with no visible evidence of predation or destruction. Recorded as (i) deserted without ever laying eggs; (ii) deserted at egg stage, due to death of or abandonment (e.g. in bad weather) by parents, or due to infertile or chilled eggs; (iii) death of the whole brood due to insufficient food or death of (or abandonment by) the parents.

- Accidental destruction – failed nests, which were accidentally destroyed by agricultural operations.

- Unknown – nests with an unknown outcome.

Nest data collected using these criteria were used to calculate measures of nesting success and productivity (see 4.3.4.4).

Partial reductions in clutch or brood size (i.e. the death or removal of one or more eggs/nestlings but not the loss of the entire nest contents) were also noted. Partial reduction in brood size was used as an indication that insufficient nestling-food was available to sustain the whole brood, as starvation is the main cause of partial brood loss in skylarks during the nestling stage (Donald 2004). Partial brood loss to predators appears to be very rare and was not suspected in this study (see Chapter 7), probably occurring only when a predator is disturbed in the act of predation. Partial loss to disease also appears to be very rare, and ectoparasites on chicks are virtually unknown (Donald 2004). Partial brood reduction due to accidental damage by machinery is known (David Buckingham - unpublished data) but was not recorded in the SAFFIE study. Nest location (in the crop; on a tramline; in or within 10 m of an undrilled patch) was recorded to ascertain whether this varied with treatment or time of year.

For nestlings, biometric measurements of body weight and tarsus length (from the depression in the angle of the inter-tarsal joint to the end of the folded foot) were, where circumstances allowed, taken on two dates when the chicks were aged from 3 to 8 days old. Weight (to the nearest 0.1 g) was measured with a Marsden electronic mini balance and the tarsus length measured with dial callipers (to the nearest 0.1 mm). The age, in days, of the nestlings was calculated from the date of hatch when known, or by back-calculation from the first egg date. When neither was known with certainty, nestling age was estimated from feather development. These data were used to calculate indices of chick body condition (see 4.3.4.4). Faecal samples collected from individual nestlings during biometric recording were preserved in 70% ethanol for dietary analysis by the Game Conservancy Trust.

Visual observations of parents provisioning nestlings were used to assess foraging habitat selection. Where possible, two one-hour observation sessions were made per brood. All observations were conducted during dry weather conditions from a concealed location. For each provisioning flight, the habitat at the foraging location, whether it was within or outside of the same experimental treatment as the nest, and the distance from the nest to the feeding site, were recorded. If the flight destinations were unobservable, they were recorded as such and discounted from the analysis.

For all bird species, during 2003, transect walks were undertaken in each treatment to establish whether there was variation in treatment use by (i) all species combined or (ii) between individual species or species groups. All transect routes were 1km in length, walked at a constant speed (approximating to normal walking pace), along alternate tramlines (c. 50 m apart) through the crop. Distance walked was measured using a hand-held pedometer. During both years in the UP treatments, timed watches from a concealed location were made to compare the numbers of birds foraging within the undrilled patches and the surrounding crop.

4.3.4 Statistical analysis

4.3.4.1 Agronomy

The data were analysed using General Analysis of Variance (ANOVA), using Genstat 8.1, and treating the design as a randomised block, with the 10 sites being treated as blocks. The sites available for sampling varied between years and consequently years were analysed separately.

4.3.4.2 Vegetation

Plant species were classified in groupings relating to their desirability with respect to both agronomic issues and biodiversity benefits (Table 4.5) and also as grasses or broad-leaved species. Data for these groupings were analysed, plus data for crop, litter and bare ground cover. Where groupings have been combined for analysis they are referred to as 'Groups12' (Group 1 + Group 2), 'Groups123' (Group 1 + Group 2 + Group 3) and 'All weeds' (Group 1 + Group 2 + Group 3 + Group 4). Data for a small number of species that were common across sites were analysed by individual species. Species richness was also calculated, as the number of species recorded per plot, and analysed.

Table 4.5. Plant species were classified in groupings relating to their desirability with respect to both agronomic issues and biodiversity benefits.

Group 1 – Aim to increase	**Group 3 – Neutral**
Chenopodium album	Species not included in groups 1, 2 and 4 including *Cirsium vulgare*, volunteer kale and linseed.
Fallopia convolvulus	
Poa annua	
Persicaria lapathifolia	
Persicaria maculosa	
Polygonum aviculare	
Raphanus raphanistrum	
Sinapis arvensis	
Stellaria media	

Group 2 – Increase if possible	**Group 4 – Not acceptable in the crop**
Cerastium spp.	*Alopecurus myosuroides*
Fumaria officinalis	*Anisantha sterilis*
Matricaria discoides	*Anisantha diandra*
Matricaria recutita	*Avena fatua*
Tripleurospermum inodorum	*Avena ludoviciana*
Senecio vulgaris	*Bromus commutatus*
Sonchus spp.	*Bromus hordaceous*
Viola arvensis	*Cirsium arvense*
Viola tricolor	*Elytrigia repens*
	Galium aparine
	Holcus mollis
	Lolium multiflorum
	Lolium perenne
	Phalaris paradoxa
	Rumex obtusifolius
	Volunteers – beans, potatoes, sunflowers, OSR, cereals

The sites available for sampling varied between years and consequently years were analysed separately (nine sites only in 2003). The means of data collected in the 24 vegetation quadrats or eight seed and structure samples were calculated for each treatment. Percentage cover data (vegetation cover and structure) were angular transformed and count data (seeds) were $\log_{10}$ transformed prior to analysis. Seed data were analysed both as 'viable' and as 'total'. Data for species richness defined as the number of species per plot were not transformed.

To determine the field-scale effect of undrilled patches on vegetation cover and seed production, a weighted mean was calculated using samples collected from within the PAs and the crop surrounding the PAs, to reflect the relative areas of crop and patches within the UP treatment. This weighted mean reflected the effect of treatment over the whole treatment area and was thus directly comparable with samples collected from WSR and CONV treatments. Direct comparisons between the patches themselves (PAs) and the crop surrounding PAs (CropUP) were also made to determine the small-scale impact of the patches on the vegetation. Information on vegetation structure is only relevant at a local scale, therefore these data have been analysed to compare CONV with WSR and PA with the CropUP.

All analyses were carried out using General Analysis of Variance (ANOVA) with site specified as 'block'. Vegetation cover and structure were sampled on two occasions each year and have therefore been analysed using repeated measures ANOVA. All analyses were carried out using Genstat 8.1, 2005, Lawes Agricultural Trust.

4.3.4.3 Invertebrates

The sites available for sampling varied between years and consequently years were analysed separately.

Species data were bulked to give a number of variates as summarised in Table 4.6. The groups were defined primarily to determine the experimental effects on key invertebrate food made available to birds through implementation of the treatments. Data collected by sweep net was sparse and consequently fewer groups were analysed.

The arithmetic mean of data from the eight samples collected within each treatment was calculated and data were log transformed prior to analysis. To determine the field-scale effect of the UP treatment, a weighted mean (WUP) was calculated using samples collected from within the undrilled patches and the crop surrounding the patches. The WUPs represented the UP treatment over the whole field, so was directly comparable with data from the WSR and CONV treatments.

Differences between treatment effects were analysed using General Analysis of Variance (ANOVA), using repeated measures where appropriate (Greenhouse & Geisser 1959); site was specified as 'block'.

To determine the extent to which the UP treatment affected distribution of invertebrates within the field, samples collected from within individual PA were compared with CropUP samples. As before, data were analysed using ANOVA with site specified as 'block'.

At least partly, the distribution of invertebrates in arable crops is related to weed cover (Norris & Kogan 2000, Hawes et al. 2003). The response of the predetermined invertebrate groups to components of vegetation cover (bare ground, litter, crop cover, broadleaf weed cover and grass cover) was determined using a Generalised Linear Model (GLIM). For these analyses, PA samples and CropUP samples were used as a subset of the data to further investigate the distribution of invertebrates in the UP treatment. We selected invertebrate groups that had shown a response to treatment as our response variables. Normal distribution and identity link function were used in all models. Best model was selected manually. Before analysis, a correlation matrix of the vegetation components was calculated in order to exclude unnecessary auto-correlated variables from the model. ANOVA, repeated measures ANOVA and GLIM were carried out using Genstat 8.2, 2005, Lawes Agricultural Trust.

A multivariate approach was used to determine linear relationships between the invertebrate community and environmental variables (in this case, the components of vegetation described above) using redundancy analysis (RDA, ter Braak & Smilauer 1997-2002). Data were $\log_{10}$ transformed before analysis, blocks were defined by sites and Monte Carlo permutations were randomised within block. The environmental variables were added manually by forward selection, their significance was tested using 499 Monte Carlo permutations and those significant at 5% were included. The significance of the overall model was also tested using 499 Monte Carlo permutations.

The strength of association between faecal data and invertebrate data collected by pitfall trap and vacuum was tested using PRIMER v 6.1.5, PRIMER-E, Plymouth. For each year faecal data were bulked, reducing the variates to the following: Arachnid, Hemiptera, adult Hymenoptera, Lepidoptera, carabids, other Coleoptera, Diptera, other invertebrates. Data were bulked within site and year and then converted to proportions. The same process was then followed for ground and crop active invertebrate data. The resulting data matrices were converted into resemblance matrices in PRIMER and compared using RELATE, a test for hypothesis of no relation between multivariate pattern from two sets of samples.

Table 4.6. Bulked variates used in statistical analyses.

Source of variation	Group members	Pitfall	Vacuum	Sweep net
Total Invertebrate Catch	Sum total of all invertebrates	✓	✓	✓
CFI	Grey partridge chick-food index (Potts & Aebischer, 1991; updated Aebischer pers. comm.)		✓	
SFI	Sum of Skylark food items, derived from faecal analysis		✓	✓
Generalist predators	Groups within which the species were predominately predatory	✓	✓	
Phytophagous groups	Groups within which the species were predominately herbivorous or were expected to be pollinators or nectar feeders	✓	✓	
Homoptera	Sum of Homoptera (hoppers)		✓	
Heteroptera	Sum of Heteroptera (true bugs)		✓	
Carabidae	Sum of carabid (ground beetle) species	✓	✓	
Carabid species richness	Number of carabid species	✓		
Staphylinidae	Sum of staphylinid (rove beetle) species	✓	✓	
Staphylinid species richness	Number of staphylinid species	✓		
Total Coleoptera	Sum of Coleoptera (beetles)	✓	✓	
Lycosidae	Sum of Lycosidae (wolf spiders)	✓		
Linyphiidae	Sum of Linyphiidae (money spiders)		✓	
Diptera	Sum of Diptera (flies)		✓	✓
Species richness	Number of species	✓		

4.3.4.4 Birds

In the analyses of skylark territories, nests, nestling body condition, parental foraging patterns and individual parameters of nest productivity, General Linear Mixed Modelling (GLMM) was used to identify those predictors explaining significant variation in the response variables. 'Site' and 'field', the latter identifying individual fields (= management units) nested within the 'site', were specified as random effects to account for unmeasured spatial variation. Unlike General Linear Models, this approach allows modelling of non-independence of 'field' use within a 'site' (Milsom et al. 2000). In addition, because between field-site effects were controlled, the estimated fixed effects had wider inference, thus they apply to any 'field', not just those within the study sites. GLMMs were fitted using the macro GLIMMIX, supplied with SAS software (Littell et al. 2002). The GLIMMIX macro automatically rescaled the model deviance to correct for under/over-dispersion. Predictors were incorporated into the models as fixed effects using a manual step-up procedure (in which each variable was added and then deleted from the model in turn, with the most statistically significant variable re-fitted to the model after each iteration) to establish the minimum adequate model (MAM). Type 3 significance tests of fixed effects were made using Wald *F* tests using Satterthwaite's approximation to the denominator d.f.. Wald *t* tests were used to perform pairwise treatment comparisons. This approach was used, as opposed to an AIC-based multi-model comparison approach (Whittingham et. al. 2005), as this experiment tested specific hypotheses about the effects of only a small number of predictor variables.

Predictors tested in all models as fixed effects included 'treatment' (three-level factor) and 'year' (two-level factor). In most models, the two-level factor 'period' represents data from 'early' (April-May) and 'late' (June-July) in the breeding season. The division was based on observed gaps in the instigation of nesting attempts. Although the exact dates varied slightly between years, in both 2002 and 2003 there was a period of five to seven days in the last week of May when no new clutches were laid. This corresponds well with a decline in nesting activity in conventional wheat crops reported by Donald (2004), and also with the onset of canopy senescence in winter wheat (Sylvester-Bradley 1998).

Two further predictors, 'adjacent habitat scores' and 'boundary index', were calculated according to the methods outlined in section 4.3.3.1. These were included in the models to test whether the treatments in the study conformed to desired attributes; primarily winter-cereal based rotations with relatively open aspects favoured by skylarks.

Clutch size, variations in the density of territories per 5 ha of SAW plot, and the number of nests per treatment, were modelled with Poisson errors and log-link functions. In the nest analysis, ln area (ha) was included as an offset in the model to control for differences in treatment size. Only nests for which the maximum clutch size was known with certainty were included in the analysis of the number of eggs laid.

The distance of foraging flights, the proximity of nests to the nearest undrilled patch (UP nests only) and tramline, and the mean nestling body condition of each brood was modelled using normal errors and identity link. To maximise the chance of cumulative environmental effects on nestling body condition, while minimising the bias of confounding effects related to nestling age, log mean brood mass from the final biometric measurement of nestlings aged 4-9 days was stipulated as the response variable, with log mean tarsus length included in the model as a covariate (García-Berthou 2001). The use of the final biometric measurement of broods about to leave the nest provided a close approximation of fledging condition, an important measure of fitness because it correlates with subsequent survival in many species (e.g. Magrath 1991). Any broods in which there was reduction before the measurement used to calculate the condition index were excluded from the brood condition analysis. Brood reduction could complicate the analysis of brood condition for two reasons. First, assuming the nestlings that die were those in poorest condition, brood mean condition is immediately inflated relative to unreduced broods. Second, the remaining nestlings may be able to respond to the reduced sibling competition by increasing condition or growth rate, again inflating these measures relative to unreduced broods (Shkedy & Safriel 1992).

Nevertheless, brood reduction is a more drastic event than a reduction in nestling condition, so variation in brood reduction from starvation was also analysed to ascertain which variables explained a significant proportion of nestling mortality arising from starvation. The model was constructed with binomial errors and a logit link function. The proportion of nestlings starved in a brood was specified as the response variable, with the binomial denominator specified as one (to represent the original brood size at hatching). Depredated broods or broods of uncertain original sizes were excluded from the analysis. Only nests for which the brood sizes at hatching were known, were included in the analysis of nestling starvation.

Binomial errors and logit links were also used to model partial reductions in clutch size, foraging patterns and daily failure rates (dfr) of nests, using 'field' means to control for non-independence of nests in the same field. The nest failure model represented a modification of the Mayfield method that uses data only from the period during which a nest was under observation to estimate success. Thus it avoids over-estimation of success, as nests found at a later stage are more likely to succeed than those that are found earlier, because they have already survived for part of the requisite duration (Johnson 1979). The number of failures per 'field' was specified as the response variable and total exposure days of all nests in the 'field' as the binomial denominator. In the foraging model, the number of foraging flights within the treatment where the nest was situated was specified as the response and the total number of foraging flights observed (within and outside of the treatment) from the nest was specified as the binomial denominator.

Nest productivity figures were calculated using data on daily nest survival rates, the numbers of eggs laid, the numbers of nestlings hatched and the numbers of nestlings leaving the nest, as in Donald et al. (2002).

Use by foraging birds of undrilled patches within the crop was tested using a one-sample chi-squared test, in which the observed sample was compared to anticipated use under a theoretically derived expectation (based on the area occupied by each habitat), specified by the null hypothesis.

4.4 RESULTS

4.4.1 Agronomy

All 10 sites were established successfully in autumn 2001 and were taken to harvest. Autumn 2002 was wet and the delays and problems in establishing some sites were reflected in lower overall spring plant populations (Figure 4.1). In 2002, plant populations were significantly ($P < 0.05$) lower in the WSR treatment. In 2003, there were no differences in plant population between the treatments. All fields received a conventional pesticide regime (see Appendix 1) and there were no reported weed, pest and disease problems.

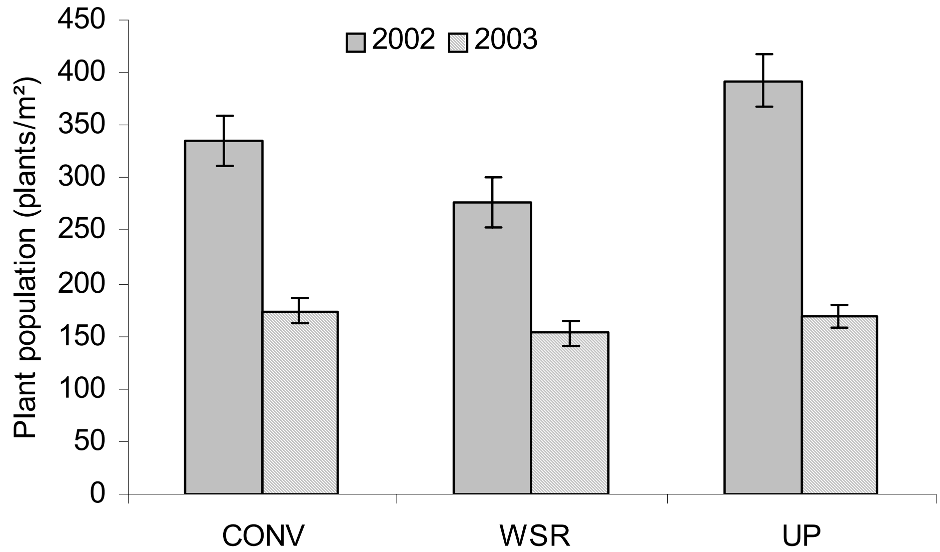

Figure 4.1. Mean spring plant population with 95% CI.

Fertile tiller numbers were similar between treatments (Figure 4.2) and it was interesting to note that the lower spring plant populations in 2003 had similar fertile tiller populations to those in 2002, indicating the compensatory abilities of winter wheat.

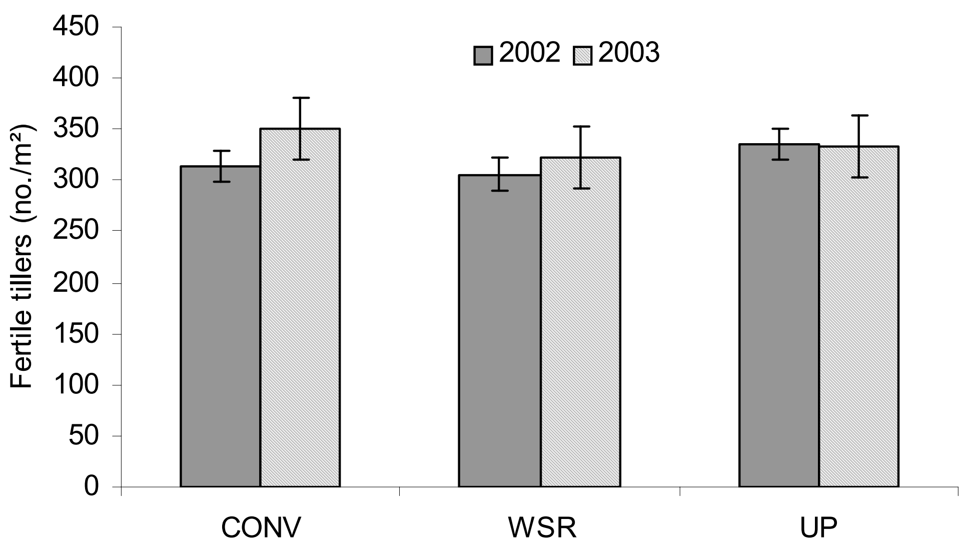

Figure 4.2. Mean fertile tiller number with 95% CI.

Yields were slightly lower in 2003 than 2002. There were no differences between the treatments (Figure 4.3).

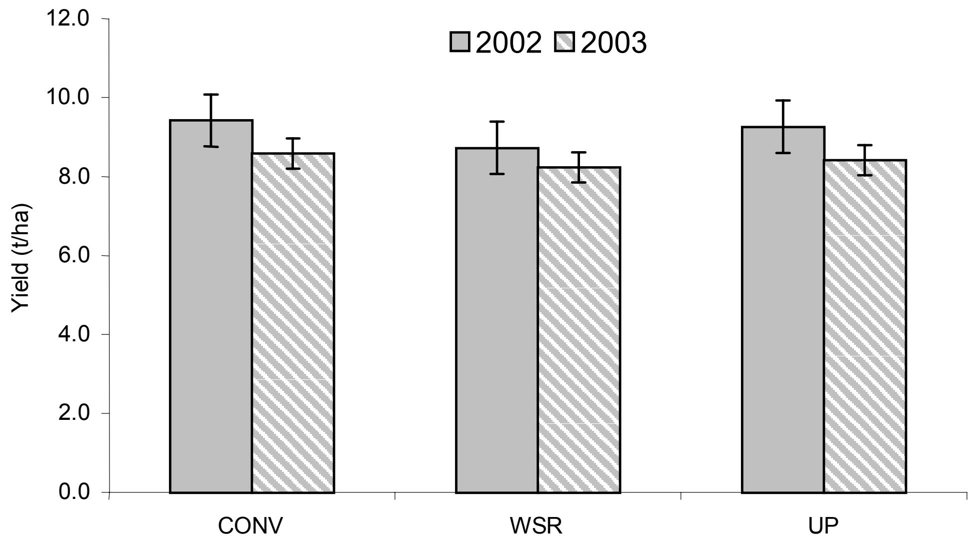

Figure 4.3. Mean grain yield with 95% CI.

At the end of the season, the participating farmers were asked for their opinions and perceptions of the three treatments and these are detailed in Table 4.7.

Table 4.7. Farmer perceptions arising from SAFFIE experiment 1.1.

Farmer perception	Fact
Plants were more crowded within the row in the wide-row treatment, this resulted in poorer spray penetration.	True – the seedrates used were identical for all treatments so plants were crowded in the wide-row treatment. No differences in disease levels were noted.
Some drills were unable to cope with putting tramlines in wide-rows.	True – if wide rows are to be used then we need to refer back to the drill manufacturer to refine the technique.
More weeds were present earlier in the season in the wide-spaced rows.	False - no differences in weed cover were recorded from May onwards between the conventional and wide-spaced rows.
Weed levels were variable in the undrilled patches.	True – numbers were variable between sites and undrilled patches.
Yields were lower in wide-spaced rows.	True/False – There was some evidence that yields were lower in the wide-spaced rows but this was not the case at all sites.

4.4.2 Vegetation

A large number of weed species were recorded but only a very small number were common and overall percentage weed cover was generally low (Table 4.8). Only black-grass, *Alopecurus myosuroides,* was recorded at more than 1% cover during July in either year when averaged across all sites and treatments. However, as would be expected, there was considerable variability between sites and some species were locally common. For example, volunteer potatoes were recorded at >5% in July at ADAS High Mowthorpe, but were absent from all other sites. Percentage cover of species groupings were also different at each site (Figure 4.4). Total weed cover in July ranged from 14% at WF (2002 only) to <1% at PX (mean of 2002 and 2003). Some sites were dominated by undesirable (Group 4) species (e.g. WF, whereas beneficial species were much more common at PH. Weed cover in each treatment was different in the two years, partly due to natural variation, but also because treatments were not necessarily located in the same fields each year and some of the sites were different in 2002 and 2003 (Figure 4.5). Differences between years were particularly marked in the undrilled patches themselves (Figure 4.6) where weed cover was much higher in 2002 than 2003 (July cover = 51% and 20% respectively).

Table 4.8. Most common species recorded in July across all sites in each year. [1] Recorded only at one site.

2002		**2003**	
Species	**Mean % cover**	**Species**	**Mean % cover**
Alopecurus myosuroides	3.10	*Alopecurus myosuroides*	2.13
Galium aparine	0.95	Volunteer potato[1]	0.74
Poa annua	0.82	*Aethusa cynapium*	0.62
Volunteer potato[1]	0.56	*Viola arvensis*	0.53
Elytrigia repens	0.39	*Galium aparine*	0.48
Veronica persica	0.17	*Bromus commutatus*	0.25
Viola arvensis	0.13	Volunteer kale	0.13
Aethusa cynapium	0.12	*Fallopia convolvulus*	0.13
Anisantha tectorum	0.08	*Sinapis arvensis*	0.11
Senecio vulgaris	0.07	*Chenopodium album*	0.10

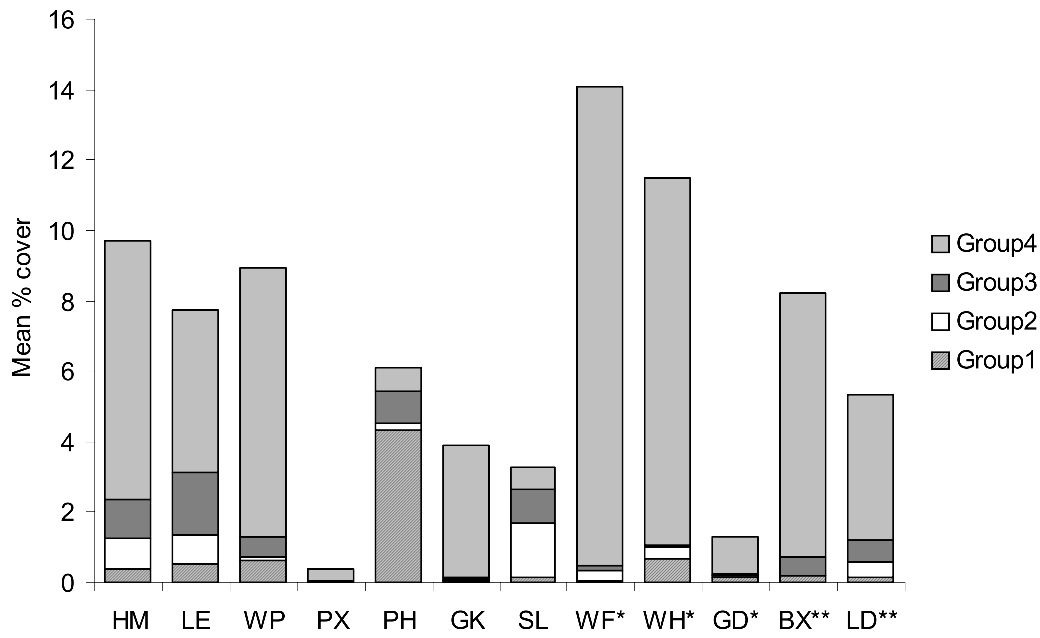

Figure 4.4. Mean weed cover (%) of species groupings for all treatments at individual sites. Means are for both years, except as indicated: *only 2002 data, **only 2003 data. See Table 4.5 for group definitions.

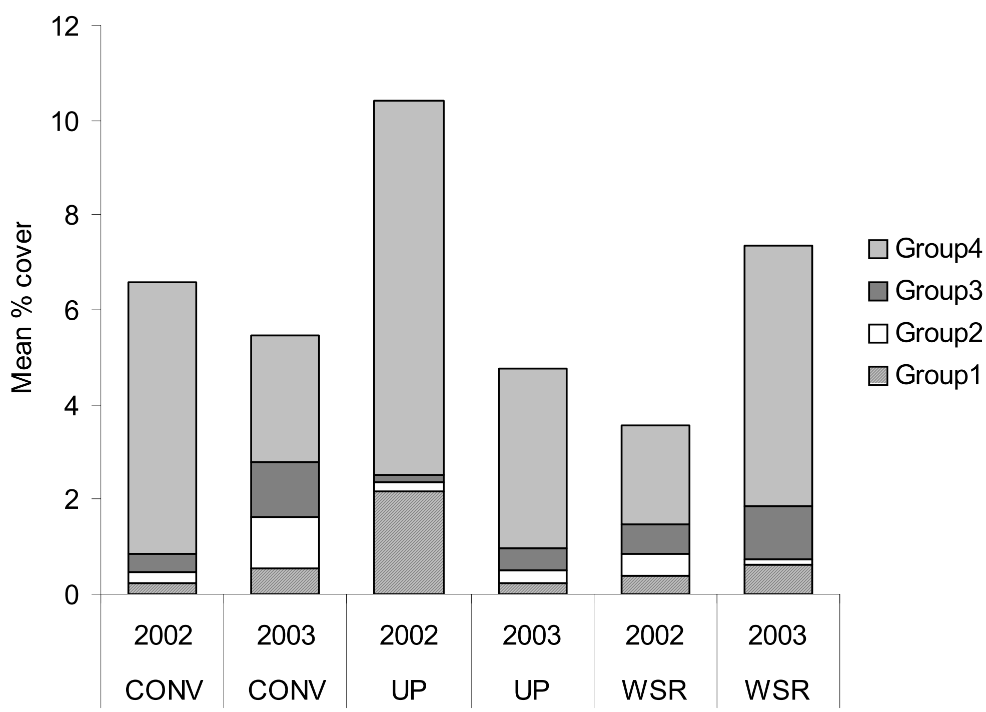

Figure 4.5. Mean weed cover (%) in July by species groupings for the 3 treatments in 2002 and 2003.

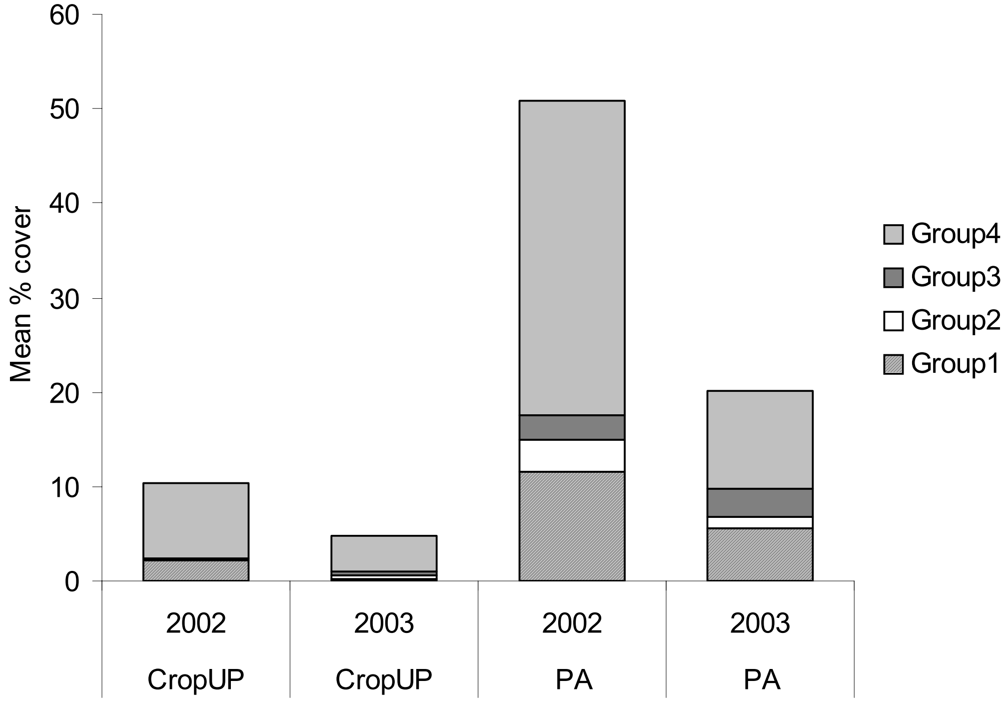

Figure 4.6. Mean weed cover (%) in July by species groupings in patches (PA) and surrounding crop (CropUP) in 2002 and 2003.

Unsurprisingly the vegetation structure changed markedly between May and July (Figure 4.7 & Figure 4.8; 2003 data only presented), but the pattern of structure through the profile was similar in both years. The conventionally drilled crop was apparently denser than WSR close to ground level, but the crop appeared to grow taller in the WSR treatment.

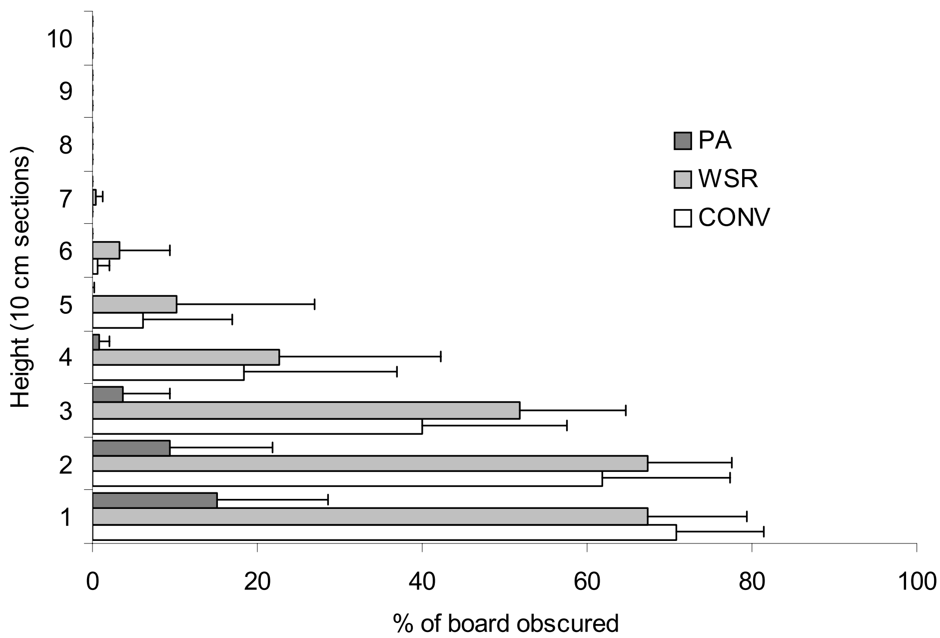

Figure 4.7. Vegetation structure in CONV, WSR and PA in May 2003, with +95% CI. Height classes are sections numbered sequentially from the ground upwards, each 10 cm high. See section 4.3.3.3 for details.

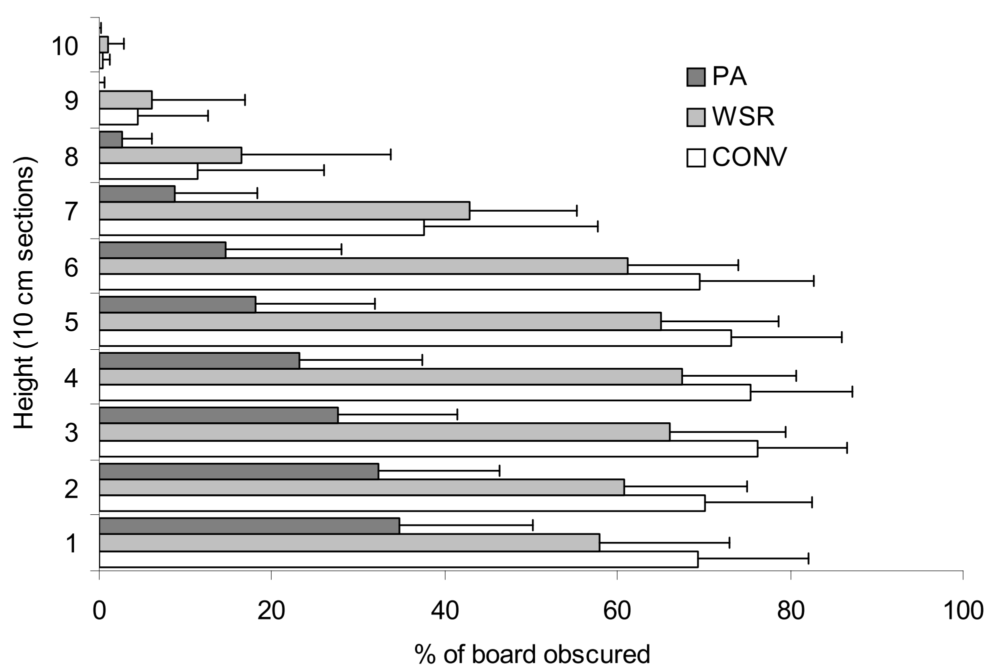

Figure 4.8. Vegetation structure in CONV, WSR and PA in July 2003, with +95% CI. Height classes are sections numbered sequentially from the ground upwards, each 10 cm high. See section 4.3.3.3 for details.

Analysis of weed cover data for CONV, WSR and UP indicated few differences in vegetation cover between treatments in either year (significant treatment effects presented in Table 4.9). For many of the variates analysed, there was a significant difference in vegetation cover between May and July (see Appendix 2 for full details of ANOVA output). Crop cover was not significantly different between treatments in either year, but bare ground values were higher in WSR than the other treatments in 2002. Species richness was higher in UP than in the other treatments in both years and, in 2002, it was higher in May than July ($P = 0.002$).

Comparisons of vegetation cover between the patches and the surrounding crop indicated significantly higher weed cover in PA than CropUP for most of the variates analysed in both years. Significant treatment effects are presented in Table 4.10.

However, for many variates there was an interaction between treatment and time of sampling because there was a much greater increase in vegetation cover in PA than CropUP over time (Table 4.11, Figure 4.9). Crop cover was lower in PA than CropUP in both years. Species richness was higher in PA.

Table 4.9. Comparison of back transformed means for vegetation cover (%) and species richness (species number per plot) across the three treatments (repeated measures ANOVA).

	Means					Treatment		Time	
	CONV	**UP**	**WSR**	**May**	**July**	***F***	***P***	***F***	***P***
2002: Treatment d.f. = 2, 18; Time d.f. = 1; n = 60									
Group 4	2.30	3.54	0.97	1.15	3.41	3.55	0.050	23.73	<0.001
All weeds	3.25	5.12	1.91	1.90	5.08	3.75	0.044	25.56	<0.001
Bare ground	78.99	78.61	80.71	79.76	79.13	5.54	0.013	0.23	0.632
Species richness	6.85	10.9	6.55	8.97	7.23	7.21	0.005	11.60	0.002
2003: Treatment d.f. = 2, 15; Time d.f. = 1; n = 52									
Broad-leaved speciesf	2.13	0.83	1.39	0.94	1.96	3.72	0.049	4.41	0.047
Species richness	6.89	10.89	5.83	7.97	7.76	9.01	0.003	0.13	0.721

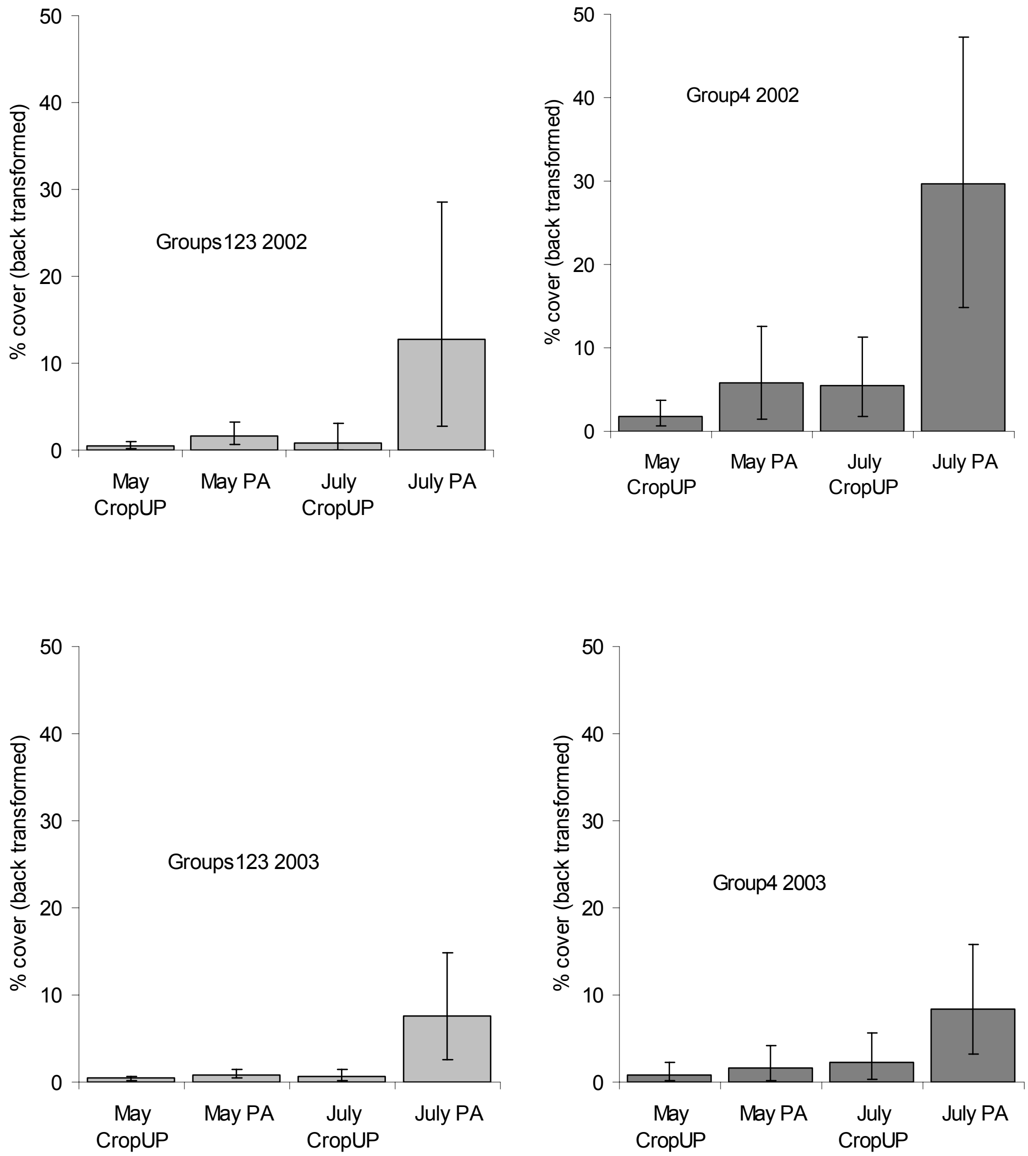

Figure 4.9. PA & CropUP. Interaction between treatment and sampling time in 2002 & 2003 for Group 1, 2 and 3 species combined compared to Group 4 species, with 95% CI.

Table 4.10. Comparison of back transformed means for vegetation cover (%) and species richness (number of species per plot) on patches and in surrounding crop (repeated measures ANOVA).

	Means				Treatment		Time	
	CropUP	**PA**	**May**	**July**	***F***	***P***	***F***	***P***
2002: Treatment d.f. = 1, 9; Time d.f. = 1; n = 40								
Group1	0.26	2.50	0.29	2.39	7.29	0.024	5.71	0.028
Groups12	0.42	3.84	0.51	3.58	9.08	0.015	6.65	0.019
Grasses	2.34	11.59	2.50	11.36	14.74	0.004	21.20	<0.001
Alopecurus myosuroides	1.24	5.66	1.50	5.14	5.43	0.045	11.17	0.004
Galium aparine	0.45	1.41	0.37	1.56	6.91	0.027	14.38	0.001
Species richness	6.30	9.40	8.80	6.90	12.29	0.007	5.97	0.025
2003: Treatment d.f. = 1, 8; Time d.f. = 1; n = 36								
Group1	0.12	1.57	0.22	1.29	10.53	0.012	5.45	0.033
Group2	0.08	0.37	0.07	0.40	23.25	0.001	7.08	0.017
Group3	0.19	0.85	0.22	0.78	9.62	0.015	5.01	0.040
Crop	34.73	4.64	11.44	23.18	41.95	<0.001	31.15	<0.001
Alopecurus myosuroides	0.72	2.37	0.59	2.61	9.17	0.016	21.34	<0.001
Species richness	6.06	9.56	7.33	8.28	7.38	0.026	1.24	0.281

Table 4.11. Comparison of back transformed means for vegetation cover (%) on patches and in surrounding crop where there was an interaction between treatment and time.

	May		July		Treatment		Time		TreatmentXTime	
	CropUP	**PA**	**CropUP**	**PA**	***F***	***P***	***F***	***P***	***F***	***P***
2002: Treatment d.f. = 1, 9; Time d.f. = 1; TreatmentXTime d.f. = 1,18; n = 40										
Group3	0.17	0.54	0.07	1.81	22.61	0.001	1.72	0.207	5.04	0.038
Group4	1.84	5.77	5.53	29.66	18.68	0.002	35.57	<0.001	10.31	0.005
Groups123	0.51	1.66	0.76	12.84	16.14	0.003	6.93	0.017	5.26	0.034
All weeds	2.67	8.26	8.07	50.87	35.31	<0.001	51.78	<0.001	18.78	<0.001
Broad-leaved species	0.82	1.99	1.53	18.94	20.44	0.001	15.82	<0.001	10.18	0.005
Bare ground	79.67	87.85	77.52	67.43	0.00	0.989	13.57	0.002	9.08	0.007
Crop	35.05	2.72	74.70	4.68	117.38	<0.001	20.96	<0.001	12.57	0.002
2003: Treatment d.f. = 1, 8; Time d.f. = 1; TreatmentXTime d.f. = 1,16; n = 36										
Group4	0.85	1.59	2.27	8.39	10.62	0.012	43.81	<0.001	10.12	0.006
Groups12	0.21	0.52	0.32	4.96	15.01	0.005	7.30	0.016	5.46	0.033
Groups123	0.41	0.87	0.59	7.51	18.82	0.002	9.79	0.006	7.38	0.015
All weeds	1.55	2.99	3.48	18.63	24.55	0.001	32.78	<0.001	12.83	0.002
Broad-leaved species	0.68	1.25	0.92	9.28	24.90	0.001	12.07	0.003	9.16	0.008
Grasses	0.47	1.17	1.76	6.45	8.30	0.020	33.58	<0.001	5.26	0.036
Litter	1.74	1.60	4.43	2.13	5.65	0.045	15.22	0.001	5.50	0.032

Repeated measures analysis of variance carried out on structure data for the two sections closest to ground level combined (0-20 cm) showed a significantly greater vegetation density in the CONV than WSR in 2002, but no difference in 2003 (Table 4.12).

Table 4.12. Comparison of back transformed means for structure (% of board obscured) at 0-20 cm in CONV and WSR treatments.

	Treatment		**Time**		**Treatment**		**Time**	
	CONV	**WSR**	**May**	**July**	***F***	***P***	***F***	***P***
2002: Treatment d.f. = 1, 9; Time d.f. = 1. n = 40								
	91.9	75.2	80.8	88.0	23.06	<0.001	2.88	0.107
2003: Treatment d.f. = 1, 7; Time d.f. =1. n = 36								
	69.9	64.8	68.1	66.6	2.01	0.200	0.08	0.780

Comparison of PA with CropUP indicated a significant interaction between treatment and time of sampling in both years. At this height above ground level, vegetation density increased between May and July in PA, but changes in CropUP were different in each year. Vegetation was denser in the cropped areas than the patches themselves, but the changes with time were greatest in PA (Table 4.13).

Table 4.13. Comparison of back transformed means for structure (% of board obscured) at 0-20 cm in PA and surrounding crop (CropUP).

	May		**July**		**Treatment**		**Time**		**TreatmentX Time**	
	CropUP	**PA**	**CropUP**	**PA**	***F***	***P***	***F***	***P***	***F***	***P***
2002: Treatment d.f. = 1, 9; Time d.f. = 1; TreatmentXTime d.f. = 1, 18. n = 40										
	89.5	9.0	95.8	58.9	79.89	<0.001	40.07	<0.001	16.33	<0.001
2003: Treatment d.f. = 1, 8; Time d.f. = 1; TreatmentXTime d.f. = 1, 16. n = 36										
	83.7	8.2	78.5	31.8	45.70	<0.001	7.72	0.013	18.43	<0.001

Similar to the results for vegetation cover, seed production was rarely different between CONV, WSR and UP. In 2002, more viable seeds of broadleaf species were produced on UP than CONV, and more viable grass seeds were produced on UP than WSR. In 2003, more total seeds of *Alopecurus myosuroides* were produced on UP than CONV. Significant results are presented in Table 4.14. Species richness was consistently higher in UP than other treatments.

Table 4.14. Comparison of seed production (number of seeds m^{-2}) and species richness (number of species per plot) for the three treatments. Back transformed means for total and viable seeds.

	Means			Overall		CONV vs. UP		WSR vs. UP	
	CONV	**UP**	**WSR**	***F***	***P***	***F***	***P***	***F***	***P***
2002 – Total Seeds: Treatment d.f. = 2; 18; Contrast d.f. = 1; n = 30									
Groups12	20.4	52.7	10.2	2.37	0.122	1.64	0.216	4.69	0.044
Species richness	6.2	10.4	5.1	10.65	<0.001	12.01	0.003	19.12	<0.001
2002 – Viable Seeds: Treatment d.f. = 2; 18; Contrast d.f. = 1; n = 30									
Group2	0.9	4.4	1.6	2.89	0.082	5.41	0.032	2.84	0.109
Groups12	4.8	23.5	4.8	3.37	0.057	5.04	0.038	5.06	0.037
Groups123	5.5	32.1	10.0	3.52	0.051	6.77	0.018	3.09	0.096
All weeds	74.9	379.2	56.5	3.12	0.069	3.91	0.063	5.34	0.033
Broad-leaved species	4.0	24.1	15.6	3.99	0.037	7.36	0.014	0.46	0.507
Grasses	40.7	228.1	11.6	4.38	0.028	3.03	0.099	8.66	0.009
Species richness	4.0	8.2	3.5	9.67	0.001	12.80	0.002	16.02	<0.001
2003 – Total Seeds: Treatment d.f. = 2; 15; Contrast d.f. = 1; n = 26									
Alopecurus myosuroides	4.1	55.2	25.9	3.52	0.056	6.72	0.020	0.65	0.434
Species richness	3.7	9.1	3.7	33.06	<0.001	49.91	<0.001	49.27	<0.001
2003 – Viable Seeds: Treatment d.f. = 2; 15; Contrast d.f. = 1; n = 26									
Species richness	2.1	7.2	2.9	27.51	<0.001	47.12	<0.001	34.41	<0.001

All variates analysed (total and viable seeds and both years) indicated higher seed numbers produced on PA than CropUP, except for total seeds of *Alopecurus myosuroides* in 2002 (data presented in Appendix 2).

4.4.3 Invertebrates

4.4.3.1 Total catch of ground active invertebrates

The total catch of ground active invertebrates was greatest in 2003. This was accounted for by an increase in the number of ground beetles, particularly the predatory *Pterostichus madidus*, *P. melanarius* and *Carabus* spp., which together accounted for 79% and 88% of the catch in 2002 and 2003 respectively. Spiders, rove beetles and other beetles all occurred in lower numbers in the second year. Pitfall traps which were used to sample ground active invertebrates are known to detect, not only changes in density, but also activity (Winder et al. 2001) and it may be that the higher cover of bare ground in 2003 (indicated by a slightly lower crop yield (see section 4.4.1) and weed cover (see section 4.4.2)) resulted in greater activity by these species. Annual fluctuations of the order recorded here are not unusual. The major components of the ground dwelling invertebrate catch were wolf spiders, ground beetles (mostly *Anchominus dorsalis*; *Pterostichus madidus* and *P. melanarius*) and rove beetles (mostly *Philonthus cognatus*; *Tachyporus hypnorum* and *Tachinus* spp.). The catch totals are summarised in Table 4.15.

Table 4.15. Total number of invertebrates captured by pitfall trap.

Order	Family	Species	Common name	2002	2003
Araneae	*Lycosidae*		Wolf spider	291	127
Coleoptera	*Carabidae*	*Anchominus dorsalis*	A ground beetle	1106	723
		Agonum muelleri	A ground beetle	12	0
		Amara spp.	Ground beetles	208	86
		Asaphidion flavipes	A ground beetle	11	2
		Bembidion lampros	A ground beetle	156	217
		Bembidion obtusum	A ground beetle	94	2
		Calathus fuscipes	A ground beetle	24	28
		Carabus spp.	Ground beetles	58	708
		Demetrias spp.	Ground beetles	5	9
		Harpalus affinis	A ground beetle	85	47
		Harpalus rufipes	A ground beetle	267	815
		Loricera pillicornis	A ground beetle	83	137
		Nebria brevicollis	A ground beetle	212	147
		Notiophilus biguttatus	A ground beetle	35	57
		Poecilus cupreus	A ground beetle	456	83
		Pterostichus madidus	A ground beetle	2751	11685
		Pterostichus melanarius	A ground beetle	18552	19225
		Trechus quadristriatus	A ground beetle	32	605
		Zabrus tenebriodes	A ground beetle	0	2
			Ground beetle larvae	113	68
			Total ground beetles	24147	34578
	Staphylinidae	*Aleocharinae* spp.	Rove beetles	79	0
		Paederus spp.	Rove beetles	3	6
		Philonthus cognatus	A rove beetle	608	334
		Philonthus spp.	Rove beetles	45	79
		Stenus spp.	Rove beetles	2	16
		Tachinus spp.	Rove beetles	529	266
		Tachyporus chysomelinus	A rove beetle	4	4
		Tachyporus hypnorum	A rove beetle	233	124
		Tachyporus nitidulus	A rove beetle	0	7
		Tachyporus obtusus	A rove beetle	26	21
		Xantholinus spp.	Rove beetles	24	10
			Rove beetle larvae	59	26
			Total rove beetles	2318	1227
	Elateridae		Click beetles	11	31
	Curculionidae		Weevils	11	2
	Coccinelidae		Ladybirds	104	11
	Coccinelidae larvae			0	1
	Chrysomelidae	*Gastrophysa polygoni*	A leaf beetle	7	3
			Other leaf beetles	16	74
		Anchominus dorsalis	Other beetles larvae	1	6
		Agonum muelleri	Total number of invertebrates	26906	36060

4.4.3.2 Total catch of crop active invertebrates:

The total catch of crop active invertebrates was greatest in 2002. With the exception of aphids and money spiders, both of which occurred in greater numbers in 2003, all groups conformed to this pattern. Vacuum samples were dominated by aphids and flies; the majority of the flies were Nematocera, a group composed of gnats, mosquitoes and midges (Tipulidae excluded). Nitidulids (pollen beetles) were also present in high numbers in 2002. Catch totals are summarised in Table 4.16.

Sweep net samples were not taken in UP fields and, in comparison with vacuum sampling, the total catch was low. However, sweep net sampling is not an accurate quantitative method, rather it gives an indication of presence. Despite this, the catch totals did mirror those of the vacuum samples and the number of invertebrates captured was lower in 2003. Catch totals are summarised in Table 4.17.

Table 4.16. Total number of invertebrates captured by vacuum.

Order	Sub-order	Family	Species	Common name	Life stage	2002	2003
Araneae		*Liniphyiidae*		Money spiders	Adult	795	951
		Lycosidae		Wolf spiders	Adult	3	0
				Other spiders	Adult	41	99
Opiliones				Harvestmen	Adult	6	10
Meso-gastropoda				Snails	Adult	3	27
Orthoptera				Grasshoppers	Adult	3	1
Hemiptera	*Homoptera*			Hoppers	Adult	771	900
Hemiptera	*Homoptera*	*Aphididae*	*Metopolophium dirhodum*	Rose grain aphid	Adult	3292	10000
			Sitobion avenae	Wheat grain aphid	Adult	948	2495
		Miridae	*Calocoris* spp.	True bugs	Adult	36	50
			Leptoterna spp.	True bugs	Adult	27	2
			Stenodemini spp.	True bugs	Adult	10	3
		Nabidae		True bugs	Adult	0	0
		Anthocoridae	*Anthocoris* spp.	True bugs	Adult	14	14
				Other true bugs	Adult	38	130
Neuroptera				Lacewings	Larvae	50	62
Lepidoptera				Butterflies and moths	Larvae	22	64
Hymenoptera	*Symphyta*			Sawfly	Adult	15	14
	Symphyta			Sawfly	Larvae	43	51
Hymenoptera		*Formicidae*		Ants	Adult	0	2
Coleoptera		*Carabidae*		Ground beetle	Adult	145	259
		Staphylinidae		Rove beetles	Adult	568	612
		Chrysomelidae		Leaf beetles	Adult	257	113
		Curculionidae		Weevils	Adult	65	21
		Cantharidae		Soldier beetle	Adult	33	141
		Elateridae		Click beetle	Adult	164	53
		Nitidulidae		Pollen beetle	Adult	2120	729
		Coccinellidae		Ladybird	Adult	9	3
		Coccinellidae		Ladybird	Larvae	7	13
				Other beetles	Adult	1259	932
				Total number of beetles	All	4627	2876
Diptera	*Nematocera*	*Tipulidae*		Cranefly	Adult	118	166
	Other Nematocera			Gnats, mosquitoes and midges	Adult	12808	9707
	Brachycera			Hoverfly and horsefly	Adult	2228	3146
	Aschiza			Flies	Adult	6106	1811
	Acalypterae			Flies	Adult	6999	4796
	Calyptera			Flies	Adult	1182	970
				Fly larvae	Larvae	28	1
				Total flies	All	29469	20597
				Total invertebrates		40213	38348

Table 4.17. Total catch of invertebrates captured by sweep net.

Order	Sub-order	Family	Species	Common name	Life stage	2002	2003
Araneae		*Linyphiidae*		Money spiders	Adult	75	51
		Lycosidae		Wolf spiders	Adult	1	2
				Other spiders	Adult	28	18
Opiliones				Harvestmen	Adult	104	0
Mesogastropoda				Snails	Adult	0	7
Orthoptera				Grasshoppers	Adult	62	0
Hemiptera	*Homoptera*			Hoppers	Adult	50	60
Hemiptera	*Homoptera*	*Aphididae*	*Metopolophium dirhodium*	Rose grain aphid	Adult	4	333
			Sitobion avenae	Wheat grain aphid	Adult	592	302
	Heteroptera			True bugs	Adult	639	14
Neuroptera				Lacewings	Larvae	53	7
Lepidoptera				Butterflies and moths	Larvae	18	24
Hymenoptera	*Symphyta*			Sawflies	Adults	5	17
	Symphyta			Sawflies	Larvae	8	42
Hymenoptera		*Formicidae*		Ants	Adult	0	0
Coleoptera		*Carabidae*		Ground beetles	Adult	3	0
		Staphylinidae		Rove beetles	Adult	1	20
		Chrysomelidae		Leaf beetles	Adult	64	18
		Curculionidae		Weevils	Adult	83	21
		Cantharidae		Soldier beetles	Adult	56	25
		Elateridae		Click beetles	Adult	30	1
		Nitidulidae		Pollen beetles	Adult	7	38
		Coccinellidae		Ladybirds	Adult	77	0
		Coccinellidae		Ladybirds	Larvae	8	0
				Other beetles	Adult	87	98
				Total number of beetles	Adult	416	221
Diptera	*Nematocera*	*Tipulidae*		Cranefly	Adult	145	18
	Other Nematocera			Gnats, mosquitoes and midges	Adult	63	223
	Brachycera			Hoverflies and horseflies	Adult	36	147
	Aschiza			Flies	Adult	329	35
	Acalypterae			Flies	Adult	97	536
	Calyptera			Flies	Adult	11	331
				Flies	Larvae	662	0
				Total flies	Adult	1343	1290
				Total invertebrates		3398	2388

4.4.3.3 Between site differences

It is to be expected that differences in local climate, other specific site conditions and farm management will lead to differences in invertebrate abundance and diversity. In this study, each farm was used as a replicate and the site differences are taken into account in analysis. It is of general interest to note the extent of differences between sites and summary graphs showing total catch at each farm are given below (Figure 4.10, Figure 4.11, Figure 4.12, Figure 4.13).

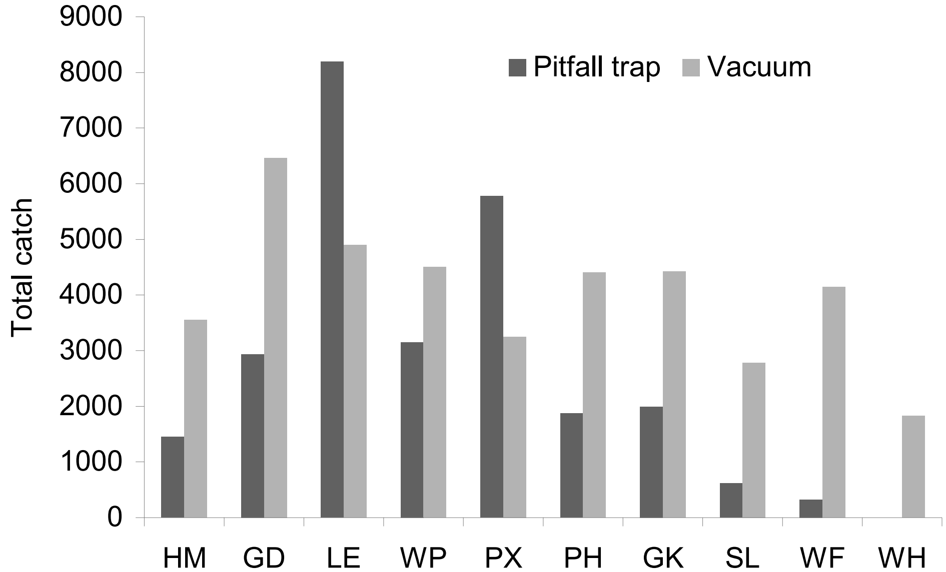

Figure 4.10. Invertebrate catch by pitfall trap and vacuum at each site in 2002. See Table 4.1 for site abbreviations.

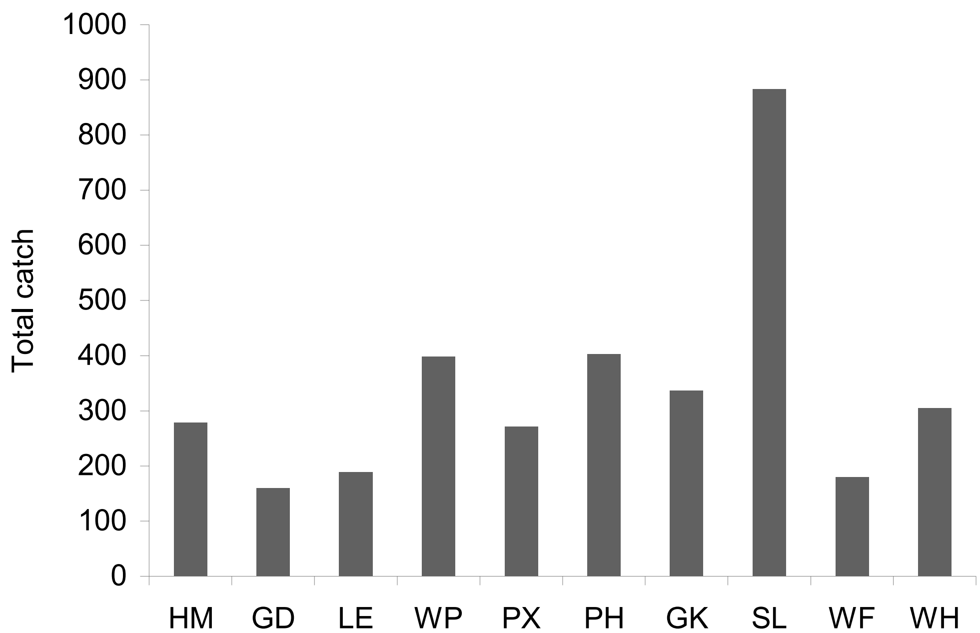

Figure 4.11. Invertebrate catch by sweep net at each site in 2002. See Table 4.1 for site abbreviations.

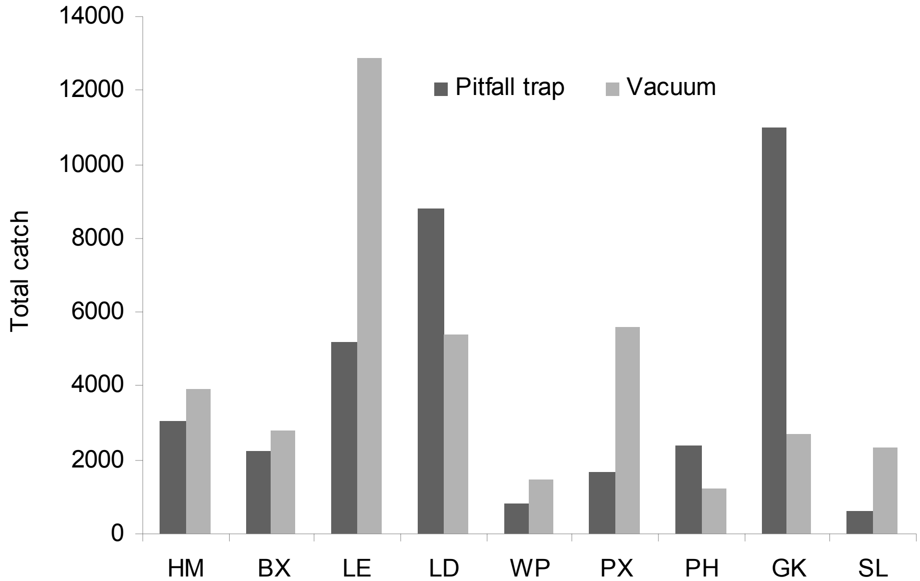

Figure 4.12. Invertebrate catch by pitfall trap and vacuum in at each site in 2003. See Table 4.1 for site abbreviations.

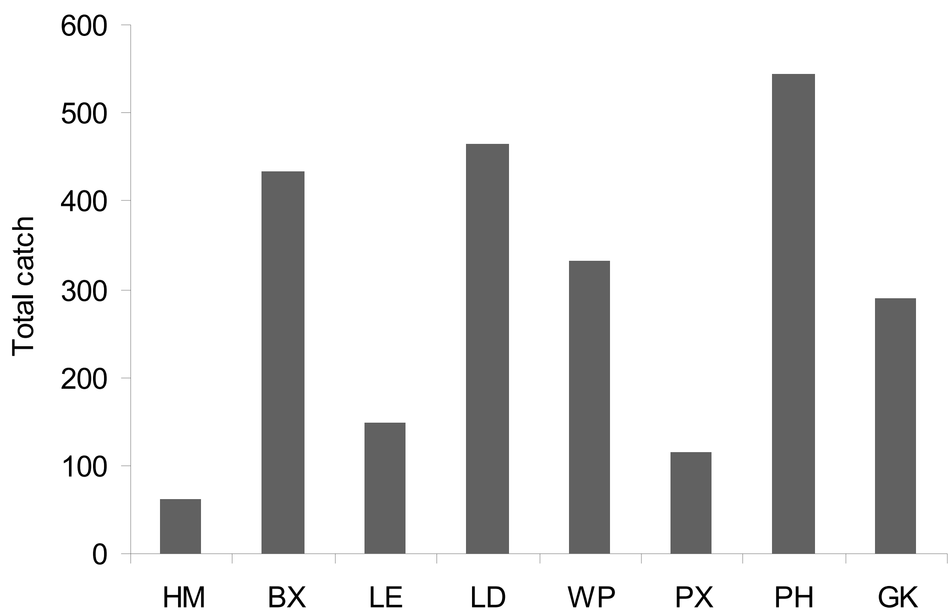

Figure 4.13. Invertebrate catch by sweep net at each site in 2003. See Table 4.1 for site abbreviations.

4.4.3.4 Treatment effects

At the field scale there was little effect of the novel treatments UP and WSR on invertebrate abundance.

Ground active invertebrates

In 2002, there were differences in species richness, abundance of staphylinid (rove) beetles and of lycosids (wolf spiders). Average species richness and overall abundance of staphylinid beetles was highest in UP while lycosids were more abundant in WSR and least abundant in CONV (Figure 4.14). The staphylinid catch comprised largely of *Philonthus cognatus*, other *Philonthus* species, *Tachyporous chrysomelinus*, *Tachyporous hypnorum*, *Stenus* spp. and *Tachinus* spp.; *Aleocharinae* spp. and *Paederus* spp. were also present but in low abundance. Table 4.18 gives summary means and the results of statistical analyses.

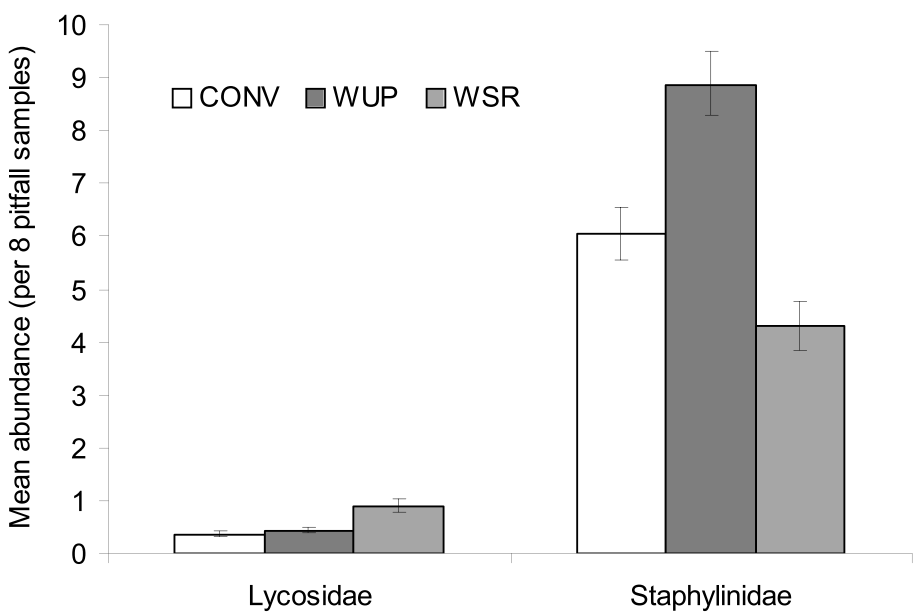

Figure 4.14. Significant treatment differences for ground active invertebrates in 2002. CONV and WSR: Means (with 95% CI) are of eight pitfall samples, open for 7 pitfall days on three occasions. WUP: a weighted mean (with 95% CI) of eight pitfall samples from each of CropUP and PA. See section 4.3.3.4 for details.

Crop active invertebrates:

Only 'generalist predators' (which included the predatory flies) responded to the treatments; Figure 4.15 shows that significantly fewer generalist predators were captured in the UP fields in June and July. There were no significant differences for invertebrates captured by sweep net. Table 4.19 and Table 4.20 show mean data and results of analyses. In general, invertebrate abundance fluctuated over time, significantly for many species, but there were no significant treatmentXtime interactions, reflecting the natural phenology of sampled invertebrates.

There was no significant effect of UP or WSR on the abundance of ground or crop active invertebrates at the field scale in 2003 (Table 4.18, Table 4.19 and Table 4.20).

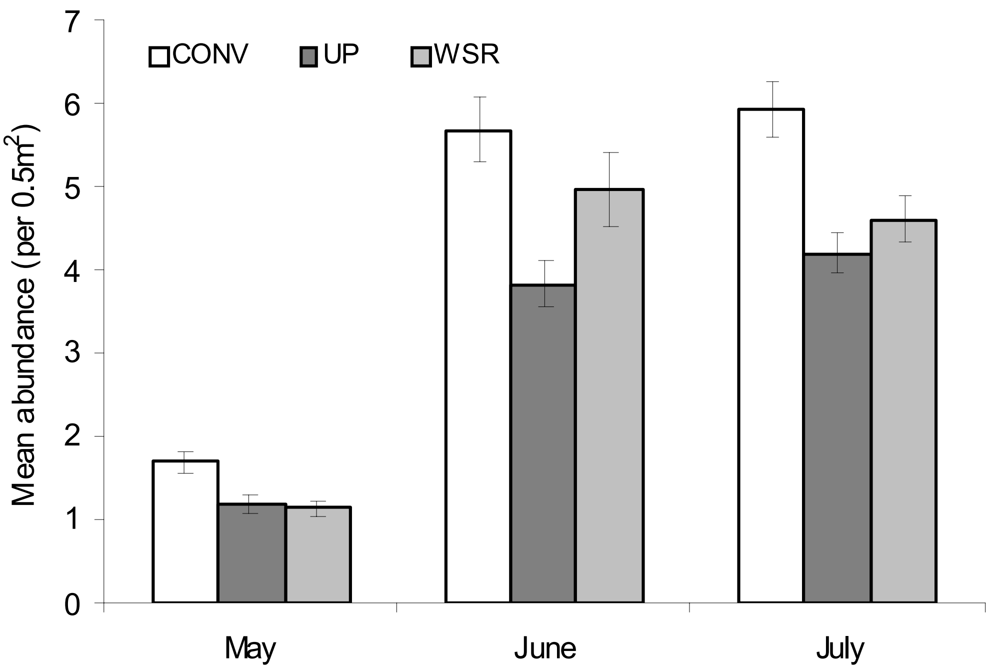

Figure 4.15. Significant treatment differences for total abundance of generalist predators in 2002. Mean abundance per 0.5m^2 with 95% CI.

When PA and CropUP samples were compared, differences were detected in both years although the effect was stronger in 2003. Of the ground active species in 2002 staphylinid abundance and staphylinid species richness were both higher in the CropUP than within PA, while Lycosidae were more abundant in PA (Figure 4.16). Mean data and results of analyses are summarised in Table 4.21.

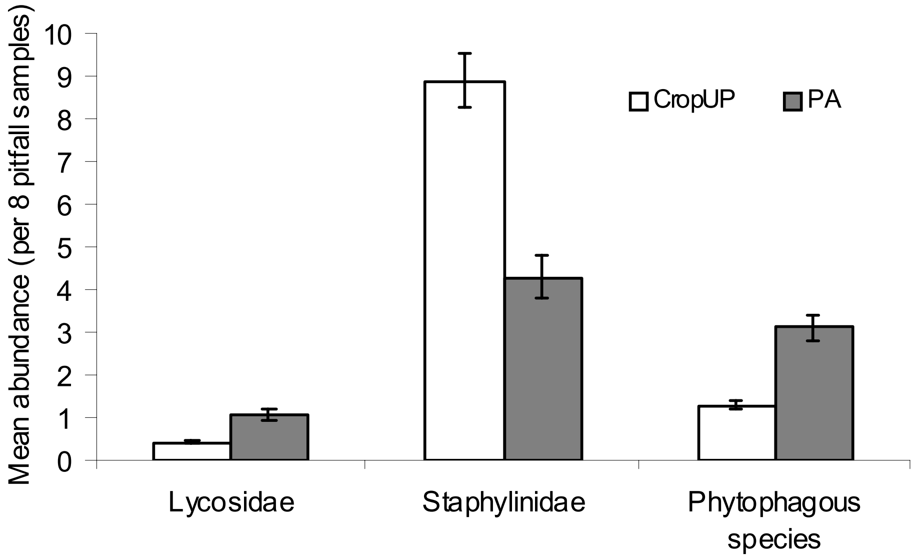

Figure 4.16. Significant differences between ground active invertebrates in the CropUP and PA in 2002. Means (with 95% CI) are of eight pitfall samples, open for 7 pitfall days on three occasions. See section 4.3.3.4 for details.

Crop active invertebrates were sampled in UP treatments by vacuum but not sweep net. In 2002, the number of phytophagous invertebrates (Figure 4.17), total number of crop active invertebrates (Figure 4.18), skylark food items (SFI) (Figure 4.19) and Heteroptera varied between CropUP and PA. There were also treatmentXtime interactions for total invertebrates, SFI and Heteroptera. Although the analysis was significant, Heteroptera occurred in very low numbers and no data are presented. In May and June, there were a higher number of invertebrates in the crop but in July, as the crop ripened and weed cover became better established in PA, invertebrates colonised the weedy areas.

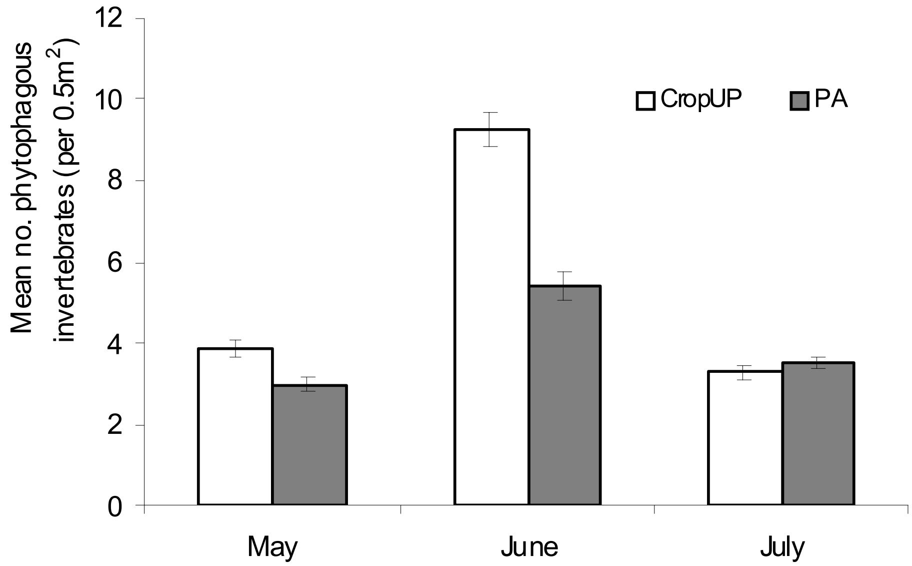

Figure 4.17. Significant differences between phytophagous invertebrates in CropUP and PA in 2002. Mean abundance per $0.5m^2$ with 95% CI.

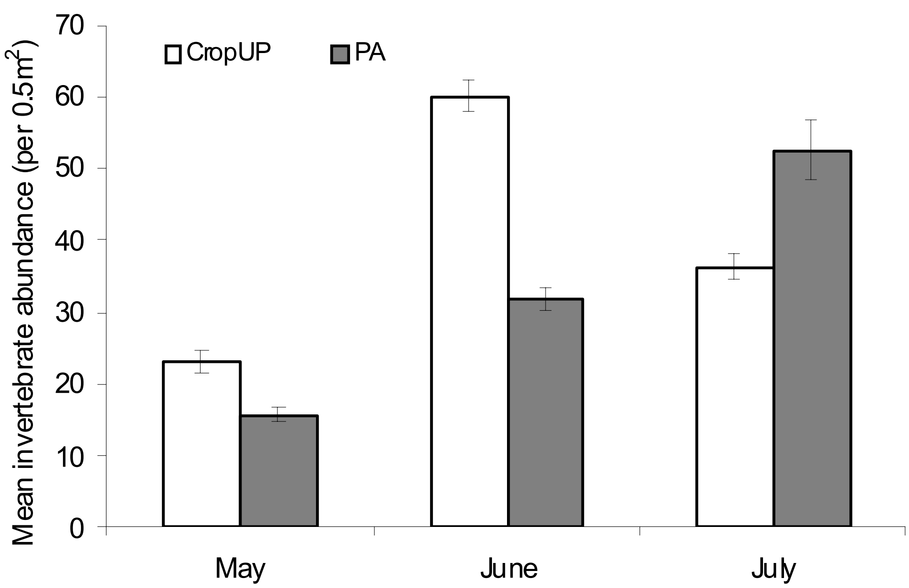

Figure 4.18. Significant differences between total crop active invertebrates in the CropUP and PA in 2002. Mean abundance per $0.5m^2$ with 95% CI.

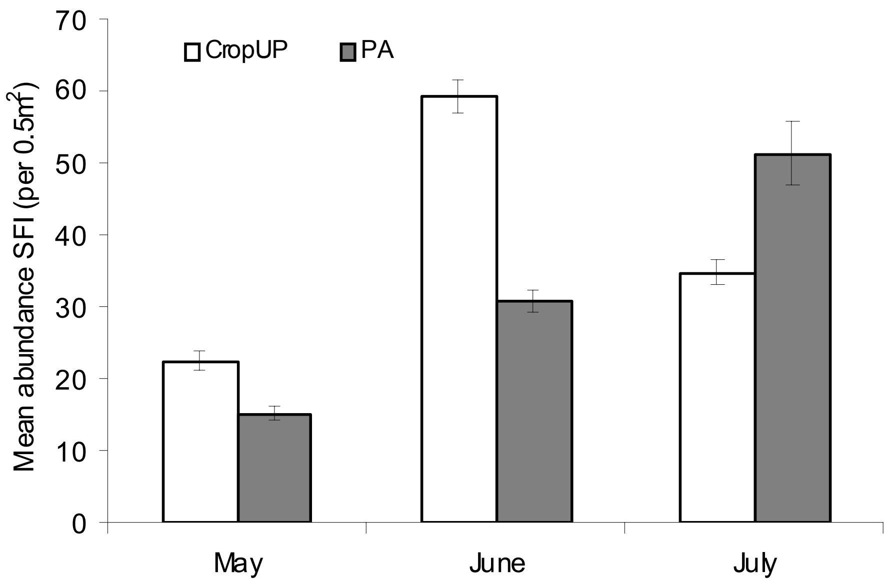

Figure 4.19. Significant differences between SFI in the CropUP and PA in 2002. Mean abundance per $0.5m^2$ with 95% CI.

In 2003, the most striking feature was the lack of invertebrates sampled within PA. With the exception of the number of rove beetle species, all groups of ground active invertebrates were significantly lower in PA (see Table 4.21 for means and results of analyses).

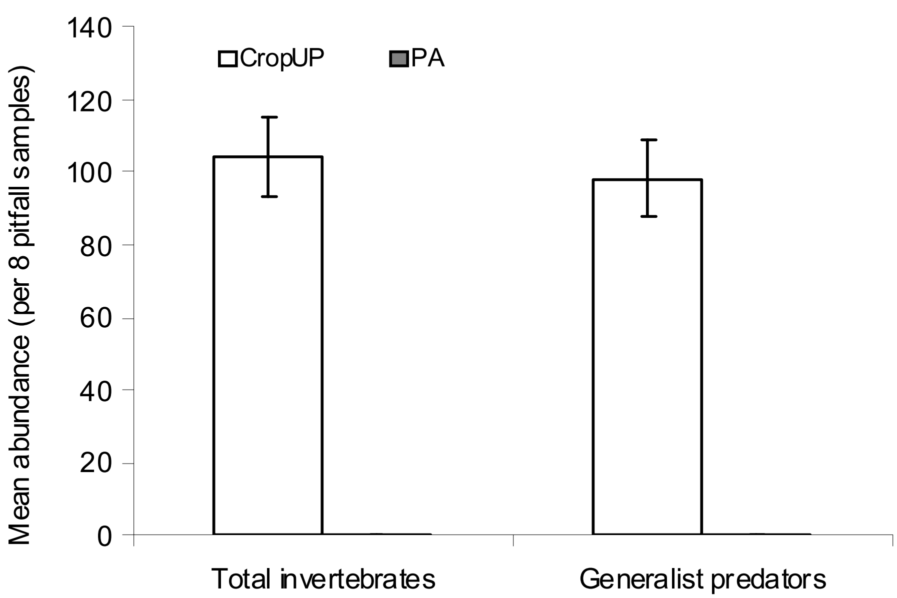

Figure 4.20. Significant differences between total invertebrate abundance and abundance of generalist predators in the CropUP and PA in 2003. Means (with 95% CI) are of eight pitfall samples, open for 7 pitfall days on three occasions. See section 4.3.3.4 for details.

A similar pattern emerged for the crop active invertebrates and although there were some changes in invertebrate abundance within the crop over the sampling period, there was no treatmentXtime interaction. Numbers of invertebrates within PA remained negligible throughout the season. The means and results of analyses are shown in Table 4.22. Total invertebrate abundance (Figure 4.21), SFI (Figure 4.22) and CFI (Figure 4.23) illustrate the pattern found in other data.

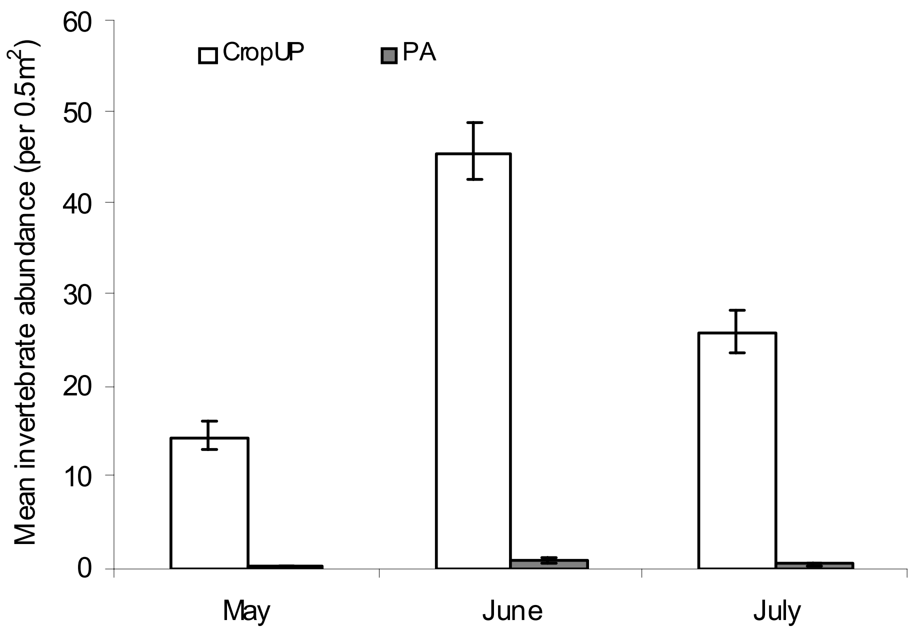

Figure 4.21. Significant differences between total invertebrate abundance in CropUP and PA in 2003. Mean per $0.5m^2$ with 95% CI.

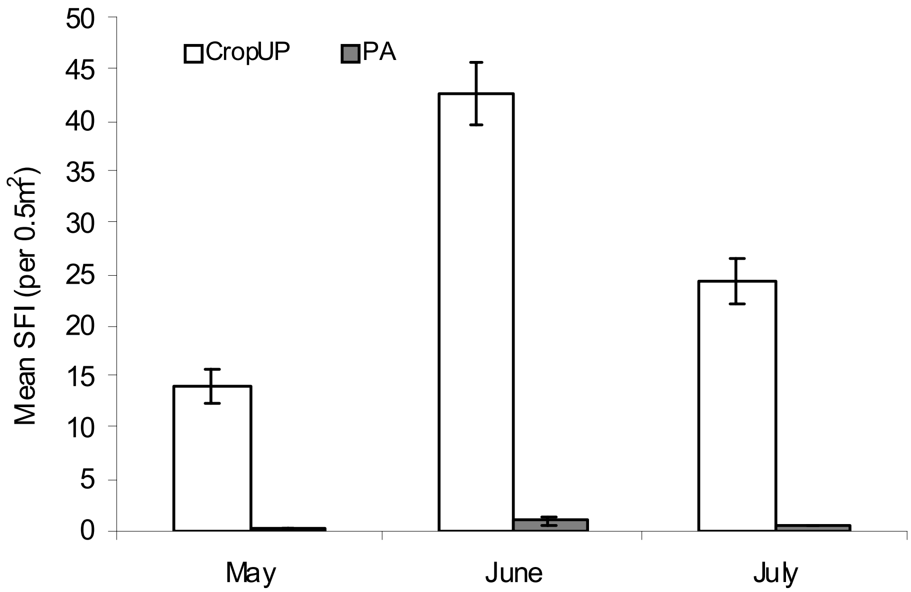

Figure 4.22. Significant differences between SFI in CropUP and PA in 2003. Mean per $0.5m^2$ with 95% CI.

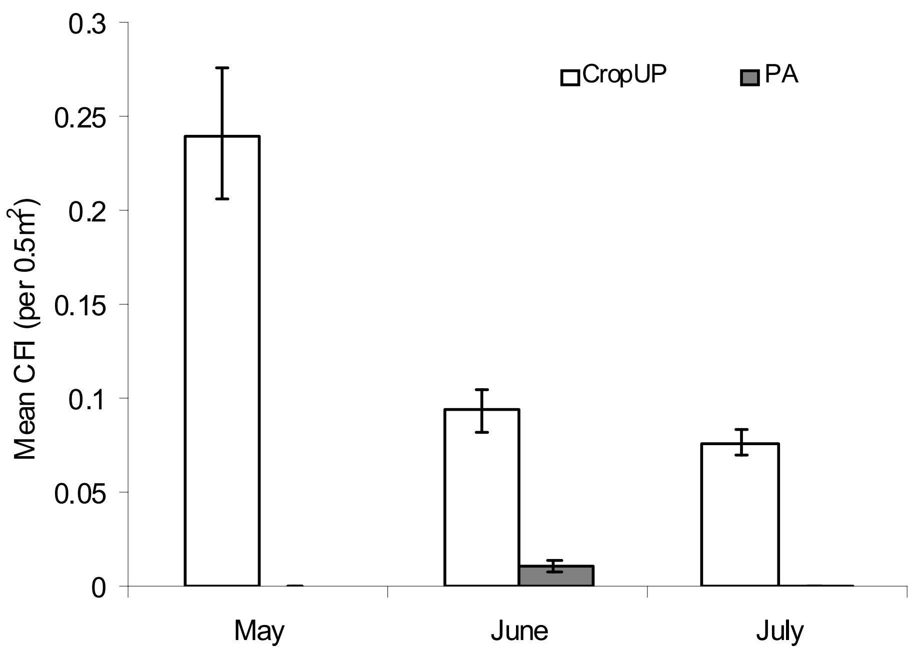

Figure 4.23. Significant differences between CFI in CropUP and PA in 2003. Mean per $0.5m^2$ with 95% CI

Table 4.18. A comparison of ground active invertebrate samples collected by pitfall trap from CONV, UP and WSR treatments. Values are back transformed means (across site, mean of 8 pitfall samples; see section 4.3.3.4 for details).

Source of variation	**CONV**	**UP**	**WSR**	***F***	***P***
2002: d.f., 2, 26 n = 27					
Total invertebrates	52.54	65.24	35.80	2.36	0.126
Generalist predators	57.95	68.23	38.45	2.67	0.100
Phytophagous groups	1.00	1.31	0.65	1.48	0.257
Carabidae	47.53	59.73	33.28	1.98	0.171
Number of carabid species	4.21	4.57	3.97	1.67	0.220
Staphylinidae	6.04	8.87	4.30	3.67	0.049
Number of staphylinid species	2.17	2.47	1.76	2.99	0.079
Lycosidae	0.37	0.43	0.90	3.73	0.047
Species richness	6.21	9.52	5.62	24.42	<0.001
2003: d.f. = 2, 25 n = 26					
Total invertebrates	1.75	1.98	2.04	1.48	0.259
Generalist predators	4.51	5.44	5.44	1.73	0.211
Phytophagous groups	0.31	0.50	0.53	2.09	0.158
Carabidae	1.83	5.52	5.34	1.76	0.206
Number of carabid species	1.65	1.91	2.01	2.15	0.151
Staphylinidae	0.67	0.63	0.72	0.29	0.756
Number of staphylinid species	1.83	1.81	1.90	0.01	0.992
Lycosidae	0.13	0.10	0.12	0.72	0.501
Species richness	0.89	0.95	0.94	1.8	0.200

Table 4.19. A comparison of crop active invertebrate samples collected by vacuum from CONV, UP and WSR treatment on three sampling occasions. Values are back transformed means (across sites, per $0.5m^2$).

Source of variation	May			June			July			Treatment		Time		TreatmentXTime	
	CONV	**UP**	**WSR**	**CONV**	**UP**	**WSR**	**CONV**	**UP**	**WR**	***F***	***P***	***F***	***P***	***F***	***P***
2002: Treatment, d.f. = 2, 18; Time d.f. =2, TreatmentXTime d.f. = 4, 51 n=90															
Total invertebrates	64.46	61.62	53.79	33.36	37.12	32.60	33.36	37.12	32.60	0.73	0.50	32.70	<0.001	0.21	0.892
Phytophagous groups	4.55	4.18	4.27	11.32	9.66	9.55	3.85	3.52	4.30	0.67	0.52	23.87	<0.001	0.09	0.976
Generalist predators	1.68	1.18	1.12	5.67	3.82	4.93	5.93	4.19	4.60	4.70	0.02	30.31	<0.001	0.20	0.937
Homoptera	1.25	1.02	0.91	0.88	0.64	0.79	0.31	0.33	0.29	1.13	0.34	9.19	0.001	0.20	0.908
Heteroptera	0.13	0.10	0.05	0.14	0.11	0.03	0.08	0.11	0.08	1.34	0.29	0.01	0.979	0.55	0.683
Diptera	19.30	16.01	20.23	46.02	46.02	38.39	23.92	29.14	22.81	0.21	0.81	13.28	<0.001	0.50	0.727
Linyphiidae	0.29	0.23	0.22	0.68	0.45	0.45	2.11	1.13	1.30	2.33	0.13	28.01	<0.001	0.63	0.607
Total Coleoptera	1.98	1.71	1.39	2.36	3.23	3.14	2.16	2.18	2.78	0.42	0.66	3.21	0.05	0.80	0.528
Carabidae	0.03	0.12	0.04	0.18	0.22	0.15	0.15	0.13	0.19	0.96	0.40	2.70	0.087	0.21	0.908
Staphylinidae	1.04	0.66	0.69	0.43	0.34	0.37	0.42	0.42	0.33	0.78	0.47	9.07	<0.001	0.44	0.775
SFI	26.94	22.67	27.04	63.37	60.90	53.03	30.56	35.62	30.79	0.12	0.89	18.47	<0.001	0.39	0.793
CFI	0.08	0.09	0.05	0.10	0.12	0.13	0.06	0.07	0.09	0.96	0.40	1.94	0.166	0.49	0.696

(continued)

Source of variation	May			June			July			Treatment		Time		TreatmentXTime	
	CONV	**UP**	**WSR**	**CONV**	**UP**	**WSR**	**CONV**	**UP**	**WR**	***F***	***P***	***F***	***P***	***F***	***P***
2003: Treatment, d.f. = 2,15;Time d.f. = 2, TreatmentXTime d.f. 4, 56 n=81															
Total invertebrates	17.36	15.06	19.30	34.24	49.59	50.70	31.92	25.95	32.20	1.05	0.375	12.2	<0.001	0.47	0.735
Phytophagous groups	1.13	1.28	1.28	1.52	1.65	1.67	0.64	0.63	0.55	0.24	0.792	80.1	<0.001	0.70	0.555
Generalist predators	2.38	2.87	2.81	8.49	11.80	8.94	5.19	5.09	4.64	0.61	0.556	19.77	<0.001	0.20	0.921
Homoptera	0.75	0.90	0.86	0.57	0.91	0.65	1.34	1.00	1.07	0.36	0.702	3.47	0.053	0.74	0.538
Heteroptera	0.00	0.03	0.00	0.21	0.19	0.18	0.23	0.13	0.22	0.32	0.728	5.13	0.011	0.21	0.923
Diptera	12.26	10.36	13.51	22.58	32.30	36.45	16.31	12.88	15.36	1.32	0.296	11.55	<0.001	0.53	0.673
Linyphiidae	0.64	0.88	0.75	1.33	1.72	1.62	0.77	0.79	0.78	0.73	0.499	4.81	0.017	0.06	0.988
Total Coleoptera	2.23	3.00	2.43	2.19	5.02	2.95	1.38	1.61	1.93	2.73	0.098	4.21	0.023	0.65	0.626
Carabidae	0.47	0.58	0.45	0.16	0.37	0.09	0.00	0.03	0.04	2.0	0.170	14.11	<0.001	0.47	0.686
Staphylinidae	1.09	1.53	1.22	0.32	0.62	0.40	0.37	0.27	0.29	0.44	0.65	18.31	<0.001	0.43	0.711
SFI	16.64	14.39	18.32	32.24	46.42	48.19	30.69	24.46	30.52	1.04	0.376	11.95	<0.001	0.49	0.719
CFI	0.11	0.12	0.11	0.07	0.11	0.04	0.07	0.08	0.07	0.86	0.442	2.41	0.123	0.43	0.714

Table 4.20 A comparison of crop active invertebrate samples collected by sweep net from CONV and WSR treatment on two sampling occasions. Values are back transformed means (across sites, mean of two sweep samples).

Source of variation	May		July		Treatment		Time		TreatmentXTime	
	CONV	**WR**	**CONV**	**WR**	***F***	***P***	***F***	***P***	***F***	***P***
2002: Treatment, d.f. =1,8; Time d.f. =2, TreatmentXTime d.f.=4,16 n=18										
SFI	5.19	7.14	13.78	10.90	0.05	0.831	1.92	0.185	0.29	0.595
Total invertebrates	17.70	17.30	25.85	27.30	0.02	0.903	1.12	0.305	0.01	0.922
2003: Treatment, d.f.=1,7; Time d.f.=2, TreatmentXTime d.f.=4,14 n=16										
SFI	0.02	1.38	0.01	15.52	0.09	0.769	28.35	<0.001	0.38	0.55
Total invertebrates	16.60	21.20	30.05	29.62	0.15	0.713	1.90	0.189	0.15	0.708

Table 4.21. A comparison of ground active invertebrate samples collected by pitfall trap from PA and CropUP. Values are back transformed means (across site, mean of 8 pitfall samples; see section 4.3.3.4 for details).

Source of variation	**CropUP**	**PA**	***F***	***P***
2002: d.f. =1, 17 n = 18				
Total invertebrates	71.06	64.78	0.53	0.486
Generalist predators	57.29	66.33	0.04	0.850
Phytophagous groups	1.30	3.11	7.91	0.023
Carabidae	67.58	61.45	0.58	0.467
Number of Carabid species	7.17	6.32	2.62	0.144
Staphylinidae	8.87	4.29	8.93	0.017
Number of staphylinid species	5.47	4.29	20.63	0.002
Lycosidae	0.43	1.07	6.13	0.038
Species richness	15.04	13.96	1.55	0.248
2003: d.f. =1, 17 n = 18				
Total invertebrates	103.95	0.31	209.91	<0.001
Generalist predators	97.86	0.27	194.00	<0.001
Phytophagous groups	2.29	0.02	19.14	0.002
Carabidae	95.83	0.27	180.07	<0.001
Number of carabid species	5.63	0.02	1666.31	<0.001
Staphylinidae	3.31	0.01	29.99	<0.001
Number of staphylinid species	1.72	0.00	0.14	0.871
Lycosidae	0.29	0.00	5.10	0.054
Species richness	8.00	0.03	1516.06	<0.001

Table 4.22. A comparison of crop active invertebrate samples collected by vacuum from PA and CropUP. Values are back transformed means (across sites, per $0.5m^2$).

	May		June		July		Treatment		Time		TreatmentXTime	
Source of variation	**CropUP**	**PA**	**CropUP**	**PA**	**CropUP**	**PA**	***F***	***P***	***F***	***P***	***F***	***P***
2002: Treatment, d.f. = 1, 9; Time d.f. =2, TreatmentXTime d.f. = 2, 34 n=20												
Total invertebrates	22.81	15.52	59.91	31.69	36.12	52.48	4.96	0.053	11.72	<0.001	3.87	0.048
Phytophagous groups	3.83	2.96	9.25	5.38	3.27	3.52	3.64	0.047	17.16	<0.001	1.17	0.333
Generalist predators	6.96	7.47	19.03	16.75	24.68	32.39	0.01	0.990	45.15	<0.001	0.43	0.769
Homoptera	1.03	0.64	0.62	0.69	0.32	0.63	0.00	0.995	1.36	0.264	1.28	0.280
Heteroptera	0.10	0.10	0.11	0.16	0.11	0.39	9.18	0.014	4.38	0.038	3.84	0.052
Diptera	16.00	10.66	44.74	22.22	28.34	38.23	5.79	0.039	12.81	<0.001	3.61	0.056
Linyphiidae	0.23	0.16	0.44	0.48	1.10	0.80	1.82	0.210	9.7	0.003	0.36	0.604
Total Coleoptera	1.71	2.03	3.14	2.87	2.12	3.79	0.32	0.584	1.04	0.336	0.73	0.431
Carabidae	0.12	0.28	0.21	0.23	0.05	0.10	1.57	0.242	2.22	0.126	0.6	0.552
Staphylinidae	0.66	0.49	0.34	0.31	0.41	0.29	1.52	0.249	2.82	0.076	0.2	0.810
CFI	0.09	0.14	0.12	0.15	0.07	0.09	2.17	0.175	1.42	0.256	0.12	0.818
SFI	22.35	15.30	59.20	30.83	34.63	51.01	4.94	0.053	11.45	<0.001	3.96	0.046

(continued)

	May		June		July		Treatment		Time		TreatmentXTime	
Source of variation	**CropUP**	**PA**	**CropUP**	**PA**	**CropUP**	**PA**	***F***	***P***	***F***	***P***	***F***	***P***
2003: Treatment, d.f. = 1, 8; Time d.f. =2, TreatmentXTime d.f. = 2, 32 n=18												
Total invertebrates	14.48	0.18	45.48	0.88	25.81	0.38	103.68	<0.001	4.89	0.016	0.81	0.446
Phytophagous groups	x	x	x	x	x	x	76.07	<0.001	11.62	<0.001	4.82	0.019
Generalist predators	2.82	0.01	10.19	0.45	5.12	0.03	142.47	<0.001	5.42	0.014	1.04	0.356
Homoptera	0.95	0.00	0.85	0.05	1.00	0.01	29.07	<0.001	0.03	0.963	0.36	0.678
Heteroptera	0.03	0.00	0.19	0.00	0.15	0.00	7.64	0.025	1.15	0.302	1.12	0.31
Diptera	14.12	0.17	30.04	0.77	12.85	0.11	215.98	<0.001	3.41	0.063	0.24	0.722
Linyphiidae	0.90	0.00	1.61	0.07	0.79	0.00	82.13	<0.001	2.22	0.128	1.08	0.349
Total Coleoptera	3.36	0.01	3.69	0.47	1.67	0.03	38.07	<0.001	2.61	0.108	0.84	0.413
Carabidae	0.56	0.00	0.37	0.00	0.03	0.00	15.8	0.004	4.28	0.029	4.24	0.03
Staphylinidae	1.58	0.00	0.57	0.03	0.29	0.00	23.55	0.001	8.45	0.005	8.73	0.004
CFI	0.24	0.00	0.09	0.01	0.08	0.00	15.25	0.005	1.32	0.277	1.52	0.238
SFI	13.86	0.18	42.55	0.87	24.31	0.37	102.09	<0.001	4.72	0.018	0.76	0.468

4.4.3.5 Relationship between invertebrate groups and components of weed cover

In 2002, the vegetation components were uncorrelated (Table 4.23) and bare ground, litter, crop, grass cover and broadleaf weed cover were included in the models. In 2003, bare ground was negatively correlated with all other components and was excluded from the model. Ground invertebrate data in 2003 was excluded as data transformation and alternative error distribution models were not sufficient meet the requirements of normal distribution and homoscedasticity.

Table 4.23. Correlation tables of vegetation components. ***=significant at 0.001, **=significant at 0.01, *=significant at 0.1.

		Bare ground	**Crop**	**Broadleaf**	**Grass**
2002	Crop	0.189	1***		
	Broad-leaved	-0.081	-0.317	1***	
	Grasses	-0.724	-0.308	0.041	1***
	Litter	-0.15	0.036	-0.19	-0.056
2003	Crop	-0.58***	1***		
	Broad-leaved	-0.65***	0.416*	1***	
	Grasses	-0.517***	-0.159	0.386*	1***
	Litter	-0.578***	0.477*	0.341*	0.173

The results in Table 4.24 indicate a positive relationship between the invertebrate groups and vegetative cover; most groups avoid bare ground (with the notable exception of staphylinids and carabids). In 2003, of all vegetation components, broadleaf weed cover was the most important factor in determining invertebrate abundance.

Table 4.24. GLIM best model * C = crop, BG = bare ground, L = litter, G = grass, BL = broadleaf. Model components in order of contribution of variation explained. (-) indicates negative relationship.

Year	Group	n	d.f.	Best model*	Variance explained (%)	SE	*P* (overall regression)
2002	**Ground active**						
	Staphylinids	143	3	C>G>BG	22.40	0.41	<0.001
	Phytophagous	143	3	BG(-)>G>BL	25.80	0.32	<0.001
	Crop active						
	Generalist predators	318	3	L(-)>BL>C>G	26.60	0.33	<0.001
2003	**Crop Active**						
	Total invertebrates	278	3	BL>C>G	31.80	0.48	<0.001
	Total Coleoptera	278	3	BL>C	15.70	0.37	<0.001
	Total carabids	278	3	L>G (-)>C (-)	2.30	0.17	0.030
	SFI	278	3	BL>G>C	30.50	0.47	<0.001
	Linyphiidae	278	3	BL>C	6.90	0.24	<0.001
	Generalist predators	278	3	BL>G>C	24.10	0.37	<0.001
	Diptera	278	3	BL>G>C	21.10	0.47	<0.001
	Phytophagous	278	3	BL>G>C	35.70	0.49	<0.001

4.4.3.6 Invertebrate community composition

Community composition data were analysed using RDA after examining gradient lengths obtained from *a priori* DCA analysis (<3 in all cases).

Ground active invertebrates, 2002

In 2002, differences between farms explained 72% of the variance in the species data. After this effect was removed, the environmental variables explained 45% of the remaining variance. The overall model was significant (Trace = 0.125, F = 1.956, P = 0.004). Environmental variables that were significantly correlated with variance in the species data were crop cover (F = 3.88, P = 0.004) and grass cover (F = 4.04, P = 0.006). Grass and crop cover were uncorrelated (Figure 4.24).

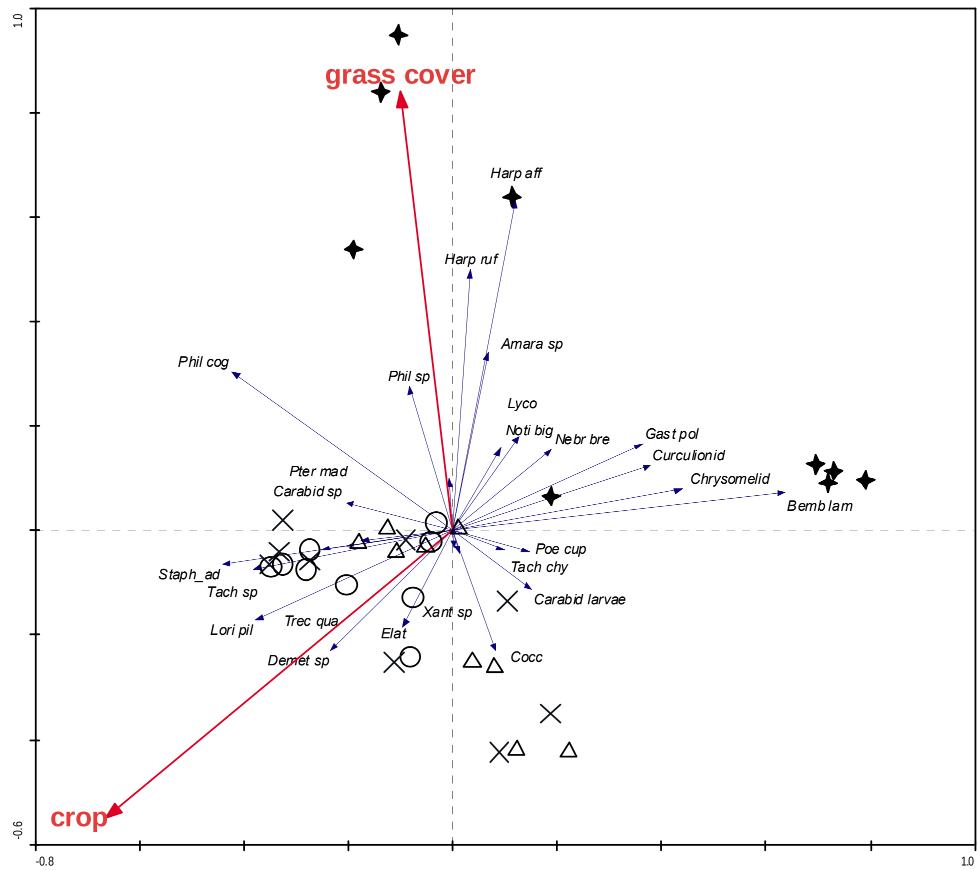

Figure 4.24 RDA triplot for ground active invertebrates in 2002. Symbols represent samples collected as follows: ○= crop surrounding PA, ✦= PA, △= WR, ×= conventional. Abbreviated species key: Bemb lam= *Bembidion lampros*; Cocc= Coccinelidae; Demet sp= *Demetrias* spp.; Elat= Elateridae; Harp aff= *Harpalus affinis*; Harp ruf= *Harpalus rufipes*; Lori pil= *Loricera pillicornis*; Lyco= Lycosidae; Nebr bre= *Nebria brevicollis*; Noti big= *Notiophilus biguttatus*; Poe cup= *Poecilus cupreus*; Phil cog= *Philonthus cognatus*; Phil sp= *Philonthus* spp.; Pter mad= *Pterostichus madidus*; Staph_ad= Staphylind adults; Tach sp= *Tachinus* spp.; Tre qua= *Trechus quadristriatus*; Xant sp= *Xantholinus* spp.

Grass cover was associated with the samples from PA, and phytophagous beetles such as *Harpalus rufipes*, *Harpalus affinis* and *Amara* spp. These carabid species were likely to colonise grass where it occurred and that this was frequently in the patches. Crop was associated with some of the predatory species such as the carabids *Demetrias* spp. and *Trechus quadristriatus.*

Crop active invertebrates, 2002

As for crop active invertebrates, between site variation explained a high percentage of the variance (79%). Of the remaining variance, 47% was explained by the environmental variables. Significant variables were May and July (F = 36.31, P = 0.002), forb cover (F = 8.20, P = 0.002) and grass cover (F = 2.49, P = 0.008), PA was of borderline significance but included (F = 2.19, P = 0.06). The overall test was significant (Trace = 0.372, F = 6.028, P = 0.002). The triplot (Figure 4.25) suggests that in May the invertebrate community was similar across all treatments but by July there was some separation between PA and other samples. Broadl-leaved weeds and grasses colonised the patches, the length of the arrows indicating that broadleaf cover was higher. Heteroptera (largely phytophagous bugs) and Nitidulidae (pollen beetles) were closely correlated with broadleaf cover. Grass cover was also correlated (though less closely) with these invertebrates as well as flies of the sub-order Acalyptera. In general, the results suggest that although colonisation by broad-leaved weeds and grasses was important, other factors, such as season, were more influential.

Ground active invertebrates, 2003

In 2003, differences between farms explained 38% of the variance in community composition; with environmental variables explaining 67% of the remaining variance. Only PA was significant (F = 29.70, P = 0.002). The overall model was significant (Trace = 412, F = 4.63, P = 0.002). The triplot (Figure 4.26) illustrates very clearly that the most influential factor in 2003 for ground active invertebrates was the absence of vegetative cover in the patches. The only species associated with PA in this year was *Gastrophysa polygoni*, a small leaf beetle frequently found on *Polygonum* spp.

Crop active invertebrates, 2003

Differences between farms explained only 16% of the variance. Of that remaining, the environmental variables explained 66.5%. Significant environmental variables were: May and July (F = 16.11, P = 0.002), crop cover (F = 35.47, P = 0.002), PA (F = 31.47, P = 0.002) and broadleaf cover (F = 19.94, P = 0.002). The overall model was significant (Trace = 0.656, F = 11.75 P = 0.002). The lack of vegetation in PA is evident in the triplot (Figure 4.27). Furthermore, there are differences over the season, both broadleaf cover and crop cover increased in July and the analysis suggests that broadleaf cover was more likely to be among the crop (or perhaps tramlines) than in the patches. The majority of invertebrates are associated with the vegetative cover in July including aphids, plant bugs and flies such as Aschiza and Brachycera.

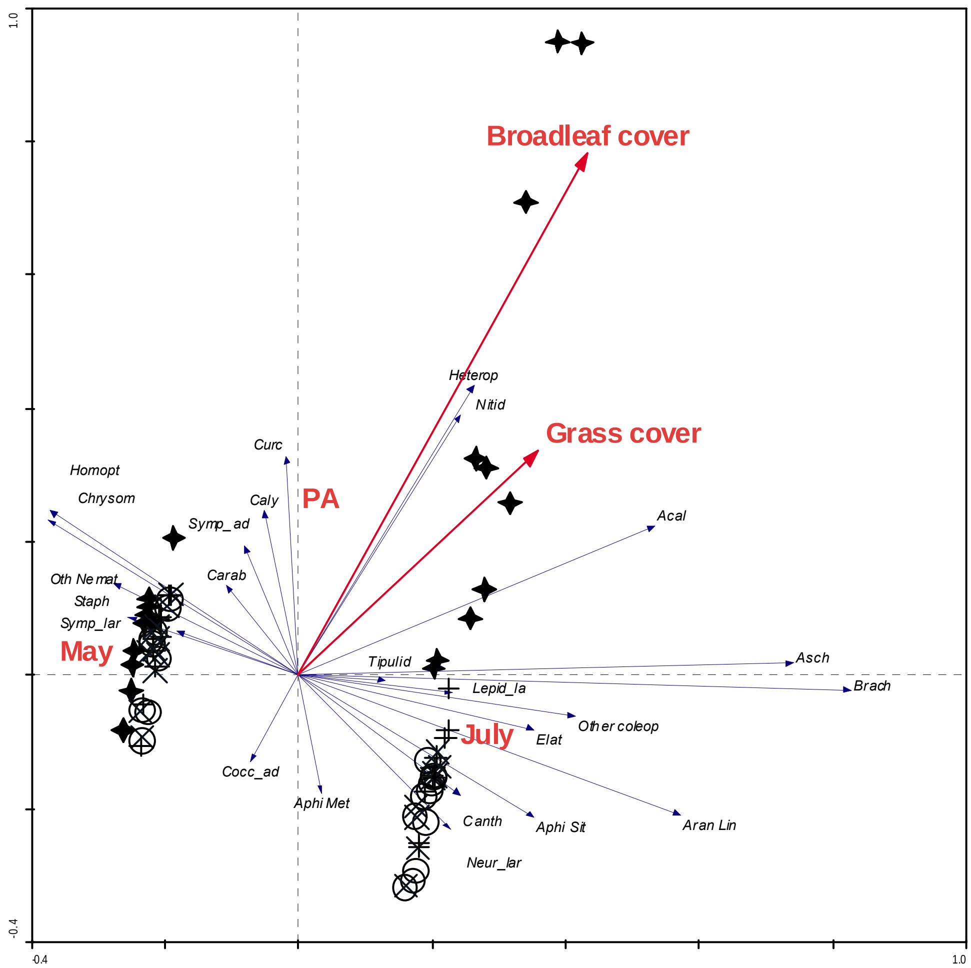

Figure 4.25 RDA triplot for crop active invertebrates in 2002. Symbols represent samples collected as follows: ○= crop surrounding PA, ✦= PA, △= WR, ×= conventional. Abbreviated species key: Aphi met= *Metopolophium dirhodium*; Aphi sit= *Sitobion avenae*; Acal= Acalyptera; Aran lin= Linyphiidae; Asch= Aschiza; Brach= Brachycera; Caly=Calyptera; Canth= Cantharidae; Chrys= Chrysomelidae; Cocc_ad= Coccinelidae adult; Cocc_lar= Coccinelidae larvae; Curc= Curculionidae; Elat= Elateridae; Heterop= Heteroptera; Homopt= Homoptera; Lepid_la= Lepidoptera larvae; Neur_lar= Neuroptera larvae; Nitid= Nitidulae; Oth Aran= Other Araneae; Other coleop= Other Coleoptera; Staph= Staphylinid spp.; Symp_ad= Symphyta adults; Symp_lar= Symphyta larvae.

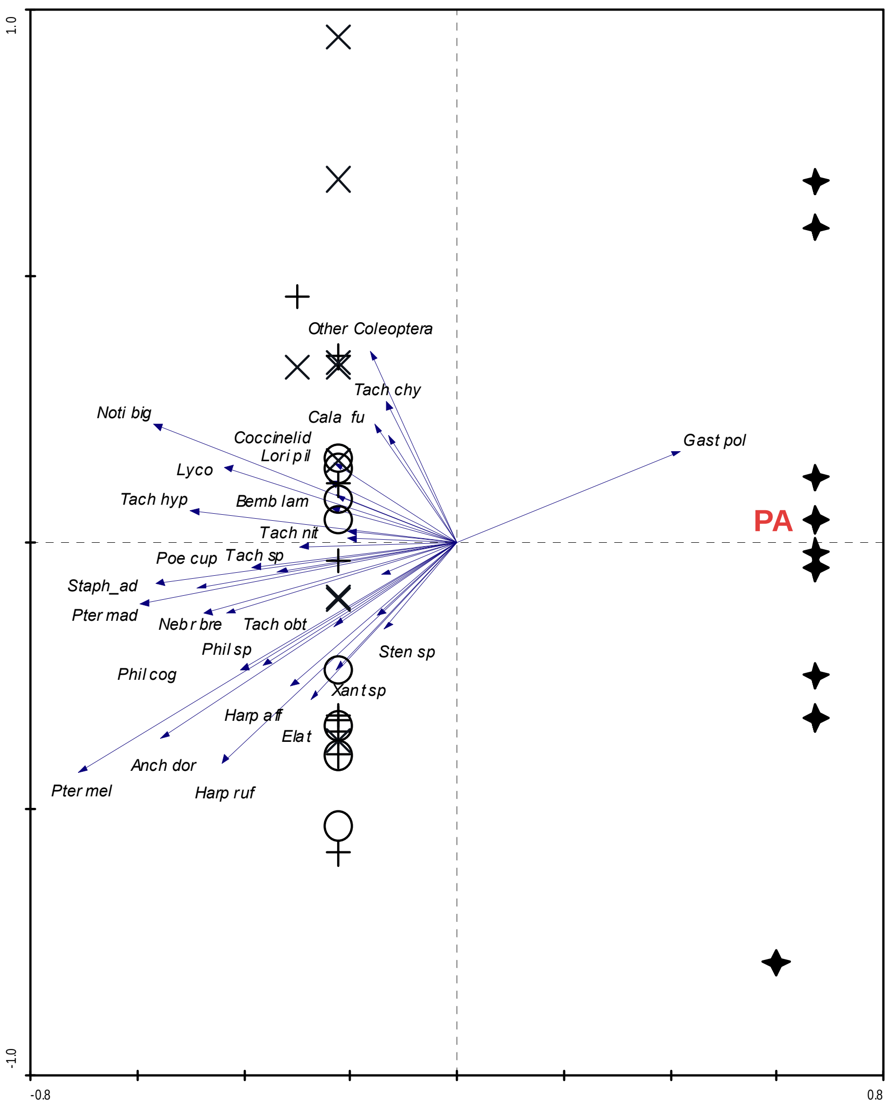

Figure 4.26 RDA triplot for ground active invertebrates in 2003. Symbols represent samples collected as follows: ○= crop surrounding PA, ✦= PA, △= WR, ×= conventional. Abbreviated species key: Anch dor= *Anchomenus dorsalis*; Bemb lam= *Bembidion lampros*; Cal fus= *Calathus fuscipes*; Elat= Elateridae; Gast pol= *Gastrophysa polygoni*; Harp aff= *Harpalus affinis*; Harp ruf= *Harpalus rufipes*; Lori pil= *Loricera* Lyco= Lycosidae; Nebr bre= *Nebria brevicollis*; Noti big= *Notiophilus biguttatus*; Poe cup= *Poecilus cupreus*; Phil cog= *Philonthus cognatus*; Phil sp= *Philonthus* spp.; Pter mad= *Pterostichus madidus*; Pter mel= *Pterostichus melanarius*; Staph_ad= Staphylinid adults; Sten sp= *Stenus* spp.; Tach chy= *Tachyporus chrysomelinus*; Tach hyp= *Tachyporus hypnorum*; Tach nit= *Tachyporus nitidulus*; Tach obt= *Tachyporus obtusus*; Tach sp= *Tachinus* spp.; Xant sp= *Xantholinus* spp.

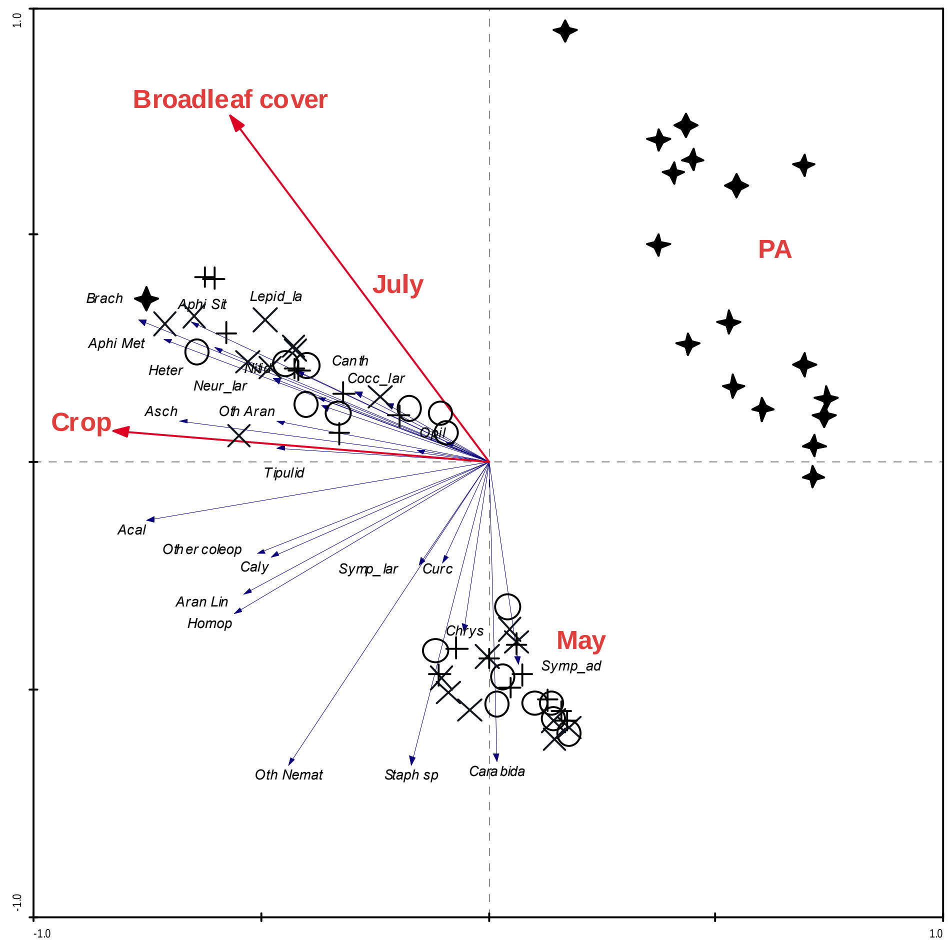

Figure 4.27 RDA triplot for crop active invertebrates in 2003. Symbols represent samples collected as follows: ○= crop surrounding PA, ✦= PA, △= WR, ×= conventional. Abbreviated species key: Aphi met= *Metopolophium dirhodum*; Aphi sit= *Sitobion avenae*; Acal= Acalyptera; Aran lin= Linyphiidae; Asch= Aschiza; Brach= Brachycera; Caly=Calyptera; Canth= Cantharidae; Chrys= Chrysolmelidae; Cocc_lar= Coccinelidae larvae; Curc= Curculionidae; Heter= Heteroptera; Homop= Homoptera; Lepid_la= Lepidoptera larvae; Neur_lar= Neuroptera larvae; Oth Aran= Other Araneae; Other coleop= Other Coleoptera; Stap_sp= Staphylinid spp.; Symp_ad= Symphyta adults; Symp_lar= Symphyta larvae.

4.4.3.7 Faecal data

Faecal samples were collected from nests in each of the treatments. Figure 4.28 shows the relative proportion of insect food consumed by skylark nestlings as determined by identification of invertebrate remains in faecal samples. Data was bulked across nests and time. The graph suggests that between year differences are greater than between treatment differences. The proportion of 'other invertebrates' was larger in 2003, while the proportion of carabids was reduced. In 2002, the invertebrate data collected by vacuum were positively correlated with the contents of faecal samples; invertebrate data collected by pitfall sample were not (Table 4.25). In 2003, invertebrates sampled by both methods were uncorrelated with the faecal material.

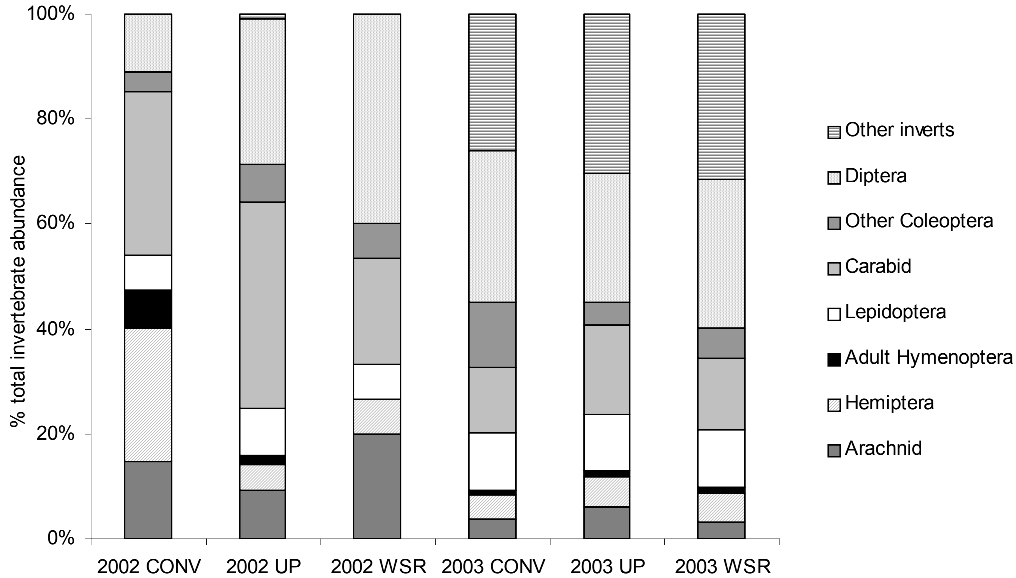

Figure 4.28. Summary of the composition of skylark chick faecal samples in 2002 and 2003.

Table 4.25. Association between skylark faecal data and invertebrates sampled by pitfall trap and vacuum.

Relate	Rho	Significance
Faecal data 02		
Ground dwelling invertebrates	0.148	0.90
Crop dwelling invertebrates	0.542	0.01
Faecal data 03		
Ground dwelling invertebrates	0.058	0.27
Crop dwelling invertebrates	-0.204	0.93

4.4.4 Birds

In the skylark models, in no case did 'adjacent habitat score' or 'boundary index' significantly affect the response variables and they were dropped from the models. This was hoped for, given that sites were chosen to try to minimise variation in these factors. 'Year' was only significant in the within-treatment foraging model and was dropped from the other models.

Skylark territory density in the 5 ha SAW plots varied significantly with treatment, period and treatmentXperiod interaction. Overall, densities were greater in the early breeding season (April-May) and were greatest on UP. The interaction term indicated that territory densities were similar between the three treatments early in the breeding season (April-May) but later, densities were maintained in UP and WSR but fell in CONV. The highest density was recorded in late UP (Table 4.26).

Table 4.26. GLMM MAM – significant predictors of skylark territory density per 5 ha SAW & back-transformed least squared means for fixed effects.

Predictor		**Least squares means**	**Significance tests**
Period			$F_{1,185}$ 7.99 P = 0.048
	Early	1.11	
	Late	0.99	
Treatment			$F_{2,202}$ 6.32 P = 0.002
	CONV	0.91	
	UP	1.22	
	WSR	1.04	
TreatmentXPeriod			$F_{2,185}$ 5.28 P = 0.006
	CONV Early	1.09	
	CONV Late	0.76	
	UP Early	1.18	
	UP Late	1.26	
	WSR Early	1.07	
	WSR Late	1.02	

Differences in the least squared means of the treatmentXperiod interaction, showed that later in the breeding season UP and WSR held significantly more territories (+40% and +25% respectively) than CONV, while UP held borderline-significantly more (+24%) territories than WSR (Figure 4.29).

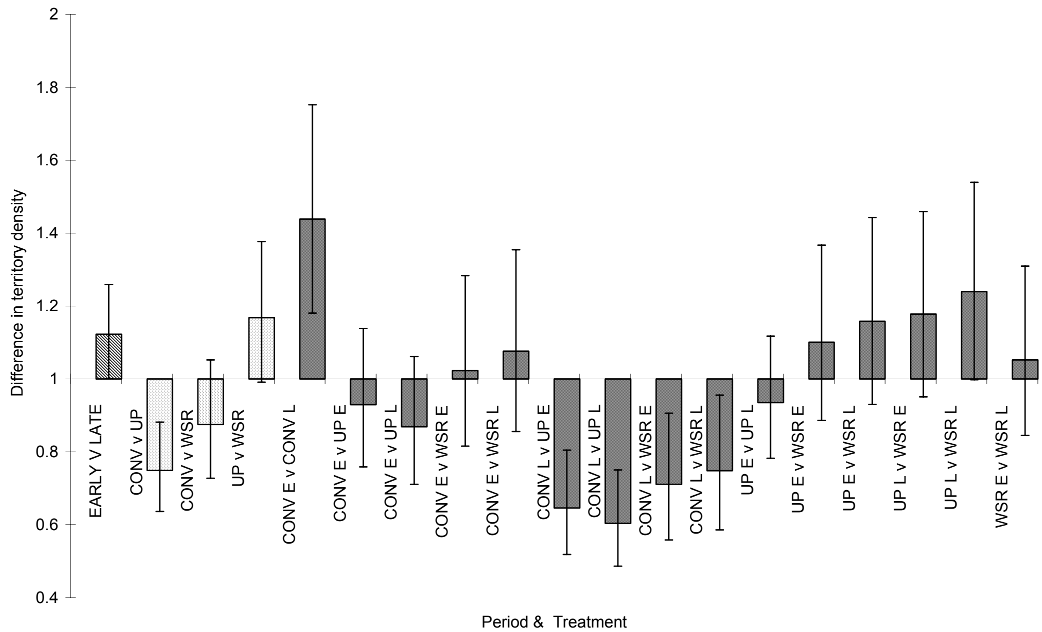

Figure 4.29. Percentage differences in least squared means between factor levels for treatment, period and their interaction in the skylark territory density GLMM. Values <1 indicate a greater density of territories in the second factor-level; values >1 indicate greater density in the first factor level – e.g. in the CONV E v CONV L contrast, a value of 1.42 equates to 42% more territories in the early period than in the late period in conventional wheat; in the CONV v UP contrast, a value of 0.75 equates to 25% less territories in CONV than in UP. Contrasts were significant at P <0.05 if CI bars do not overlap the origin line on the graph (1 on Y axis).

Over the entire breeding season, period was the sole significant predictor of skylark nest density per 10 ha, with a decrease in density later in the breeding season. Non-significant differences in the least squares means for periodXtreatment interaction, showed that early-season densities on CONV and UP were similar and there was a trend for them to be higher than on WSR. Densities in all treatments decreased (again, non-significantly) later in the season, with the decreases averaging 55% in CONV, 21% in UP and just 5% in WSR. Late season nest densities in CONV averaged only 44% of those in WSR and 49% of those in UP (Table 4.27). However, there were variations between sites and individual fields, which meant that these overall mean differences between treatments were not significant – e.g. 53% of all late WSR nests were found on a single site, with 42% found on a single field within that site in 2003. When WSR nests were dropped from the analysis, a comparison of late-season CONV and UP nest densities showed significantly greater densities per 10 ha on UP (Back-transformed Means: CONV = 0.47; UP = 1.01: F = 5.25 d.f. = 1 P = 0.029).

Table 4.27. GLMM MAM – predictors of skylark nest density per 10 ha and back-transformed least squared means for fixed effects.

Predictor		Least squares means		Significance tests
Period				$F_{1,87}$ 3.99, $P = 0.049$
	Early	1.07		
	Late	0.75		
Treatment				*ns*
	CONV	0.73		
	UP	1.08		
	WSR	0.90		
TreatmentXPeriod		Early	Late	*ns*
	CONV	1.1	0.49	
	UP	1.22	0.96	
	WSR	0.93	0.88	

The mean first egg date in 2003 was ten days later than in 2002 (31 and 21 May respectively), probably because of very dry conditions and cool nights in March and early April 2003.

There was a weak non-significant trend for later nests in UP treatments to be situated closer to the patches but mean distance from the nest to the nearest patch continued to be over 20 m. Only 17% of nests were within 10 m of a patch. Based on an estimate of the available area of the patches and the surrounding crop within 10 m of the patch edge, PA and the surrounding crop-edge were not significantly selected in relation to their availability for the purpose of nesting ($\chi^2 = 2.49$ d.f. = 1 $P = 0.11$). Later nests in CONV were situated significantly nearer to tramlines but there was only a weak non-significant trend for late nests in UP and WSR to be closer to the tramlines.

There was no indication that mean brood weight varied with any predictor other than a positive relationships with the covariate 'tarsus', included in the model to account for nestling age ($F_{1,51} = 351.52$ $P < 0.0001$).

Most of the constituent estimates of nest productivity were similar between treatments both for (i) the entire breeding season and (ii) by period, for early and late summer. Failure of eggs to hatch through causes other than physical destruction and nestling starvation were both rare events (<10% of total laid/hatched) and neither were influenced by any predictors in the models. Nest daily failure rate was highest for late season CONV nests but there was no significant effect of treatment overall, or of the treatmentXperiod interaction. Predation rates of nestlings did not vary between treatments. However, clutch size did vary slightly, although significantly, with treatment ($F_{2,90}$ = 3.1 P = 0.05), with mean number of eggs laid per clutch being greater in UP than CONV (Figure 4.30).

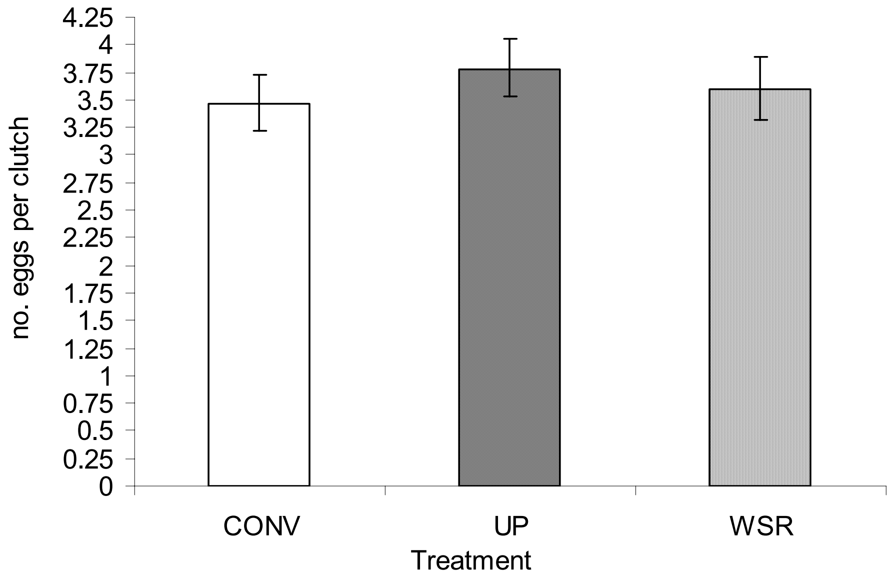

Figure 4.30. Skylark mean number of eggs per clutch (with 95% CI) by treatment.

In UP and WSR, the larger initial clutch sizes, combined with the non-significant trends for greater nest survival, meant that the number of skylark chicks produced per nesting attempt was greater than in CONV, especially for later nests. Over the entire breeding season, per breeding attempt UP nests produced an average of 0.5, and WSR nests 0.25, more chicks than CONV. During the late period, per breeding attempt UP nests produced an average of 1.5 more chicks than CONV nests and over one more chick than WSR nests. Late-season UP nests had a slightly (but non-significantly) higher survival rate and a lower partial brood loss per breeding attempt compared with CONV and WSR nests. There was also a non-significant late-season trend for larger clutch sizes in UP than in WSR. WSR nests produced 0.4 more chicks per attempt more than CONV nests and, over the entire breeding season, produced an average of only 0.25 chicks less than UP nests. Early period productivity per attempt was very similar (1.5 chicks) in CONV and UP and slightly higher (1.8 chicks) in WSR (Figure 4.31), although the latter comprised of a relatively small sample size.

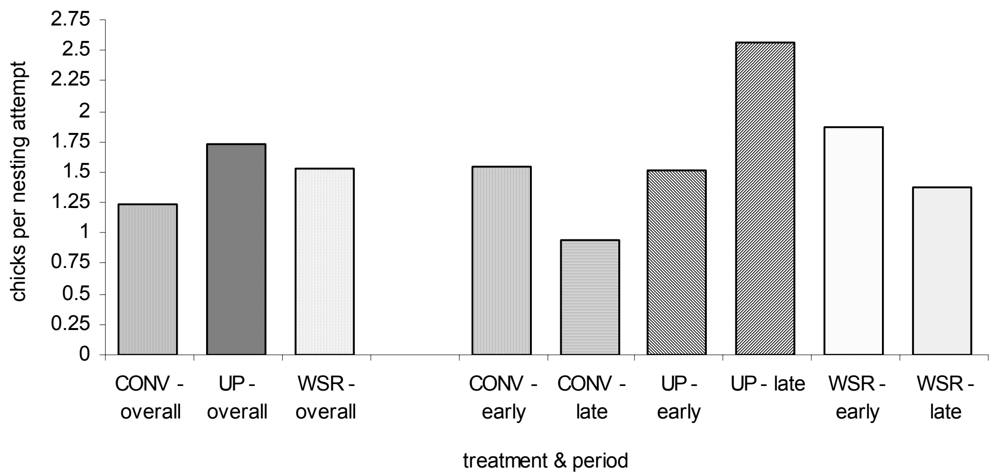

Figure 4.31. Skylark estimated productivity, in terms of chicks produced per nesting attempt per treatment for: (i) the entire breeding season and (ii) by period, for early & late summer.

Skylark foraging patterns varied significantly with year and the treatmentXperiod interaction. Results from WSR should be treated with some caution, as the sample sizes were small. Between April-May (early) and June-July (late), the proportion of flights by parents provisioning nestlings within the field where the nest was situated significantly decreased in CONV, remained the same in UP and significantly increased in WSR. During June-July, UP and WSR had a significantly greater percentage of foraging within the treatment where the nest was situated than CONV (Table 4.28).

Foraging distance did not differ significantly with treatment or the treatmentXperiod interaction but this may be attributable to low accuracy of distance estimates for some of the longer foraging flights off-treatment.

Undrilled patches were significantly selected by foraging skylarks compared to their availability (X^2 = 1376.71; d.f. = 1; P <0.001). On a subset of sites with good overall visibility, at least 17% of foraging flights to a known destination (24% of foraging within the treatment) were to undrilled patches. This compared to 0.42% of the treatment area covered by the patches. This figure represents minimum usage, as, even on sites with good overall visibility, it was impossible to accurately observe all the locations of patches during the watches.

The use of the cropped area by species other than skylark was rare and did not vary with treatment. In 2003, transect walks through the crop recorded an average of just one non-skylark per 1 km. In a total of 72 km walked, pheasant (*Phasianus colchicus*) and yellowhammer (*Emberiza citrinella*) were the only other species for which more than 10 individuals were recorded. During 27 hours of foraging watches on undrilled patches and the surrounding crop and tramlines, 13 species other than skylark were recorded, of which 10 made use of the undrilled patches. For these species, foraging within the patches comprised 33% of all visits (n = 80) to the cropped area. Linnet (*Carduelis cannabina*) was the most frequently recorded species (9 individuals on 4 occasions), all of which foraged within the patches.

Table 4.28. GLMM MAM – Predictors of the proportion of foraging flights, by skylarks provisioning nestlings, within the treatment where the nest was situated. Back-transformed least squares means for fixed effects and significant differences in and direction of factor-level pairwise comparisons: < = greater use in the first factor-level, significant at P = 0.05; << = greater use in the first factor-level, significant at P = 0.01; > = greater use in the second factor-level, significant at P = 0.05; >> = greater use in the second factor-level, significant at P = 0.01; >>> = greater use in the second factor-level, significant at P <0.001.

Predictor		**Least squares means**	**Significance tests for fixed effects & pairwise comparisons**
Year			$F_{1,39}$ 7.00 P = 0.01
	2002	91%	significance differences between factor levels:
	2003	72%	*2002 > 2003*
Period			*ns*
Treatment			*ns*
TreatmentXPeriod			$F_{2,27}$ 9.69 P < 0.001
	CONV Early	0.90	significant differences between factor levels:
	CONV Late	0.53	CONV Early v CONV Late <<
	UP Early	0.72	CONV Late v UP Late >
	UP Late	0.86	CONV Late v WSR Late >>>
	WSR Early	0.78	UP Early v WSR Late >>
	WSR Late	0.97	WSR Early v WSR Late >>

4.5 DISCUSSION

4.5.1 Agronomy

There were no overall differences between the treatments in terms of spring plant population, fertile tiller number and yield. For wheat crops, increasing crop row spacing from normal practice (10 – 12.5 cm) to wide rows (20 – 30 cm) can result in a significant reduction in yield of the order 5–10 % (Welsh et al. 2002). Some farms in this study experienced a yield decrease but the overall trend was for similar yields between the treatments. Previous research has shown that varieties that perform well in wide rows tend to be either tall by nature or grow tall due to favourable weather. They also have a non-erect growth habit that allows them to fill in the wide row middles, and also compensate for low population (Beuerlein 2002). However, tall canopies and in-filling, which may create a dense sward, may be detrimental to biodiversity such as arable weeds and birds.

UP did not result in a yield decrease over CONV but some comments were made on the unacceptable levels of cleavers. *Galium aparine,* and black-grass, *Alopecurus myosuroides,* in a small minority of PA. Most wheat herbicides rely on competition from the crop to achieve total weed suppression. Where this competition is removed, some weeds are able to succeed in germinating and developing even though they have been sprayed. It is preferable that any PA with heavy weed cover is spot-treated with a non-specific herbicide such as glyphosate. UP is unlikely to be suitable option for fields with a uniform heavy weed burden of the more competitive species such as black-grass, wild-oats *Avena* spp. and cleavers.

4.5.2 Vegetation

PA had very different vegetation cover compared to CropUP, with lower crop cover, generally higher weed cover and consistently greater seed production. Weed species composition did not generally change, but total weed cover increased in the absence of competition from the crop. However there was considerable variability between sites and years, although these differences were not statistically analysed. Differences between years could have been due to seasonal weather conditions, establishment and management of the crop, method of patch creation or to a combination of factors. Further work is needed on the impact of patch establishment method and subsequent management on the weed flora.

The impact of individual PA in subsequent years was not studied here. Greater seed production in PA than in CropUP indicates that there is the potential to generate localised weed problems. However, the absence of field-scale impacts suggests that any small-scale effects will not generate widespread problems but the presence of undrilled patches is likely to raise awareness of an existing weed problem. In fields where competitive weed species such as *Alopecurus myosuroides* are already an issue, UP may not be an appropriate measure. In such situations, PA infested with competitive weeds are also unlikely to be of value to ground-foraging birds because they often form dense vegetative mats that deny access and do not generally form an important component of bird diet.

At the field scale, manipulating the crop architecture had little impact on the crop and weed cover in late May and early July or on the subsequent seed production. However, between-site variability was high and this could have obscured treatment differences. In the WSR treatment, the crop canopy may be more open early in the season. However, autumn germinating species are usually controlled by herbicides, and the more open canopy does not result in germination and establishment of weed species later in the season, which are limited by the crop canopy and a lack of soil disturbance, since seeds of many species require light to stimulate germination.

Despite the significantly higher weed cover and seed production in individual PA, the UP treatment did not have an impact on weed cover at the field scale. This is because the area represented by the patches is small and even high cover values on a small area will not translate to an overall increase when averaged over a much larger area. Seed production has the potential to result in much larger differences between treatments. However, when averaged over the total area, there were very few differences between treatments.

4.5.3 Invertebrates

In recent years, the simplification of arable farming associated with agricultural change has reduced crop diversity and led to the loss of non-crop habitats; these factors, in combination with modern herbicide and pesticide regimes, have contributed to a decline in invertebrate diversity on arable land (Potts 1991, Stoate et al. 2001). Furthermore, a switch from spring sown to winter sown crops has had an effect on weed flora by selectively encouraging autumn-germinating species (Chancellor 1985, Hald 1999) and this has led to reduced diversity of weeds and possibly associated invertebrates (Marshall et al. 2003). Evidence of decline has been published for polyphagous predators, staphylinid beetles (rove beetles), chrysomelids (leaf beetles), parasitoid wasps, moths, localised Lepidoptera (butterfly) species, Araneae (spiders) and Opiliones (harvestmen) (Donald 1998, Aebischer 1991).

One aim of implementing UP and WSR was to reverse this trend by opening up areas to be colonized by weeds and associated invertebrates in winter wheat fields. Although we found no consistent effect of treatment on invertebrate abundance or diversity, there were some limited effects on a small number of predatory species in 2002. UP increased both species richness and abundance of staphylinid (rove) beetles, which are the second most important group of epigeic invertebrates in agricultural environments (after Carabidae), representing 19% of all beetles in terms of abundance (Bohac 1999). Within arable fields, staphylinids are important predators of pests such as aphids, caterpillars and wire worms (Chiverton 1987; Dennis et al. 1994, Bohac 1999). An increase in the abundance of these beetles is likely to be an advantage for farmers and they are also a component of chick-food. However, the effect was not carried over into 2003 when no field-scale effects of treatment were found.

For invertebrates, the effect of introducing WSR was negligible and, for most species, the effect of introducing UP was localised. In 2002, there was some indication that the patches may have encouraged phytophagous ground active species in late summer, when colonised by weeds. There was a dramatic difference in 2003, when many PA remained bare, possibly due to a dry summer and, on a few sites, perhaps also partly because the patches were ‘sprayed out’ with glyphosate in the spring rather than being created by not drilling the area in the previous autumn.

The principle that weed cover encourages invertebrates is well established and it has long been suggested that small islands of grass within a crop could maintain a population of carabids (Thomas et al. 1991). The effectiveness of this idea is demonstrated by the success of beetle banks as an overwintering site for beetles and through their encouragement of chick-food invertebrates in the summer (Thomas et al. 2001). Weed cover, particularly grass cover, has been shown to increase the abundance of generalist predators such as ground beetles and spiders (Speight & Lawton 1976, Norris & Kogan 2000). However, it is likely that a certain threshold must be reached before any significant effect is detected. Speight & Lawton (1976) showed a linear relationship between the number of carabid beetles and the cover of *Poa annua* and Sotherton (1982) demonstrated that although the chrysomelid *Gastrophysa polygoni* depends on *Polygonum* (knotgrass), there must be at least eight plants per metre to attract ovipositing females. The results from this study confirm the relationship between weeds and invertebrates: even with relatively low weed cover some plant-insect interactions were detected. Using 2002 data, RDA demonstrated an association between Heteroptera and broadleaved weed cover while phytophagous staphylinids were associated with grass cover. The GLIM analysis also suggests that an increase in weed cover would benefit many invertebrate species. It seems that a major limitation for invertebrates on the experimental farms was low weed cover. Whether farmers could tolerate the threshold at which weed cover would be beneficial for invertebrate abundance within the crop is a matter for debate.

Although dry weather in 2003 undoubtedly played some part in the low abundance of invertebrates, farm management was also influential. Part of the ethos of SAFFIE was to maintain ICM on the experimental farms, a management practice which uses herbicide and pesticides. Herbicide applied to winter wheat has been shown to reduce the number of Araneae, Auchenorrhyncha, Heteroptera, Curculionidae, total Coleoptera and key chick-food items, (Moreby 1997). Insecticides have been shown to have a negative effect on the abundance of non-target species such as Coleoptera (including Curculiondae, Chrysomelidae, Carabidae, Elateridae and Staphylinidae), Diptera and Lepidoptera (Wilson et al. 1999, Dover et al. 1990, Purvis & Bannon 1992). Conversely, conservation headlands that are selectively sprayed with herbicides increased the abundance and fecundity of many chick-food insects and polypagous predators (Chiverton & Sotherton 1991 Moreby & Southway 1999). Opening up crop structure by implementing UP and WSR may well provide gaps for weeds and invertebrates but chemical controls may mitigate the effect; the more open structure may even render these controls more effective.

In conclusion, there was little overall effect of the experimental treatments on invertebrate abundance and diversity. The effects of introducing UP were largely localised and, in 2003, UP positively discouraged invertebrates due to low weed cover. The plant-insect analyses suggest that a higher establishment of weeds would benefit the invertebrate community. Better management may improve the effectiveness of UP for invertebrate biodiversity, preferably by the reduction of chemical controls, however this may not be acceptable for farmers and land-managers.

The lack of correlation between the faecal material and the invertebrates sampled in the field suggests that the skylarks were not necessarily foraging exclusively within the treatments, especially in the second year when invertebrate numbers were relatively low. This corresponds with the observed foraging patterns (see 4.5.4).

4.5.4 Birds

The discovery of the importance of crop structure, particularly the unfavourable nature of the sward structure of winter-cereals, to skylarks and other species (Donald et al. 2001a, Wilson et al. 2005), suggested that measures to open up the sward of winter-cereals might mimic some of the benefits of spring-sown cereals, while maintaining the high yields of the winter-sown varieties. The findings of SAFFIE Experiment 1.1 support these conclusions.

The lack of variation explained by the habitat surrounding the treatments suggests that the pre-selection of sites based on criteria chosen to ensure a uniform breeding habitat for skylarks was largely successful and that results observed within the treatments were unlikely to have been influenced by the surrounding landscape. Breeding skylarks were present on all farms in the study but although fields were selected to meet landscape criteria favoured for breeding (Wilson et al. 1997), 21% held no proven breeding records. This could suggest that the steep decline in breeding numbers observed over the last thirty years has resulted in a situation where not all available breeding habitat is occupied.

There was little variation between the two years of the study. Only in the foraging pattern model, was there a significant effect of year, with less use of the treatment blocks (and PA) in 2003. This mirrors the reduced availability of arable weeds and associated invertebrate food in 2003 (see 4.5.2 and 4.5.3), probably due to very hot, dry weather conditions.

As with previous studies of skylarks in intensive modern arable farmland (e.g. Daunicht 1998, Donald et al. 2001a), this research showed that skylark activity in winter wheat decreased by the beginning of June, corresponding to the time when canopy expansion reaches its maximum and crop height exceeds 60 cm (Sylvester-Bradley 1998). The two experimental treatments maintained the early season territory densities, while those in CONV decreased significantly. The maintenance of late-season territorial activity in the experimental treatments reflects the previous finding that crop structure diversity and territory densities were positively correlated (Donald et al. 2001a). Although, as expected, the greatest differences between the two experimental treatments and CONV occurred in late-season (when virtually all of the vegetation in the CONV treatments reaches a sub-optimal height), there were also indications that UP held slightly more territorial birds than either of the other two treatments when the crop was less developed. This suggests that the PA afford some kind of additional benefit to skylarks throughout the breeding season, although this is greatest later on. Nest densities showed a similar pattern, although in this case the effect in the three-treatment model was non-significant, as there was (i) much variation in WSR and (ii) general decrease in late-season nest density in all treatments, suggesting some deterioration in the suitability of nesting habitat even the experimental treatments. However, decreases in UP and WSR were less than in CONV and a comparison of late-season nest density in CONV and UP revealed significantly greater densities in the latter.

Previous research has demonstrated that bare areas within the crop provide no guarantee of suitable nesting sites. For example, tramlines make poor nesting habitat for skylarks because of the high rates of nest predation from opportunistic predators using the tramlines to traverse the dense crop (Donald et al. 2002). It was hoped that the PA, which were isolated from tramlines to minimise the risk from opportunistic mammalian predators, would provide suitable and safe nesting sites for skylarks. However, they were rarely used for nesting. It is uncertain why skylarks made relatively little use of PA as nest sites. One possible explanation is that the very small, but enclosed and (at least in 2003) sparsely vegetated areas are perceived as being of high predation risk. A shortage of cover from aerial predators, coupled with the tall dense crop on all sides, which offers concealment close to the nest for mammalian predators, may mean that incubating or brooding adults and nestlings are vulnerable. No data are available for incubating or brooding passerines, but studies suggest that foraging individuals surrounded by dense vegetation are slower to respond to predator attacks (Whittingham et al. 2004). Nests situated on tramlines also provide plenty of surrounding cover for predators, but their linear nature may mean that adults and older nestlings are able to run (or, in the case of adults, flutter) off the nest to escape attacks. On tramlines, adults may also adopt tactics to disguise the exact position of the nest by flying into the tramline some distance from the nest and then running along the bare area to the actual nest location; although this strategy is ineffective against opportunist nest predators. This is not possible in PA, were the small amount of open ground means that adults would constantly have to land very close to the nest. In late-season UP, there was a trend, although a relatively weak one, for nests to be located closer to PA. This, together with some foraging observations, suggests that a minority of pairs were building nests in the crop relatively close to PA, which were used as landing areas by adults feeding the nestlings; the provisioning birds were then running up to 10 m to the more concealed nest sites.

Given the limited use of PAs, it is unsurprising that there was a late-season decrease in nest densities in UP, as most of the treatment area was by then covered by crop with a sub-optimal structure. There were few indications that WSR provided enhanced nesting opportunities. Although nest densities differed little between early and late summer, except on one or two sites, nest densities were low to start with and 42% of WSR treatments had no proven breeding attempt; a higher ratio even than CONV. This suggests that WSR are no more attractive than CONV at the start of the breeding season, when perhaps the crop on some sites is too sparse. The WSR treatment performed well in retaining early season densities but later on, they did not seem to attract pairs displaced from other cropped habitat; perhaps because by June, although the rows remained open at ground-level, the canopy was tall and had largely closed over the rows on many sites. Although neither of the experimental treatments provided prime late-season nest sites, they were more effective than CONV in retaining breeding pairs and in reducing the extent of the shift towards nesting nearer to the high-predation-risk tramlines.

Despite the limited success as nest sites, the results indicated that the experimental treatments, particularly UP, had a strong positive effect on Skylark reproduction. During the early part of the breeding season, while conditions in winter-cereals crops were still suitable, there was little difference in skylark breeding performance between the three treatments. However, in the all-important period from June onwards (when the great majority of skylark nesting attempts were once made), the number of chicks raised per nesting attempt was greatest in UP. Nest productivity in UP increased between the early and late periods, in contrast to CONV and WSR. Significantly greater clutch sizes laid in both UP and WSR, indicating that females in the experimental treatments were in better breeding condition than those in CONV, probably as a result of being able to obtain better quality food; or, more likely, the increased availability of food (see below). As this was a treatment effect (rather than the treatmentXperiod interaction), it suggests that the experimental treatments had positive impact on feeding opportunities for females throughout the season. Clutch size also showed a non-significant trend to be greater in UP than WSR during late-season. Other than clutch size, no individual constituents (partial clutch loss, partial brood loss, daily nest failure rates) of breeding performance varied significantly between treatments, although there were general trends for failure rates and partial brood loss to be lowest in late-season UP, probably as a result of better feeding opportunities. However, when taken together, a combination of these breeding parameters resulted in notable differences in productivity per nest. In UP, an average of 0.5 more chicks per breeding attempt (and 1.5 more later in the breeding season) left the nest than in CONV, with WSR nest performance being intermediate.

The per-attempt breeding performance figures, along with the greater late-season territory densities and a trend for retaining more nesting pairs into the summer, showed that the experimental treatments, particularly UP, have great potential to improve winter-wheat as a breeding environment for skylarks. Together, these data suggest that UP in winter wheat could increase the number of chicks reared by 49%.

However, given the limited impact as nest sites, clearly UP and WSR were providing benefits to nesting larks via another mechanism. The results of the foraging analyses suggest that this mechanism relates to feeding. During late-season breeding in UP and WSR treatments, the high (and increasing) proportion of foraging flights within treatments where the nest was situated indicated that birds were better able to exploit some facet of the local food resource than in CONV, where foraging visits dropped by nearly 40% and almost half of all foraging was outside the treatment. Possible explanations could relate to better quality or greater abundance or accessibility of food in the experimental treatments.

For both experimental treatments, results from the analyses of plant and invertebrate communities and the diet of skylark nestlings suggest that the overall abundance of invertebrate food was not significantly greater than in CONV; nor were the commonest invertebrates in the nestling diet mostly associated with UP or WSR. Therefore, greater accessibility to food is the likely cause of the increased nest productivity. Within the UP treatment, PA were significantly selected by foraging birds. The short, sparse ground cover recorded in PA, and the wider spacing of the drill rows in WSR, indicated that adults are likely to be able to detect and capture insect chick-food more easily than in a dense crop. In PA, the crop edge (and sometimes weeds in the centre) still provided some cover from predators.

Increased ability to access food may benefit several aspects of nest productivity. Increased feeding opportunities for females, and less effort in provisioning nestlings, showed that they were likely to attain, and retain, better breeding condition, resulting in the greater clutch size observed in this study. An inadequate local food supply can lead to reduced chick survival via several mechanisms. In extreme cases, lack of sufficient food can lead to the starvation of whole broods. This is an unusual outcome for skylark nests (Donald et al. 2002), with only six cases recorded in this study. However, four of those were on CONV. Lack of food may also indirectly lead to nest failure, through increased predation. Increased begging intensity can make broods more vulnerable to predation (Haskell 1994) and while skylark nestlings are usually silent, hungry older chicks can be audible several metres away. However, in this study nest predation rates did not differ between treatments. A commoner occurrence is for partial brood loss (the starvation of one or more nestlings), for which there was a trend for lower rates of loss on late-season UP. For some species, a lack of food can also result in decreased body condition, which may translate to a greater mortality on leaving the nest (Magrath 1991). Previous skylark research (Donald et al. 2001b, Bradbury et al. 2003) and this study found no relationship between nestling condition and habitat. However, this and the above studies indicate that quite frequently one or more nestling(s) in a brood exhibit very poor condition and die in the nest. The exclusion of such broods from the analyses (see section 4.3.4.4.) may indicate that analyses consider only nests that retain adequate local food resources. Additionally, nestling food availability could be limiting but parents compensate by working harder to find food. Organisms trade-off current reproductive success against their own body condition and survival and, thus, future reproductive success (Forbes & Mock 2000). For skylarks, where the probability of survival to the next season is generally low, it may be expected that parents buffer the effects of breeding in poor habitat by working harder and thus compromising their own survival probability or at least the capacity to have further broods. Interestingly, although the WSR treatment appeared to be very effective in providing a well-used foraging habitat in late-season[2], nest productivity decreased slightly from the early-season and was well below that of late-season UP. It is uncertain why this was the case. Possible explanations are that while the relatively open crop-base was superficially attractive to foraging skylarks, low abundance of invertebrate food, and/or low detection and capture rates under the tall, shaded canopy, were below those of the more open environment in PA. Another is that birds spend less time on food gathering and more time on predator vigilance in more enclosed areas (Whittingham et al. 2004). More time spent away from the nest searching for food can increase nestling mortality (Brickle et al. 2000) and in this study there was a trend for greater losses in WSR than in UP during late-season breeding.

Yellowhammer and linnet were the only other bird species to make use of PA on a regular basis. Yellowhammers have similar foraging requirements to skylarks for much of the breeding season, but also feed on grain taken from the ears of cereal crops later in the summer. Some of the linnets observed in PA were feeding on the

[2] Although we caution that WSR sample size for this analysis was relatively small compared with the other treatments.

seeds of low vegetation, e.g. groundsel (*Senecio vulgaris*), but others fed on taller vegetation, e.g. charlock (*Sinipis arvensis*), which had overrun a small number of PA. Recent studies of yellow wagtail, *Motacilla flava*, another cereal-dwelling species with habitat requirements similar to skylark, suggest that they may also benefit from the provision of UP (see Chapter 7, Gilroy 2007). However, few of the Experiment 1.1 study sites held breeding yellow wagtails and it was not possible to test for possible association in this experiment. No bird species was strongly associated with WSR.

4.6 CONCLUSIONS & RECOMMENDATIONS

Although the experimental treatments mostly did not deliver consistent increases in bird-food abundance or biomass, and treatments had few effects on the vegetation at the field-scale, the vegetative structure of PA was likely to have substantially increased access to bird food resources. At a local level within the UP treatment, differences in vegetation cover, structure and seed production were marked, although weed cover in PA was variable between sites and years. Compared to the surrounding crop, the vegetation in PA (including any crop-cover) was shorter, sparser and patchier.

As a result of this localised increase in food accessibility, UP winter wheat could increase the number of skylark chicks reared by nearly 50%, an increase in productivity of a magnitude potentially capable of reversing recent declines in this species. It is known that the provision of UP can produce benefits at the local scale. Since the introduction of UP at the RSPB's demonstration farm in Cambridgeshire (one of the experimental sites in this study), the skylark population has nearly trebled and there is also evidence that they moved out of CONV wheat in favour of UP (Donald & Morris 2005, Stoate & Moorcroft 2007). WSR provided some wildlife benefits (particularly for skylarks) but effects were not as consistent or as pronounced as for UP and yield reduction was reported on some sites.

The striking success of the UP treatment suggested that, if widely adopted alongside other 'skylark-friendly' options that deliver the other resources needed for skylarks to complete their life-cycle (e.g. overwintered stubbles), it could greatly benefit the skylark population. However, to ensure adoption of this technique, farmers must be compensated for the extra work and loss of yield that UP would inevitably incur. The successful demonstration of the effectiveness of UP by this study, has provided a scientific basis for the inclusion of 'Skylark Plots' in Defra's Entry Level Environmental Stewardship Scheme (ELS) in England (where most of the winter-sown rotations in the UK are concentrated). The option (EF8) is currently worth 5 points per plot. This allows farmers wishing to introduce Skylark Plots to their winter cereals to receive the funding to do so. As the option is easily adopted during existing farming operations, it is likely to be profitable for farmers in the vast majority of cases (see cost:benefit analysis, Chapter 8). However, so far take-up of Skylark Plots in ELS has been low (<3% agreements), as they do not accrue a high point total or have the familiarity of management associated with some other stewardship options. Current ELS requirements and guidelines are:

- Each year, select a field that is to be sown with a winter cereal, more than 5 ha in area and of an open aspect. A good guide is the presence of skylarks singing over the field in previous years.
- Avoid fields bounded by tree lines or adjacent to woods unless the field is greater than 10 ha.

- To create the plot, turn off the drill during sowing in order to leave an unsown area. This area should be no less than 3 m in length or width and no more than 12 m in length or width. The precise size and shape within these limits depends on what is practical with the drill. After drilling, there is no requirement to manage the plots differently to the remainder of the field (i.e. they can be over-sprayed, receive fertiliser applications, etc.). Following the Environmental Stewardship scheme review in autumn 2007, creation of plots by spraying-out with a broad-spectrum herbicide before Christmas is likely to be allowed as another method of establishment.

- Do not create the plots so that they are connected to tramlines and make sure they are well away from field boundaries.

- Space the plots across the field, creating no more than two plots per hectare.

- There must be no mechanical weeding of the plots between 1 April and harvest.

- There is no requirement to keep the plots weed-free.

- This option is a ‘rotational option’. This means that the plots may move around the farm with the normal arable rotation, but the same total number of plots must be maintained.

The successful development and trialling of UP, and their subsequent rapid integration into national agricultural policy, represents a rare example of a targeted and practicable conservation initiative that could protect the population of a widespread but declining species throughout much of its range. Attempts to protect such widespread species through, for example, the creation of nature reserves could not protect anything more than a tiny proportion of their populations. SAFFIE Experiment 1.1 has set a template for similar schemes to develop, test and implement novel options for other declining farmland species. The development and deployment of such ‘smart’ research-based schemes, along with continued financial support of agri-environment schemes, represents the only practical way that the UK Government can reach its 2020 target to reverse farmland bird declines.

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4.8 REFERENCES

Aebischer, N.J. (1991) Twenty years of monitoring invertebrates and weeds in cereal fields in Sussex. In: Firbank, L.G., Carter, N., Darbyshire, J.F., Potts, G.R. (Eds) The Ecology of Temperate Cereal Fields 305-331, Blackwell Scientific, Oxford.

Anon (2002) *Arable cropping and the environment – a guide*. HGCA/DEFRA, London.

Anon (2004a) *Defra Agricultural and Horticultural Census: 5 June 2004 – England*. Office of National Statistics, London.

Anon (2004b) *Undrilled patches for skylarks. Best Practice Guide*. Crop Protection Association, London.

Beuerlein, J.E. (2002) *Effect of Row Spacing on Wheat Yield*. Ohio State University Extension Fact Sheet: Horticulture and Crop Science.

Bohac, J. (1999) Staphylinid beetles as bioindicators. *Agriculture, Ecosystems and Environment* **74**, 357-376.

Bradbury, R.B., Wilson, J.D., Moorcroft, D., Morris, A.J. & Perkins, A.J. (2003) Habitat and weather are weak correlates of nestling condition and growth rates of four UK farmland passerines. *Ibis* **145**, 295-306.

Brickle, N.W., Harper, D.G.C., Aebischer, N.J. & Cockayne, S.J. (2000) Effects of agricultural intensification on the breeding success of corn buntings *Miliaria calandra*. *Journal of Applied Ecology* **37**, 742-755.

Browne, S.J., Vickery, J.A. & Chamberlain, DE. (2000) Densities and population estimates of breeding skylarks *Alauda arvensis* in Britain 1997. *Bird Study* **47**, 52-65.

Butler, S.J. & Gillings, S. (2004) Quantifying the effects of habitat structure on prey detectability and accessibility to farmland birds. *Ibis* **143**, 123–130.

Chancellor (1985) Changes in the weed flora of an arable field cultivated for 20 years. *Journal of Applied Ecology* **22**, 491-501.

Chiverton, P.A. (1987) Predation of *Rhopalsiphum padi* (Homoptera: Aphididae) by polyphagous predatory arthropods during the aphid's pre-peak period in Spring Barley. *Annals of Applied Ecology* **111**, 257-269.

Chiverton, P.A. & Sotherton, N.W. (1991) The effects on beneficial arthropods of the exclusion of herbicides from cereal crop edges. *Journal of Applied Ecology* **3**, 1027-1039.

Daunicht, W.D. (1998) *Zum Einfluss der Feinstrucktur in der Vegetation auf die Habitatwahl, Habitatnutzung, Siedlungsdichte und Populationsdynamic von Feldlerchen* (Alauda arvensis) *in grosparzelligem Ackerland*. Unpublished PhD thesis, University of Bern.

Dennis, P., Thomas, M.B. & Sotherton, N.W. (1994) Structural features of field boundaries which influence arthropod predators. *Journal of Applied Ecology* **31**, 361-370.

Dietrick, E.J. (1961) An improved backpack motorized fan for suction sampling of insects. *Journal of Economic Entomology* **54**, 394-395.

Donald, P.F. (1998) Changes in the abundance of invertebrates and plants on British Farmland. *British Wildlife* **9**, 279-289.

Donald, P.F. (2004) *The skylark*. Poyser, London.

Donald, P.F., Evans, A.D., Buckingham, D.L., Muirhead, L.B. & Wilson, J.D. (2001a) Factors affecting territory distribution of Skylarks *Alauda arvensis* breeding on lowland farmland. *Bird Study* **48**, 271-278.

Donald, P.F., Muirhead, L.B., Buckingham, D.L., Evans, A.D., Kirby, W.B. & Gruar, D.J. (2001b) Body condition, growth rates and diet of Skylark *Alauda arvensis* nestlings on lowland farmland. *Ibis* **143**, 658-669.

Donald, P.F., Evans, A.D., Muirhead, L.B., Buckingham, D.L., Kirby, W.B. & Schmitt, S.I.A. (2002) Survival rates, causes of failure and productivity of skylark *Alauda arvensis* nests on lowland farmland. *Ibis* **144**, 652-664.

Donald, P.F. & Morris, T.J. (2005) Saving the Sky Lark: new solutions for a declining farmland bird. *British Birds* **98**, 570-578.

Dover, J., Sotherton, N.W. & Gobbett, K. (1990) Reduced pesticide inputs on cereal field margins: The effects on butterfly abundance. *Ecological Entomology* **15**, 17-24.

Evans, A.D., Vickery, J.A. & Shrubb, M. (2004) Importance of overwintered stubble for farmland bird recovery: a reply to Potts. *Bird Study* **51**, 94-96.

Forbes, S. & Mock, D.W. (2000) A tale of two strategies: life-history aspects of family strife. *Condor* **102**, 23-24.

Fuller, R.J. (2000) Relationships between recent changes in lowland British agriculture and farmland bird populations: an overview. In: Aebischer, N.J., Evans, A.D., Grice, P.V. & Vickery, J.A. (Eds) *Ecology and Conservation of Lowland Farmland Birds*, 5-16. British Ornithologists' Union, Tring.

García-Berthou, E. (2001) On the misuse of residuals in ecology: testing regression residuals vs. the analysis of covariance. *Journal of Animal Ecology* **70**, 708-711.

Gilroy, J.J. (2007) *Breeding ecology and conservation of yellow wagtails* Motacilla flava *in intensive arable farmland*. Unpublished PhD thesis, University of East Anglia.

Greenhouse, S.W. & Geisser, S. (1959) On methods in the analysis of profile data. *Psychometrika* **24**, 95-112.

Hald, A.B. (1999) The impact of changing the season in which cereals are sown. Journal of Applied Ecology **22**, 491-501.

Haskell, D. (1994) Experimental evidence that nestling begging behaviour incurs a cost due to nest predation. *Proceedings of the Royal Society of London, Biological Sciences* **257**, 161-164.

Hawes, C., Haughton, A.J., Osbourne, J.L., Roy, D.B., Clark, S.J., Perry, J.N., Rothery, P., Bohan, D.A., Brooks, D.R., Champion, G.T., Dewar, A.M., Heard, M.S., Woiwood, I.P., Daniels, R.E., Young, M.W., Parish, A.M., Scott, R.J., Firbank, L.G. & Squire, G.R. (2003) Responses of plants and invertebrate trophic groups to contrasting herbicide regimes in the Farm scale Evaluations of genetically modified herbicide-tolerant crops. *Rhilosophical Transactions of the Royal Society* **358**, 1899-1913.

Holland, J.M., Cook, S.K., Drysdale, A.D., Hewitt, M.V., Spink, J. & Turley, D.B. (1998) The impact on non-target arthropods of integrated compared to conventional farming: Results from the LINK Integrated Farming Systems project. *Proceedings of the 1998 Brighton Crop Protection Conference, Pests & Diseases* **2**, 625-630.

Hudson, R.W., Tucker, G.M. & Fuller, R.J. (1994) Lapwing *Vanellus vanellus* populations in relation to agricultural change: a review. In: Tucker, G.M., Davies, S.M. & Fuller, R.J. *The ecology and conservation of lapwings* Vanellus vanellus, 1-33. UK Nature Conservation No.9. JNCC, Peterborough.

Johnson, D.H. (1979) Estimating nest success: the Mayfield method and an alternative. *Auk* **96**, 651-661.

Lawton, J.H. (1983) Plant architecture and the diversity of phytophagous insects. *Ann*ual *Re*view of *Entomology* **28**, 23–39.

Littell, R.C., Milliken, G.A., Stroup, W.W. & Wolfinger, R.D. (2002) SAS® System for Mixed Models. SAS Institute, Cary.

Magrath, R.D. (1991) Nestling weight and juvenile survival in blackbird *Turdus merula*. *Journal of Animal Ecology* **60**, 335-351.

Marchant, J.H., Hudson, R., Carter, S.P. & Whittington, P. (1990) *Population trends in British Breeding Birds*. BTO, Tring.

Marshall, E.J.P., Brown, V.K., Boatman, N.D., Lutman, P.J.W., Squire, G.R. & Ward, L.K. (2003) The role of weeds in supporting biological diversity within crop fields. *Weed Research* **43**, 77-89.

Milsom, T.P., Langton, S.D., Parkin, W.K., Peel, S., Bishop, J.D., Hart, J.D. & Moore, N.P. (2000) Habitat models of species' distribution: an aid to the management of coastal grazing marshes. *Journal of Applied Ecology* **37**, 706-727.

Moreby, S.J. (1997) The effects of herbicide use within cereal headlands on the availability of food for arable birds. *Brighton Crop Protection Conference Proceedings* **3**, 1197-1202.

Moreby, S.J. & Southway, S.E. (1999) Influence of autumn applied herbicides on summer and autumn food available to birds in winter wheat fields in southern England. *Agriculture Ecosystems & Environment* **72**, 285-297.

Morris, M.G. (2000) The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation* **95**, 129–142.

Norris, R.F. & Kogan, M. (2000) Interactions between non-crop plants, arthropod herbivores, and their natural enemies in managed ecosystems. *Weed Science* **48**, 94-158.

O'Connor, R.J. & Shrubb, M. (1986) *Farming and birds*. Cambridge University Press, Cambridge.

Potts, G.R. (1991) The environmental and ecological importance of cereal fields. In: Firbank, L.G., Carter, N., Darbyshire, J.F., Potts, G.R. (Eds) The Ecology of Temperate Cereal Fields pp. 3-21, Blackwell Scientific, Oxford.

Potts, G.R. & Aebischer, N.J. (1991) Modelling the population dynamics of the grey partridge. Conservation and management. In: Perrins, C.M., Lebreton. J.D., Hirons, G.J.M. (Eds) Bird Population Studies: relevance to Conservation and Management pp. 373 – 368, Oxford University Press, Oxford.

Purvis, G. & Bannon, J.W. (1992) Non-target effects of repeated methiocarb slug pellet application on carabid beetle (Coleoptera: Carabidae) activity in winter-sown cereals. *Annals of Applied Biology* **121**, 401-422.

Shkedy, Y. & Safriel, U.N. (1992) Nest predation and nestling growth rate of two lark species in the Negev Desert, Israel. *Ibis* **134**, 268-272.

Shrubb, M. (2003) *Birds, scythes and combines*. Cambridge University Press, Cambridge.

Speight, M.R. & Lawton, J.H. (1976) The influence of weed cover on the mortality imposed on artificial prey by predatory ground beetles in cereal fields. *Oecologia* **23**, 211-223.

Sotherton, N.W. (1982) Observation on the biology and ecology of the Chrysomelid beetle *Gastrophysa polygoni* in cereal fields. *Ecological Entomology* **7**, 197-206.

Stoate, C., Boatman, N.D., Borralho, R., Rio Carvalho, C., de Snoo, G. & Eden, P. (2001) Ecological impacts of arable intensification in Europe. *Journal of Environmental Management* **63**, 337-365.

Stoate, C. & Moorcroft, D. (2007) Research-based conservation at the farm scale: Development and assessment of agri-environment scheme options. *Aspects of Applied Biology* **81**, 161-168.

Sylvester-Bradley, R. (1998) *Assessments of wheat growth to support its production and improvement. Volume I: The wheat growth digest; Methods for in-field crop assessment; Forecasting crop progress for wheat*. HGCA PROJECT REPORT 151. HGCA, London.

ter Braak, C.J.F. & Smilauer, P. (1997-2002) Canoco for windows. Version 4.5 *Biometris*. Plant Research International, Wageningen.

Thomas, M.B., Wratten, S.D. & Sotherton, N.W. (1991) Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: densities and emigration. *Journal of Applied Ecology* **28**, 906-917.

Thomas, S.R., Goulson, D. & Holland, J.M. (2001) Resource provision for farmland gamebirds: the value of beetle banks. *Annals of Applied Biology* **139**, 111-118.

Vickery, P.D., Hunter, M.L. & Wells, J.V. (1992) Use of a new reproductive index to evaluate the relationship between habitat quality and breeding success. *Auk* **109**, 697-705.

Welsh, J.P., Tillett, N.D., Home, M. & King, J.A. (2002) A *Review of Knowledge: Inter-row hoeing and its associated agronomy in organic cereal and pulse crops*. Final report from DEFRA Funded Project OF0312.

Whittingham, M.J., Butler, S.J., Quinn, J.L. & Cresswell, W. (2004) The effect of limited visibility on vigilance behaviour and speed of predator detection: Implications for the conservation of granivorous passerines. *Oikos* **106**, 377-385.

Whittingham, M.J., Swetnam, R.D., Wilson, J.D., Chamberlain, D.E. & Freckleton, R.P. (2005) Habitat selection by yellowhammers *Emberiza citrinella* on lowland farmland at two spatial scales: implications for conservation management. *Journal of Applied Ecology* **42**, 270-280.

Wilson, J.D., Evans, J., Browne, S.J. & King, J.R. (1997) Territory distribution and breeding success of skylarks *Alauda arvensis* on organic and intensive farmland in southern England. *Journal of Applied Ecology* **34**, 1462-1478.

Wilson, J.D., Morris, A.J., Arroyo, B.E., Clark, S.C. & Bradbury, R.B. (1999) A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. *Agriculture, Ecosystems and Environment* **75**, 13-30.

Wilson, J.D., Whittingham, M.J. & Bradbury, R.B. (2005) The management of crop structure: a general approach to reversing the impacts of agricultural intensification on birds? *Ibis* **147**, 453-463.

Young, J.E.B., Griffin, M.J., Alford, D.V. & Ogilvy, S.E. (Eds) (2001) *Reducing Agrochemical Use on the Arable Farm: the TALISMAN and SCARAB Projects*. Defra, London.

APPENDIX 1

Table 4.A1 a) Experimental site details 2001/2002

Farm Code	Location	Soil type	Variety	Drill date	Fungicides	Herbicides	Insecticides	Other Pesticides	Wheat
HM	North Yorkshire	ZyCL	Hereward	8 Oct.	5	3	2	0	1st
PX	East Yorkshire,	Mixed clay patches	Soissons	13 Oct.	4	3	1	1	1st
WH	Cambridgeshire	C	Claire	23 Sept.	5	9	4	1	1st
GK	Cambridgeshire	C	Claire	10 Sept	-	-	-	-	1st
WH	Suffolk	C	Consort & Claire	15 Oct.	14	9	4	9	2nd
PH	Norfolk	C	Claire	13 Dec.	5	4	2	5	1st
GD/LD	Oxfordshire	-	Consort & Claire	12 Oct.	4	7	0	0	1st
WF	Wiltshire	-	Malacca	26 Sept.	4	8	2	2	1st
LE	Oxfordshire	ZyCL	Malacca	19 Oct.	5	2	0	0	1st
SL	Wiltshire	Chalky	Claire	12 Oct.	6	5	2	2	2nd
BX	Cambridgeshire	C	-	-					-

Table 4.A1 b) Experimental site details 2002/2003

Farm Code	Location	Soil type	Variety	Drill date	Fungicides	Herbicides	Insecticides	Other Pesticides	Wheat
HM	North Yorkshire	ZyCL	Napier	8 Oct.	2	4	0	1	2nd
PX	East Yorkshire,	Mixed clay patches	Claire & Soissons	10 Sept.	-	-	-	-	1st
WP	Cambridgeshire	C	Malacca	1 Oct.	-	-	-	-	2nd
GK	Cambridgeshire	C	Consort	2 Oct.	8	4	3	6	2nd
WH	Suffolk	C	-	-	-	-	-	-	-
PH	Norfolk	C	Consort		5	6	2	2	2nd
GD/LD	Oxfordshire	-	Claire	10 Dec.	3	5	3	4	2nd
WF	Wiltshire	-	-	-	-	-	-	-	-
LE	Oxfordshire	ZyCL	-	26 Sept.	-	-	-	-	1st
SL	Wiltshire	Chalky	-	-	-	-	-	-	-
BX	Cambridgeshire	C	Malacca	1 Oct.	4	9	1	5	2nd

APPENDIX 2

Table 4.A2. Comparison of back transformed means for vegetation cover (%) and species richness (number of species per plot) across the three treatments (repeated measures ANOVA).

	Means					Treatment		Time	
	CONV	**UP**	**WSR**	**May**	**July**	***F***	***P***	***F***	***P***
2002: Treatment d.f. = 2, 18; Time d.f. = 1; n = 60									
Group1	0.09	0.29	0.16	0.12	0.24	0.91	0.419	1.21	0.281
Group2	0.11	0.08	0.14	0.10	0.11	0.57	0.577	0.08	0.782
Group3	0.22	0.13	0.23	0.22	0.16	0.58	0.571	0.62	0.438
Group4	2.30	3.54	0.97	1.15	3.41	3.55	**0.050**	23.73	**<.001**
Groups12	0.26	0.45	0.34	0.26	0.44	0.37	0.695	1.26	0.271
Groups123	0.57	0.67	0.71	0.54	0.77	0.15	0.860	0.96	0.337
All weeds	3.25	5.12	1.91	1.90	5.08	3.75	**0.044**	25.56	**<.001**
Broad-leaved species	1.04	1.21	0.84	0.76	1.32	0.32	0.728	4.37	**0.046**
Grasses	1.52	2.40	0.73	0.68	2.55	1.57	0.234	21.83	**<.001**
Bare ground	78.99	78.61	80.71	79.76	79.13	5.54	**0.013**	0.23	0.632
Litter	1.27	1.41	1.02	1.41	1.05	1.17	0.332	5.80	**0.023**
Crop	55.40	55.05	48.43	34.22	71.29	2.90	0.081	49.4	**<.001**
Alopecurus myosuroides	0.66	1.25	0.21	0.30	1.10	1.61	0.228	13.59	**0.001**
Galium aparine	0.26	0.46	0.07	0.15	0.33	1.72	0.208	5.62	**0.025**
Poa annua	0.02	0.11	0.02	0.01	0.10	0.75	0.486	2.97	0.096
Species richness	6.85	10.9	6.55	8.97	7.23	7.21	**0.005**	11.60	**0.002**
2003: Treatment d.f. = 2, 15; Time d.f. = 1; n = 52									
Group1	0.27	0.14	0.31	0.21	0.26	1.05	0.374	0.30	0.589
Group2	0.20	0.08	0.06	0.06	0.16	0.90	0.426	2.46	0.130
Group3	0.58	0.20	0.35	0.30	0.43	1.12	0.352	0.64	0.433
Group4	0.76	1.49	2.16	0.63	2.50	1.49	0.257	23.73	**<.001**
Groups12	0.67	0.29	0.45	0.34	0.58	1.48	0.259	2.32	0.141
Groups123	1.43	0.53	0.91	0.72	1.14	2.03	0.166	1.76	0.197
All weeds	2.69	2.46	3.74	1.66	4.57	0.87	0.439	20.88	**<.001**
Broad-leaved species	2.13	0.83	1.39	0.94	1.96	3.72	**0.049**	4.41	**0.047**
Grasses	0.23	1.04	1.27	0.34	1.37	1.91	0.183	31.16	**<.001**
Bare ground	81.52	81.83	81.14	86.15	76.33	0.13	0.883	58.63	**<.001**
Litter	3.85	2.93	4.02	2.69	4.60	0.68	0.520	9.78	**0.005**
Crop	32.51	34.63	29.74	23.74	41.44	2.35	0.130	74.46	**<.001**
Aethusa cynapium	0.12	0.07	0.12	0.05	0.18	0.21	0.815	4.61	**0.042**
Alopecurus myosuroides	0.05	0.73	0.78	0.19	0.75	2.60	0.107	13.79	**0.001**
Galium aparine	0.15	0.12	0.23	0.10	0.24	0.38	0.687	7.75	**0.011**
Sinapis arvensis	0.02	0.03	0.07	0.04	0.03	0.68	0.522	0.06	0.815
Species richness	6.89	10.89	5.83	7.97	7.76	9.01	**0.003**	0.13	0.721

Table 4.A3. Comparison from repeated measures ANOVA of back transformed means for vegetation cover (%) and species richness (number of species per plot) on patches (PA) and in surrounding crop (CropUP).

	Means				Treatment		Time	
	CropUP	**PA**	**May**	**July**	***F***	***P***	***F***	***P***
2002: Treatment d.f. = 1, 9; Time d.f. = 1; n = 40								
Group1	0.26	2.50	0.29	2.39	7.29	**0.024**	5.71	**0.028**
Group2	0.07	0.64	0.14	0.48	3.65	0.088	1.89	0.187
Groups12	0.42	3.84	0.51	3.58	9.08	**0.015**	6.65	**0.019**
Grasses	2.34	11.59	2.50	11.36	14.74	**0.004**	21.20	**<.001**
Litter	1.41	0.84	1.19	1.02	2.53	0.146	0.38	0.543
Alopecurus myosuroides	1.24	5.66	1.50	5.14	5.43	**0.045**	11.17	**0.004**
Galium aparine	0.45	1.41	0.37	1.56	6.91	**0.027**	14.38	**0.001**
Poa annua	0.11	0.73	0.06	0.89	2.48	0.149	2.81	0.111
Species richness	6.30	9.40	8.80	6.90	12.29	**0.007**	5.97	**0.025**
2003: Treatment d.f. = 1, 8; Time d.f. = 1; n = 36								
Group1	0.12	1.57	0.22	1.29	10.53	**0.012**	5.45	**0.033**
Group2	0.08	0.37	0.07	0.40	23.25	**0.001**	7.08	**0.017**
Group3	0.19	0.85	0.22	0.78	9.62	**0.015**	5.01	**0.040**
Bare ground	81.82	86.62	89.17	78.69	4.37	0.070	67.49	**<.001**
Crop	34.73	4.64	11.44	23.18	41.95	**<.001**	31.15	**<.001**
Aethusa cynapium	0.07	0.26	0.04	0.33	2.63	0.143	3.91	0.066
Alopecurus myosuroides	0.72	2.37	0.59	2.61	9.17	**0.016**	21.34	**<.001**
Galium aparine	0.12	0.26	0.14	0.23	1.09	0.326	2.79	0.114
Sinapis arvensis	0.02	0.70	0.06	0.58	5.16	0.053	2.98	0.104
Species richness	6.06	9.56	7.33	8.28	7.38	**0.026**	1.24	0.281

Table 4.A4. Comparison of back transformed means for vegetation cover (%) on patches (PA) and in surrounding crop (CropUP) where there was an interaction between treatment and time.

	May		**July**		**Treatment**		**Time**		**TreatmentXTime**	
	CropUP	**PA**	**CropUP**	**PA**	***F***	***P***	***F***	***P***	***F***	***P***
2002:Treatment d.f. = 1, 9; Time d.f. = 1; TreatmentXTime d.f. = 1,18; n = 40										
Group3	0.17	0.54	0.07	1.81	22.61	**0.001**	1.72	0.207	5.04	**0.038**
Group4	1.84	5.77	5.53	29.66	18.68	**0.002**	35.57	**<.001**	10.31	**0.005**
Groups123	0.51	1.66	0.76	12.84	16.14	**0.003**	6.93	**0.017**	5.26	**0.034**
All weeds	2.67	8.26	8.07	50.87	35.31	**<.001**	51.78	**<.001**	18.78	**<.001**
Broad-leaved species	0.82	1.99	1.53	18.94	20.44	**0.001**	15.82	**<.001**	10.18	**0.005**
Bare ground	79.67	87.85	77.52	67.43	0.00	0.989	13.57	**0.002**	9.08	**0.007**
Crop	35.05	2.72	74.70	4.68	117.38	**<.001**	20.96	**<.001**	12.57	**0.002**
2003: Treatment d.f. = 1, 8; Time d.f. = 1; TreatmentXTime d.f. = 1,16; n = 36										
Group4	0.85	1.59	2.27	8.39	10.62	**0.012**	43.81	**<.001**	10.12	**0.006**
Groups12	0.21	0.52	0.32	4.96	15.01	**0.005**	7.30	**0.016**	5.46	**0.033**
Groups123	0.41	0.87	0.59	7.51	18.82	**0.002**	9.79	**0.006**	7.38	**0.015**
All weeds	1.55	2.99	3.48	18.63	24.55	**0.001**	32.78	**<.001**	12.83	**0.002**
Broad-leaved species	0.68	1.25	0.92	9.28	24.90	**0.001**	12.07	**0.003**	9.16	**0.008**
Grasses	0.47	1.17	1.76	6.45	8.30	**0.020**	33.58	**<.001**	5.26	**0.036**
Litter	1.74	1.60	4.43	2.13	5.65	**0.045**	15.22	**0.001**	5.50	**0.032**

Table 4.A5. Comparison of seed production (seeds m^{-2}) and species richness (number of species per plot) on the three treatments. Back transformed means for total and viable seeds.

	Means			**Overall**		**CONV vs UP**		**WSR vs UP**	
	CONV	**UP**	**WSR**	***F***	***P***	***F***	***P***	***F***	***P***
2002 – Total Seeds: Treatment d.f. = 2; 18; Contrast d.f. = 1; n = 30									
Group1	8.8	14.5	3.8	1.35	0.284	0.43	0.522	2.67	0.120
Group2	4.5	10.7	3.1	1.60	0.229	1.56	0.228	3.01	0.100
Group3	3.4	7.5	11.9	0.83	0.452	0.64	0.435	0.23	0.640
Group4	185.2	488.8	113.8	0.86	0.442	0.72	0.408	1.65	0.215
Groups12	20.4	52.7	10.2	2.37	0.122	1.64	0.216	4.69	**0.044**
Groups123	36.2	82.2	21.9	1.64	0.222	1.26	0.276	3.21	0.090
All weeds	415.9	1229.3	337.8	1.32	0.292	1.59	0.223	2.30	0.147
Broad-leaved species	33.7	88.1	29.2	1.43	0.265	1.82	0.194	2.44	0.136
Grasses	124.9	644.7	106.2	1.26	0.308	1.71	0.208	2.05	0.169
Alopecurus myosuroides	44.7	66.6	17.6	0.62	0.551	0.10	0.756	1.17	0.294
Species richness	6.2	10.4	5.1	10.65	**<0.001**	12.01	**0.003**	19.12	**<0.001**
2002 – Viable Seeds: Treatment d.f. = 2; 18; Contrast d.f. = 1; n = 30									
Group1	2.5	7.3	1.6	1.92	0.176	1.99	0.175	3.54	0.076
Group2	0.9	4.4	1.6	2.89	0.082	5.41	**0.032**	2.84	0.109
Group3	0.8	4.4	4.2	2.34	0.125	3.54	0.076	0.00	0.986
Group4	43.7	101.3	16.8	1.29	0.300	0.58	0.456	2.58	0.126
Groups12	4.8	23.5	4.8	3.37	0.057	5.04	**0.038**	5.06	**0.037**
Groups123	5.5	32.1	10.0	3.52	0.051	6.77	**0.018**	3.09	0.096
All weeds	74.9	379.2	56.5	3.12	0.069	3.91	0.063	5.34	**0.033**
Broad-leaved species	4.0	24.1	15.6	3.99	**0.037**	7.36	**0.014**	0.46	0.507
Grasses	40.7	228.1	11.6	4.38	**0.028**	3.03	0.099	8.66	**0.009**
Alopecurus myosuroides	20.4	29.9	7.5	0.76	0.483	0.12	0.729	1.44	0.246
Species richness	4.0	8.2	3.5	9.67	**0.001**	12.80	**0.002**	16.02	**<0.001**
2003 – Total Seeds: Treatment d.f. = 2; 15; Contrast d.f. = 1; n = 26									
Group1	13.8	5.3	9.7	0.59	0.566	1.16	0.298	0.44	0.518
Group2	4.2	3.3	1.9	0.27	0.766	0.07	0.790	0.21	0.654
Group3	0.8	1.8	2.1	0.28	0.760	0.33	0.575	0.02	0.898
Group4	59.3	168.8	212.8	0.84	0.451	0.98	0.338	0.05	0.822
Groups12	36.2	12.2	19.9	0.67	0.525	1.34	0.265	0.25	0.624
Groups123	40.7	16.0	28.5	0.46	0.643	0.89	0.360	0.35	0.562
All weeds	228.1	222.9	601.6	0.54	0.592	0.00	0.975	0.84	0.374
Broad-leaved species	50.3	26.5	24.1	0.50	0.614	0.65	0.431	0.01	0.914
Grasses	26.5	103.7	127.8	1.29	0.303	1.62	0.223	0.05	0.831
Alopecurus myosuroides	4.1	55.2	25.9	3.52	0.056	6.72	**0.020**	0.65	0.434
Species richness	3.7	9.1	3.7	33.06	**<0.001**	49.91	**<0.001**	49.27	**<0.001**

(continued)

	Means			Overall		Conv vs UP		WSR vs UP	
	CONV	**UP**	**WSR**	***F***	***P***	***F***	***P***	***F***	***P***
2003 – Viable Seeds: Treatment d.f. = 2; 15; Contrast d.f. = 1; n = 26									
Group1	4.9	1.8	4.2	0.47	0.634	0.80	0.385	0.60	0.452
Group2	2.7	1.1	0.8	0.47	0.632	0.57	0.464	0.03	0.875
Group3	0.0	0.7	0.8	1.53	0.248	1.97	0.181	0.04	0.840
Group4	20.9	23.0	62.1	0.61	0.556	0.01	0.933	0.83	0.376
Groups12	15.6	3.6	7.5	0.79	0.472	1.58	0.228	0.36	0.556
Groups123	15.6	4.4	8.3	0.58	0.571	1.16	0.298	0.27	0.611
All weeds	78.4	42.7	113.8	0.32	0.730	0.23	0.637	0.63	0.438
Broad-leaved species	18.5	5.9	8.1	0.68	0.524	1.27	0.278	0.10	0.756
Grasses	14.5	22.4	37.9	0.32	0.728	0.13	0.720	0.19	0.667
Alopecurus myosuroides	2.2	11.6	8.5	1.71	0.214	3.05	0.101	0.12	0.733
Species richness	2.1	7.2	2.9	27.51	**<0.001**	47.12	**<0.001**	34.41	**<0.001**

Table 4.A6. Comparison of seed production (seeds m^{-2}) and species richness (number of species per plot) in patches (PA) and surrounding crop (CropUP). Back transformed means for total and viable seeds.

	Treatment			
	CropUP	**PA**	***F***	***P***
2002 – Total Seeds: Treatment d.f. = 1, 9; n = 20				
Group1	8.5	268.2	12.67	**0.006**
Group2	6.2	176.8	12.39	**0.007**
Group3	3.1	233.4	16.44	**0.003**
Group4	322.6	5369.3	9.99	**0.012**
Groups12	29.2	1994.3	29.41	**<0.001**
Groups123	32.1	5247.1	38.83	**<0.001**
All weeds	932.3	29511.1	30.49	**<0.001**
Broad-leaved species	36.2	5369.3	38.68	**<0.001**
Grasses	425.6	15134.6	22.87	**<0.001**
Alopecurus myosuroides	62.1	203.2	4.30	0.068
Species richness	6.0	8.6	7.04	**0.026**
2002 – Viable Seeds: Treatment d.f. = 1, 9; n = 20				
Group1	4.8	116.5	11.84	**0.007**
Group2	2.2	96.7	15.04	**0.004**
Group3	2.2	74.9	9.88	**0.012**
Group4	88.1	932.3	12.32	**0.007**
Groups12	11.9	890.3	25.24	**<0.001**
Groups123	13.1	1697.2	30.15	**<0.001**
All weeds	315.2	7942.3	29.43	**<0.001**
Broad-leaved species	10.2	1583.9	41.84	**<0.001**
Grasses	168.8	4167.7	18.87	**0.002**
Alopecurus myosuroides	29.4	92.1	7.04	**0.026**
Species richness	3.8	7.1	21.26	**0.001**
2003 – Total Seeds: Treatment d.f. = 1, 8; n = 18				
Group1	3.3	337.8	87.96	**<0.001**
Group2	2.2	51.5	11.10	**0.010**
Group3	0.6	37.0	9.40	**0.015**
Group4	108.6	4896.8	25.61	**<0.001**
Groups12	8.1	500.2	50.26	**<0.001**
Groups123	8.5	811.8	45.67	**<0.001**
All weeds	137.0	6917.3	26.90	**<0.001**
Broad-leaved species	14.5	999.0	30.07	**<0.001**
Grasses	65.1	2883.0	21.28	**0.002**
Alopecurus myosuroides	49.1	548.5	11.17	**0.010**
Species richness	4.1	8.3	23.97	**0.001**

(continued)

	Treatment			
	CropUP	**PA**	***F***	***P***
2003 – Viable Seeds: Treatment d.f. = 1, 8; n = 18				
Group1	0.8	122.0	40.10	**<0.001**
Group2	0.8	20.9	10.96	**0.011**
Group3	0.5	13.5	11.06	**0.010**
Group4	14.5	1022.3	34.95	**<0.001**
Groups12	2.1	203.2	58.58	**<0.001**
Groups123	2.5	287.4	67.39	**<0.001**
All weeds	23.0	2137.0	34.79	**<0.001**
Broad-leaved species	3.5	345.7	59.46	**<0.001**
Grasses	14.1	723.4	21.04	**0.002**
Alopecurus myosuroides	8.8	181.0	11.33	**0.010**
Species richness	2.1	6.7	37.15	**<0.001**

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Chapter 5 – Experiment 1.2 – Manipulate within crop agronomy to increase biodiversity: Integrated crop management strategies

(Pages 108 – 267)

Sustainable Arable Farming For an Improved Environment

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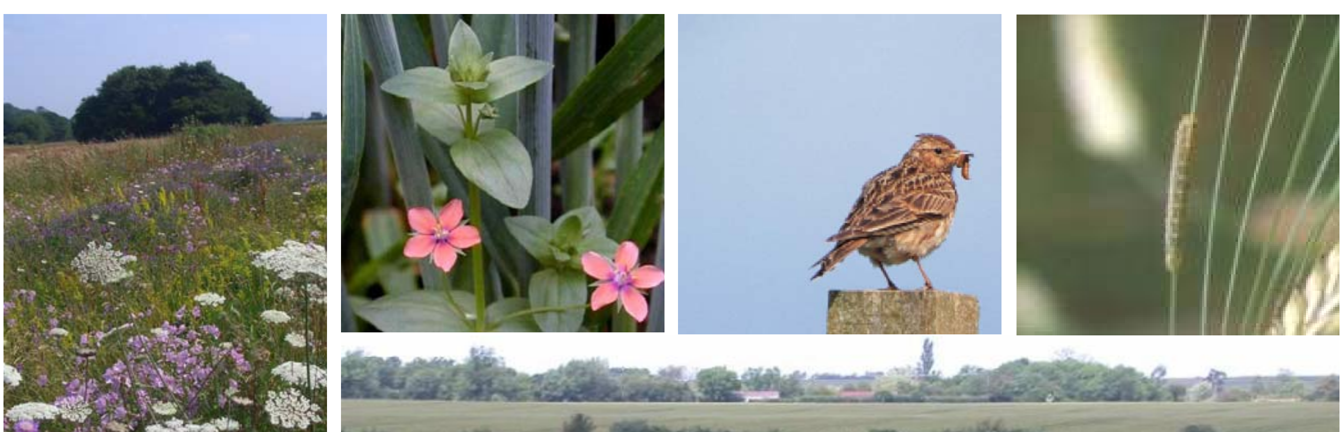

5. EXPERIMENT 1.2 – MANIPULATE WITHIN CROP AGRONOMY TO INCREASE BIODIVERSITY: INTEGRATED CROP MANAGEMENT STRATEGIES

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Chapter 5 contents:

1.1 SUMMARY

A small-scale study was undertaken to explore methods of enhancing biodiversity within winter wheat crops by increasing the abundance of beneficial plant species and associated invertebrates. A factorial design combined row spacing and cultivation treatments with targeted herbicide programmes. Conventional row spacing was compared to wide-spaced rows and to wide-spaced rows plus cultivation between the rows in spring. Herbicide treatments included a range of selective and broad-spectrum herbicides applied individually and in combination. The study was conducted at three sites with contrasting soil types over three years. Herbicide treatments were different at one site reflecting the different weed spectrum.

Vegetation cover and arthropod abundance (sampled using a Dvac suction sampler) were recorded in mid-June. Seed production was measured on a subset of treatments by pre-harvest seedhead and soil surface samples. Fertile tiller number, grain yield and grain quality were recorded. Data were analysed using a two-factor analysis of variance for each site/year individually. Plant species were grouped according to their desirability with respect to both agronomic issues and biodiversity benefits. Arthropods abundance was analysed by both taxonomic and functional groupings. Plant and arthropod communities were also analysed using multivariate techniques to investigate relationships between the two species assemblages.

Row spacing had a significant effect on fertile tiller number and yield in some, but not necessarily the same, sites/years, although crop cover was consistently lower under wide-spaced rows compared to conventional. The use of wide-spaced rows significantly reduced yield by 4% compared to conventional spacing in three site years, because of intra-row competition. Using a spring cultivation with the wide-spaced rows significantly reduced yield by 4.7% over wide-spaced rows alone in two site years. Yields were significantly lower on untreated plots compared to those that received herbicides in five of the nine site-year combinations; however, differences between herbicide treatments were only recorded in one site/year. Grain quality was generally unaffected by the treatments.

Weed and arthropod populations were different at each site and in each year, reflecting the different soil types, fields and weather. There were few effects of the spacing/cultivation treatments on either vegetation or arthropods; where differences were recorded, the effects were not consistent across sites or years.

Herbicide treatment had a significant effect on all individual weed species and groupings analysed, except where weed cover was very low (<0.5% on untreated plots). Greatest weed cover and diversity were usually recorded on plots untreated by herbicides. Generally, single-product herbicide applications left more plant cover than sequences; different sequences controlled weeds equally effectively, except at Boxworth in 2004, where some species were not fully controlled in the absence of a pre-emergence herbicide. In most sites/years a spring application of amidosulfuron allowed the greatest number weeds to survive of those treatments receiving herbicide. Where desirable species remained, undesirable species were sometimes poorly controlled. Although in some sites/years, where *Galium aparine* was the most important undesirable species, a spring application of amidosulfuron effectively controlled this species, but left appreciable cover of desirable species. Effects of herbicide on seed production were similar to those on weed cover.

The indirect effect of herbicide on arthropod abundance varied between groups, but significant effects were more common at sites/years with greater weed cover. There was variation in the degree to which groups were affected by different herbicide

regimes, but in response to vegetation cover, untreated plots usually supported greatest, and herbicide sequences led to the lowest, arthropod populations. Of the single herbicide applications, arthropod abundance was generally greatest where there was a spring application of amidosulfuron, benefiting a range of groups including nectar feeders, omnivores, Diptera, Heteroptera and species comprising skylark food items. This effect was pronounced at High Mowthorpe in 2005 and Boxworth in 2004. However, treatment effects were much more variable than for the vegetation.

Weed cover and arthropod abundance were only related where weed cover was relatively high (>25% on untreated plots), as were the species assemblages. The species composition of the weed community was affected by herbicide application; most herbicide treatments reduced the complexity of the weed spectrum. There was also an effect on arthropod species assemblage, but there was less differentiation, as might be expected, because herbicides have an indirect effect on arthropods. In contrast with the weed community, the species assemblage of the arthropod community responded to row spacing and cultivation. At Gleadthorpe in 2003, wide-spaced, cultivated rows supported a greater proportion of beetles, bugs and spiders, which are all components of chick food.

The results of this study suggest that, in certain circumstances, it is possible to increase weed cover by the use of selective herbicides and this can result in positive benefits for wider biodiversity. However, management must be site specific and reactive and this approach is not appropriate where pernicious grass weeds are common or where herbicide resistance is present.

1.2 INTRODUCTION

1.2.1 Background

Over the past few decades there has been a decline in the biodiversity associated with arable land (e.g. Pain & Pienkowski, 1997). Intensive production methods aim to minimise weed flora by the use of herbicides, competitive crop varieties and cultivations, resulting in a loss of plant biodiversity and reduced resource availability for groups at higher trophic levels. Also, a much greater proportion of cereal crops are now planted in the autumn. The result has been to encourage autumn germinating species compared to spring germinators (Hald, 1999). This has both reduced plant biodiversity and compounded the impact of other intensive methods on many other trophic groups, because many weed species that are considered most valuable as a food source are those which germinate in spring. Evans (1996) has highlighted the impact on birds of the loss of seed food over winter as a result of the switch from spring to autumn sown cereals and their treatment with herbicides. Diversity of invertebrates associated with the weed flora may also have been reduced (Marshall, 2003).

The aim of this study was to investigate the possibility of increasing populations of beneficial weeds, without increasing populations of agronomically important undesirable species. Beneficial weeds were considered to be those which are valuable to wider biodiversity but which are less competitive and do not represent a significant loss of yield except at high densities. The study combined a range of herbicide programmes with wide-spaced rows and a spring cultivation. Selective herbicides were chosen to investigate whether herbicide programmes can be used to allow the less competitive species to remain at levels which do not compromise production but which benefit wider farmland biodiversity. Lower crop competition under WSRs may allow germination later in the season and encourage greater weed cover between rows. They also allow a spring cultivation between rows which may initiate germination of beneficial species.

1.2.2 Objective

To increase the abundance and availability of plant species, such as spring germinating weeds, and associated invertebrates.

1.3 MATERIALS AND METHODS

1.3.1 Experimental design

The study was carried out at three ADAS sites representing a range of soil types, over three years (Table 5.1), moving to a different field each year. The study combined a range of herbicide treatments with three row spacing and cultivation treatments in a factorial design. The experiment was a completely randomised design except at Boxworth in 2005 where the study was a split plot design with herbicide treatments nested within spacing and cultivation treatments. Herbicide treatments were different at Boxworth to those at Gleadthorpe and High Mowthorpe reflecting the different weed communities. In the first year, a larger number of herbicide treatments were studied than in the following years. The results from the first year were used to refine the treatment list with the most interesting treatments chosen for the following two years of the trial. For simplicity, only those treatments that were applied in all three years have been included in the analyses presented here. At Boxworth, two of the 2003 treatments were different to subsequent years and in 2004 and 2005 clodinafop-propargyl was applied to all treatments to control grass weeds (Table 5.2). The row spacing/cultivation treatments were conventional spacing (Conv), wide-spaced rows (WSR) and wide-spaced rows with a spring cultivation after spring herbicide application (WSR+Cult). Wide-spaced rows were created by blocking off every other drill coulter, but the overall seed rate was the same as for Conv. In the first year, there were three replicates of each treatment. This was increased to five in subsequent years. Plots were three or four metres wide by 24 metres long. Experimental crops were managed to the ICM standard following guidelines in "Arable cropping and the environment – a guide" HGCA/DEFRA 2002. Varieties were selected from the HGCA recommended lists. Full details are given in Appendix 1.

Table 5.1 Summary of site details.

Site	Soil type	Row width Conv/WSR (cm)	No. of herbicide treatments	Plot width (m)
Boxworth (BX)	clay	12/24	8	3
Gleadthorpe (GT)	sand	12/24	7	4
High Mowthorpe (HM)	chalk	12/24	7	3

The range of herbicide treatments applied included 'untreated', 'full weed control' and a range of pre-emergence, post-emergence and spring herbicides which were applied in combination or individually (Table 5.2 & Table 5.3). Details of products used and target weed species are presented in Table 5.4. Generally, products were applied at manufacturers' recommended rates. The exception was at Boxworth where pendimethalin + flufenacet was applied both at full rate and at 75% of full rate in combination with clodinafop-propargyl. Full details of crop management are presented in Appendix 1. At High Mowthorpe, *Avena* spp. were removed from plots by hand in June 2003.

Table 5.2 Herbicide treatments applied at Boxworth[1].

Treat.	Pre-em. herbicide	Post-em. herbicide	March herbicide
a			
b	pendimethalin + flufenacet		
c		flupyrsulfuron-methyl	
d			amidosulfuron
e	pendimethalin + flufenacet	flupyrsulfuron-methyl	
	@ 75% recommended rate		
f	pendimethalin + flufenacet	flupyrsulfuron-methyl	
g[2]		flupyrsulfuron-methyl	amidosulfuron
h[3]	pendimethalin + flufenacet	flupyrsulfuron-methyl	amidosulfuron

[1]Clodinafop-propargyl applied post-emergence to all treatments (including 'untreated') in 2004 and 2005. In 2004, clodinafop-propargyl @ 125 ml ha^{-1} + Toil adjuvant @ 1 l ha^{-1}. In 2005 clodinafop-propargyl @ 125 ml ha^{-1} + Fortune adjuvant @ 0.75 l ha^{-1}.

[2] 2003 treatment included a pre-emergence application of Avadex @ 15 kg/ha.

[3] 2003 treatment included Ally @ 30 g/ha plus Starane @ 2.0 l/ha in April/May, not amidosulfuron in March.

Table 5.3 Herbicide treatments applied at Gleadthorpe and High Mowthorpe.

Treat.	Pre-em. herbicide	Post-em. herbicide	March herbicide
a			
b	diflufenican + trifluralin		
c		diflufenican + isoproturon	
d			amidosulfuron
e		diflufenican + isoproturon	amidosulfuron
f		diflufenican + isoproturon	florasulam
g		diflufenican + isoproturon	mecoprop-p

Table 5.4 Weeds controlled and products applied.

Active ingredients	Target weeds	Product	Rate of application
pendimethalin + flufenacet	grasses + dicots including *Galium aparine*	Crystal	4 l/ha[1]
flupyrsulfuron-methyl	dicots + *Alopecurus myosuroides*	Lexus	20 g/ha
amidosulfuron	*Galium aparine* + other dicots	Eagle	30 g/ha[2]
clodinafop-propargyl	*Alopecurus myosuroides* + *Avena* spp.	Topik	125 ml/ha
clodinafop-propargyl + trifluralin	*Alopecurus myosuroides*, *Avena* spp., dicots	Hawk	2.5 l/ha
diflufenican + trifluralin	*Poa annua* + dicots including *Galium aparine*	Ardent	2.5 l/ha
diflufenican + isoproturon	grasses + dicots including *Galium aparine*	Panther	2.0 l/ha
florasulam	grasses + dicots including *Galium aparine*	Boxer	0.75 l/ha[3]
mecoprop-p	*Stellaria media*, *Galium aparine* + other dicots	CMPP-p	2.0 l/ha[4]
tri-allate	grasses	Avadex	15 kg/ha
metsulfuron-methyl	dicots and *Stellaria media*	Ally	30 g/ha
fluroxypyr	*Galium aparine* + other dicots	Starane	2.0 l/ha

[1] @ 3 l/ha on treatment e at Boxworth
[2] @ 40 g/ha in 2003
[3] @ 0.15 l/ha in 2003
[4] @ 5.6 l/ha in 2003

1.3.2 Data collection

Plots were split into two areas for the purposes of monitoring with 2 m buffer areas between and at each end of the plot. All destructive monitoring including biodiversity sampling was undertaken in a 6 m length of the plot with 12 m reserved for yield estimation.

1.3.2.1 Agronomy

Plant/tiller population (March)

In the spring, plant/tiller populations were assessed in 10 x 0.5 m lengths of row per plot on the untreated and selected autumn treatments.

Row width (March)

A record of row width was made in each treatment by measurement in the field.

Disease monitoring (around 23 June)

Disease was assessed on untreated plots in mid-late June, but earlier if leaf 4 was greater than 50% dead. Percent infection of each disease and green leaf area were assessed on leaves 1, 2 and 3 separately on mainstems or tillers. This was done at 10 stops per plot. Any field-scale disease problems were recorded if patchy in nature. Where stem base diseases such as eyespot or take all were present 25 tillers were taken from each plot and assessed for presence or absence of disease.

Number of fertile tillers (early July)

Numbers of fertile tillers were assessed by counting the total number on both sides of five 0.5m lengths, along the row, per plot.

Crop yield

Grain was harvested using a plot combine. A sample of grain was assessed for moisture content, thousand grain weight (TGW) and specific weight (Spwt) in the laboratory.

Trash levels in harvested seed

After experiencing high levels of trash in the 2004 harvest year, grain samples with high levels of weeds in 2005 were assesses for level of trash.

Other records

A field diary containing site and input details was recorded.

1.3.2.2 Vegetation

Vegetation was monitored on one occasion in late June to assess the overall effects of the treatments. Five randomly positioned 0.25 m^2 quadrats (0.5 x 0.5 m) were sampled on each plot. Percent ground cover of each weed species was recorded plus crop ground cover, bare ground (viewed from below the canopy), bare ground (viewed from above the canopy) and litter. Cover was recorded in the following categories, with the midpoint value used for analysis: 0-1%, >1-2%, >2-5%, >5-10%, >10-20%, etc to >90-100%. Total plant ground cover could total more than 100% because vegetation was present at different heights in the canopy.

In order to estimate food resources available to other trophic groups, the reproductive status of each species was recorded using the following categories: vegetative growth only, flower shoots and buds present, flowering, seeds present/dehiscing. These categories were recorded at proportions of 1-25%, 26-50%, 51-75% and 76-100%.

To obtain an estimate of potential seed availability as a food source for birds over the autumn and winter, seed production was assessed in late July, pre-harvest, in a subset of herbicide treatments under conventional spacing (Boxworth: a 'untreated', b 'pre-em only', d 'spring only' and h 'full weed control'; Gleadthorpe & High Mowthorpe: a 'untreated', d 'spring only' g ' post-em followed by spring' NB. different spring herbicide in 2003). Three randomly located 0.25 m^2 quadrats were sampled per plot and samples bulked. All weed vegetation was removed from the quadrats and recently-shed seeds were sampled from the soil surface using a portable vacuum. In the laboratory, seeds were separated from vegetative matter by hand, identified and counted. Seeds were extracted from the soil surface sample by washing the soil through a 500 µm mesh sieve to remove the fine soil particles followed by floating off the organic matter using a saturated solution of $CaCl_2$. Seeds were then removed from other organic matter by hand under ×2 magnification, identified and counted. Numbers of both mature seed (assessed as viable by visual inspection or squeezing between forceps; Ball & Miller, 1989) and immature seed were assessed. Because sampling was carried out before harvest, some of the immature seed would have become viable by harvest. Also, immature seed may still form a potential food source for other species.

This assessment of seed production does not represent total seed production through the season. Some seed shed before sampling would have become incorporated into the soil and some would already have been taken by granivorous species. However, this approach will indicate the potential food source available to other species after harvest.

1.3.2.3 Arthropods

Arthropods were sampled using a Dvac suction sampler, between 2 and 7 days after vegetation sampling. In each site/year a subset of treatments were sampled based on preliminary vegetation data in order to sample the most potentially interesting treatments. One sample was collected from each plot consisting of five sub-samples each taken over ten seconds, thereby sampling a total area of 0.5 m^2. Arthropods were identified to family. Individuals were counted and are presented as number of individuals termed ‘abundance’.

1.3.3 Statistical analysis

Each site/year was initially analysed separately. Percent ground cover data (vegetation) were angular transformed and count data (seeds and arthropods) were $\log_{10}$ (x+1) transformed prior to analysis. Data for species richness (number of species per plot) were not transformed. Data were analysed using a two factor analysis of variance to determine the effects of herbicide treatment, spacing/cultivation treatment and the interaction between them. Analysis of contrasts was used to compare:

- conventional spacing vs wide-spaced rows
- wide-spaced rows vs wide-spaced rows + cultivation

Where there was no interaction between treatments, the interaction term was dropped from the model and the data reanalysed to include analysis of all pairwise comparisons of herbicide treatment means using Duncan’s multiple range test.

Seed data was collected only from the conventional spaced treatment, therefore a one factor analysis of these data was carried out. Seed data were analysed both as 'viable' and 'total'. All analyses were carried out using General Analysis of Variance (ANOVA) with blocks specified as 'block'. All analyses were carried out using Genstat 8.1, 2005, Lawes Agricultural Trust. Error bars represent +/- SEMs throughout.

Plant species were classified in groupings relating to their desirability with respect to both agronomic issues and biodiversity benefits (in terms of benefits to birds and arthropods) (Table 5.5) and also as grasses or broad-leaved species. Desirability groupings were also combined into all desirable species (Group1 + Group2; named 'Groups12') and all neutral/desirable species (Group1 + Group2 + Group3; named 'Groups123'). Unless numbers were very low, all these groupings were analysed, plus crop, litter, bare ground cover and total weed cover (sum of all individual species). For each site/year, a small number of common species were analysed as individual species.

Table 5.5 Plant groupings relating to their desirability with respect to both agronomic issues and biodiversity benefits.

Very desirable (Group1)	**Desirable (Group2)**	**Undesirable (Group4)**
Chenopodium album	*Cerastium* spp.	*Alopecurus myosuroides*
Fallopia convolvulus	*Fumaria officinalis*	*Anisantha* spp.
Poa annua	*Matricaria discoides*	*Avena* spp.
Persicaria lapathifolia	*Matricaria recutita*	*Bromus* spp.
Persicaria maculosa	*Tripleurospermum inodorum*	*Cirsium arvense*
Polygonum aviculare	*Senecio vulgaris*	*Elytrigia repens*
Raphanus raphanistrum	*Sonchus* spp.	*Galium aparine*
Sinapis arvensis	*Viola arvensis*	*Lolium* spp.
Stellaria media	*Viola tricolour*	*Rumex obtusifolius*
		Volunteers

Group 3 = Neutral species – all other species recorded which were considered neither particularly desirable nor undesirable.

Arthropods were analysed by taxonomic group (Table 5.6), in six functional groups (Table 5.7), and as total arthropods.

Table 5.6 Arthropod taxonomic groups for analysis.

Order	Sub-order	Family	Common name	Life stage
Araneae			Spiders	Adult
Opiliones			Harvestmen	Adult
Hemiptera	Homoptera		Hoppers	Adult
Hemiptera	Heteroptera		True bugs	Adult
Neuroptera			Lacewings	Larvae
Lepidoptera			Butterflies and moths	Larvae
Coleoptera		Carabidae	Ground beetle	Adult
		Staphylinidae	Rove beetles	Adult
		Cantharidae	Soldier beetle	Adult
		Elateridae	Click beetle	Adult
			Other beetles	Adult
Diptera	Nematocera	Tipulidae	Cranefly	Adult
	Other Nematocera		Gnats, mosquitoes and midges	Adult
	Brachycera		Hoverfly and horsefly	Adult
	Aschiza		Flies	Adult
	Acalypterae		Flies	Adult
	Calyptera		Flies	Adult
			Fly larvae	Larvae
			Total number of flies	All
			Total number of beetles	All
			Total number of invertebrates	All

Table 5.7 Arthropod composite variates for analysis.

Composite variate	Components
Nectar feeders	Aschiza, Elateridae, Lepidoptera (adults)
Herbivores	Homoptera, Orthoptera, Symphyta larvae, Lepidoptera larvae, Curculionidae, Chrysomelidae
Omnivore/mixed	Heteroptera, Nematocera, Carabidae, Staphylinidae, Acalyptera, Calyptera
Predators	Brachycera, Cantharidae, Neuroptera larvae
CFI	Homoptera, Heteroptera, Aphids, Neuroptera larvae, Lepidoptera larvae, Carabidae, Curculionidae, Symphyta larvae, Elateridae
Skylark Food Items	Araneae, Opiliones, Homoptera, Hemiptera, Neuroptera, Lepidoptera, Carabidae, Chrysomelidae, Staphylinidae, Cantharidae, Elateridae, Tipulidae

1.3.3.1 *Community composition*

The aim of this analysis was primarily to establish whether there was a relationship between weed and arthropod species assemblage, therefore only weed data from the subset of plots selected for arthropod sampling have been analysed. Data were analysed using a suite of analyses in PRIMER 6 (PRIMER-E Ltd, 2006). Weed data were normalised using angular transformation and arthropod data was $\log_{10}$ (x+1) transformed. Differences between treatments were analysed using a two-way crossed ANOSIM based on similarity matrices calculated using the Bray-Curtis similarity co-efficient. SIMPER was then used to identify the species which accounted for the differences between treatments. In order to establish if there was a correlation between the species matrices of weeds and arthropods the data were correlation using RELATE; where a significant correlation was found BEST was run to determine which weed species most influenced arthropod community composition.

1.4 RESULTS

1.4.1 Crop development, yield and quality

1.4.1.1 *Disease monitoring*

Disease was monitored regularly throughout the season at all sites and no differences were seen between the treatments at any site in any year. This was not surprising given that conventional fungicide programmes were applied.

1.4.1.2 *Fertile tillers*

Fertile tiller numbers were only affected significantly ($P < 0.05$) by herbicide at High Mowthorpe in 2004. At this site during this year, there were large numbers of weeds: the effects of this are discussed later.

Fertile tiller numbers were affected to a greater degree by row spacing; in six sites/years out of nine there were significantly ($P < 0.05$) fewer in the wide-spaced rows than in the conventional (Figure 5.1). Generally, lower seed rates were not used for the wide-spaced treatments, except at Gleadthorpe in 2003 when a 20% lower seedrate was used. The reduction in fertile tiller numbers was probably due to increased competition between plants within the wide-spaced rows. Overall, fertile tiller numbers were 25% fewer in the wide-spaced rows (range 10-49%).

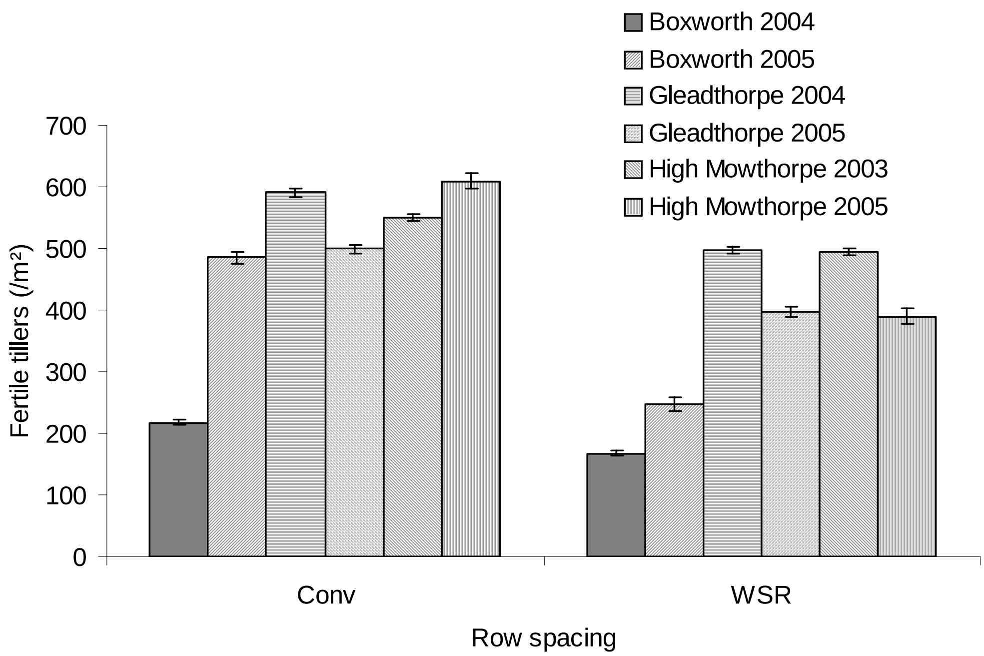

Figure 5.1 The effect of conventional row spacing (Conv) and wide-spaced rows (WSR) on fertile tiller number.

1.4.1.3 Yield

<u>Herbicides</u>

There were significant lower yields from the untreated at Boxworth in 2004 and 2005, Gleadthorpe in 2004, and High Mowthorpe in 2004 and 2005.

At Boxworth in 2004, yield was closely correlated with fertile tiller number (Figure 5.2). Yields were significantly ($P < 0.05$) lower in (a) untreated, (b) where only a pre-emergence application of pendimethalin + flufenacet was applied and (d) where a single application of amidosulfuron was applied in March. Yield reductions were related to higher weed levels in these treatments.

At Boxworth in 2005, yields in the herbicide treatments (b-h) yielded on average 0.5 t/ha more than the untreated, probably due to good weed control. Similarly, at High Mowthorpe in 2005, all herbicide treatments (b-g) yielded more (2.4 t/ha) than the untreated.

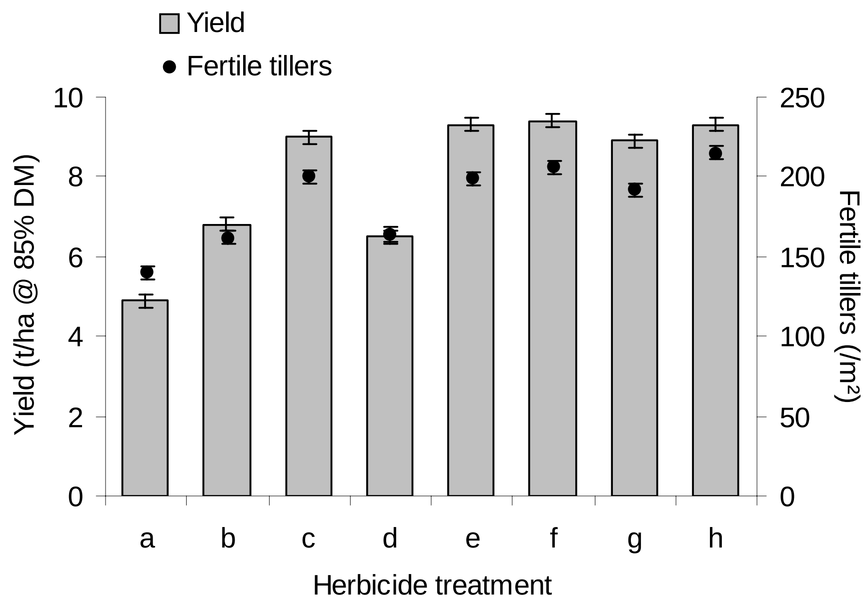

Figure 5.2 The effect of herbicide on yield of grain and fertile tiller number: Boxworth, 2004.

<u>Row width and cultivation</u>

Over the nine sites/years of the experiment there were significant ($P < 0.05$) effects of row spacing/cultivation treatments on three occasions. These were not always linked to significant ($P < 0.05$) differences in fertile tiller numbers.

The use of wide-spaced rows significantly reduced yield at Boxworth in 2005 and Gleadthorpe in 2004 and 2005. The mean yield decrease of these three site years due to the use of wide-spaced rows was 4% (Figure 5.3). Using a spring cultivation with the wide-spaced rows significantly reduced yield at Boxworth and Gleadthorpe in 2005, with a mean yield decrease of 4.7% over wide-spaced rows alone in these two site years (Figure 5.4).

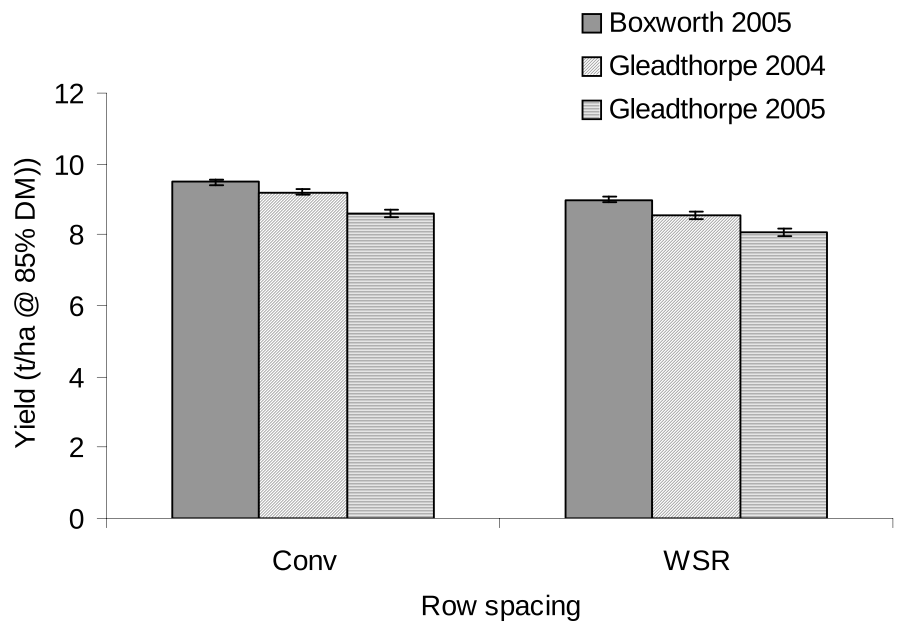

Figure 5.3 The effect of row spacing on yield of grain.

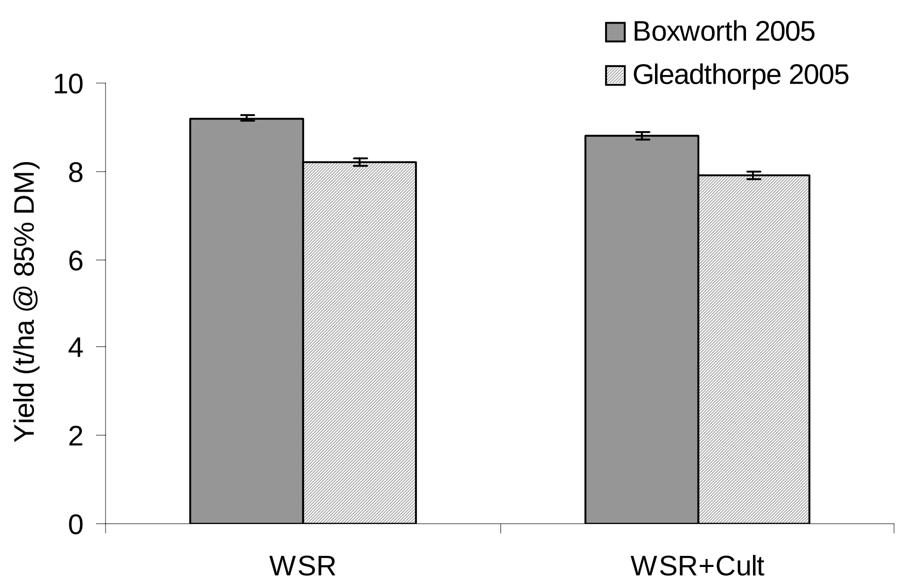

Figure 5.4 The effect of spring cultivation with wide-spaced rows on yield of grain.

1.4.1.4 Grain quality

Generally, specific weight and thousand grain weight were unaffected by herbicide treatment, but significant effects ($P < 0.05$) were seen at High Mowthorpe in 2004 and 2005 where cultivations had been made. These effects were not related to yield or fertile tiller number.

1.4.2 Vegetation

1.4.2.1 Overview

Total weed ground cover on plots untreated with herbicide was very different between years and different sites (Figure 5.5) reflecting the different soil types, fields, and weather. Most weed ground cover represented species that were considered either 'beneficial' or 'undesirable', except at High Mowthorpe in 2005, where *Papaver* spp. (a neutral species) was common on untreated plots. Ground cover of undesirable species was always lower than of other species combined, particularly at Gleadthorpe. At Boxworth, few weeds were recorded in 2003 and 2005, however, in 2004 weed cover was nearly 100% on plots untreated with herbicide.

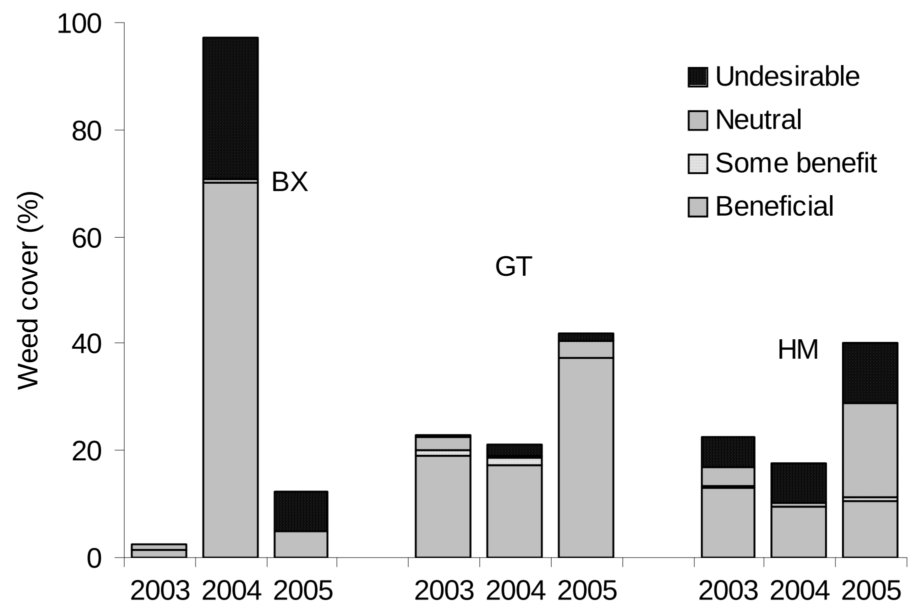

Figure 5.5 Total weed ground cover, by species grouping, on untreated plots (treatment a) (mean of 3 spacing/cultivation treatments).

At Boxworth in 2004, volunteer beans and *Anisantha sterilis* were the most common undesirable species, and *Stellaria media* and *Sinapis arvensis* the most common desirable species (Figure 5.6). In 2005, *G. aparine* and *Alopecurus myosuroides* were the most common undesirable species. At Gleadthorpe, cover of undesirable species was very low in all three years (Figure 5.7). *Poa annua* consistently represented around 15% cover, and in 2005 *S. media* was also common. At High Mowthorpe, *G. aparine* was the most common undesirable species in all three years, and similar to Gleadthorpe, *P. annua* was always an important component of the weed community (Figure 5.8). *Papaver* spp. were the most common species in

2005. At both Gleadthorpe and High Mowthorpe, the diversity of desirable species decreased between 2003 and 2005.

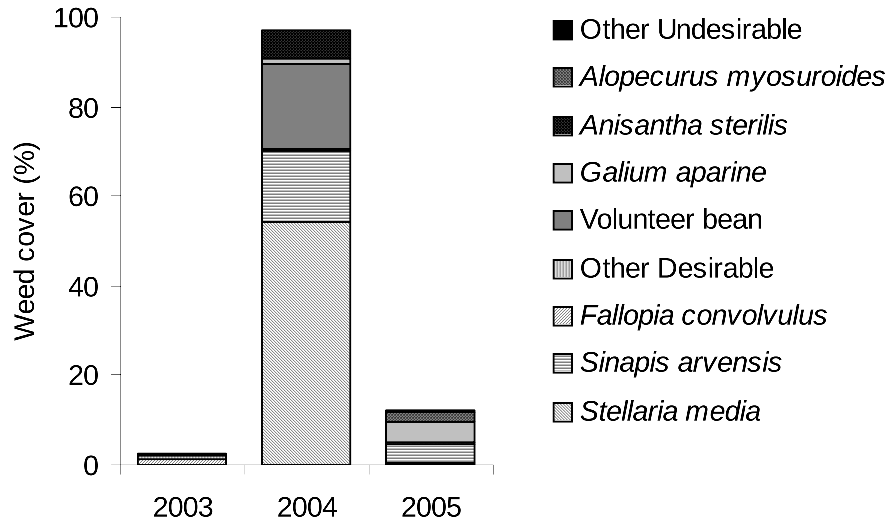

Figure 5.6 Weed ground cover and species composition on untreated plots (treatment a) (mean of 3 spacing/cultivation treatments): Boxworth.

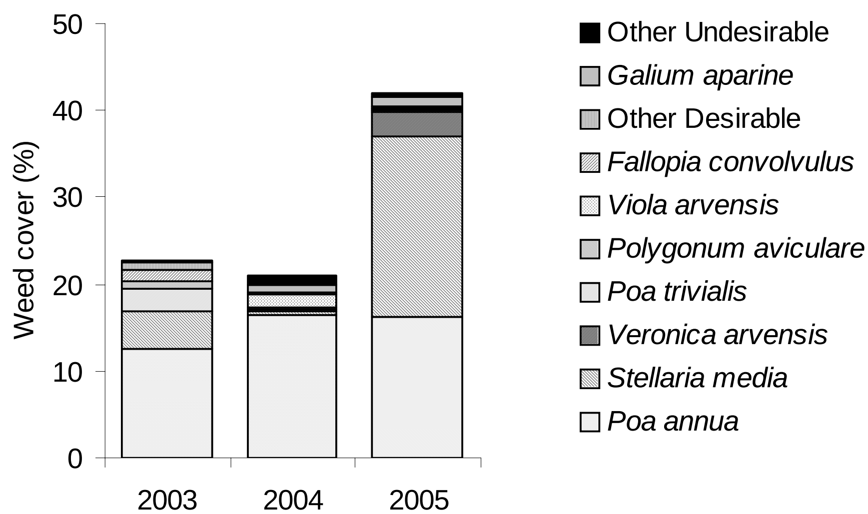

Figure 5.7 Weed ground cover and species composition on untreated plots (treatment a) (mean of 3 spacing/cultivation treatments): Gleadthorpe.

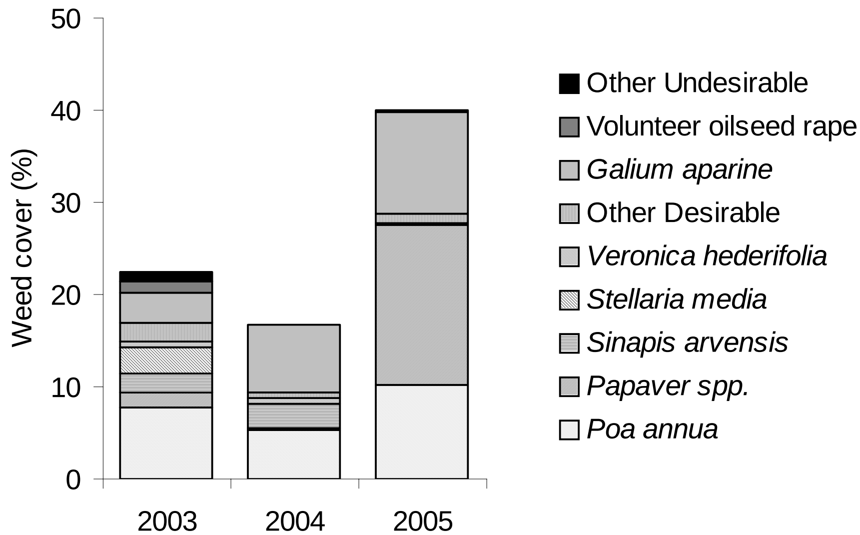

Figure 5.8 Weed ground cover and species composition on untreated plots (treatment a) (mean of 3 spacing/cultivation treatments): High Mowthorpe.

1.4.2.2 Effect of row spacing/cultivation treatment on weed vegetation

There were few differences in weed populations between row spacing/cultivation treatments. Table 5.8 lists variates for which there was a significant effect of row spacing/cultivation, with no interaction between main factors. At Boxworth in 2004, cover of broadleaf species was apparently reduced by cultivation. At Gleadthorpe, cover of Group 1 species in 2003, cover of broadleaf species in 2004 and species richness in 2004 were all significantly higher in WSR than Conv. At High Mowthorpe in 2005, cover of Group 2 species, and all weeds, was significantly higher on WSR compared to WSR+Cult. Also, species richness was higher on WSR+Cult compared to WSR. In addition, where there was an interaction with herbicide treatment, a further three variates at Gleadthorpe and nine at High Mowthorpe showed a significant effect of row spacing/cultivation (see Appendix 3). Results were similar to those where there was no interaction, with greater cover under WSR compared to Conv at Gleadthorpe and WSR compared to WSR+Cult at High Mowthorpe.

1.4.2.3 Effect of herbicide treatment on weed vegetation

Weed cover

A range of vegetation variates were analysed including individual species, groupings of species and combinations of groupings. Thus each species appears in a number of different composite variates. Generally, only a small number of species were common in each site/year, therefore a single species could be the main component of several variates analysed. This report therefore concentrates on individual species, Group1 (desirable species), Group4 (undesirable species) and Groups 1, 2 and 3 combined (i.e. all species excluding undesirables; termed 'Groups123'). All significant results for these variates are tabulated and selected results are also presented as figures. Full details of all analyses are presented in Appendix 3.

Table 5.8 The effect of row spacing/cultivation on weed cover (%) and species richness (number of species per plot) (where there was no interaction between main factors; back transformed means).

	Spacing/Cultivation					**Conv vs WSR**		**WSR vs WSR+Cult**	
	Conv	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Boxworth 2004									
Broadleaf	25.0	29.4	21.8	3.73	0.027		ns	7.41	0.008
Gleadthorpe 2003									
Group1	1.1	3.2	2.4	3.43	0.040	6.59	0.013		ns
Gleadthorpe 2004									
Broadleaf	0.2	0.6	0.3	4.66	0.012	9.30	0.003		ns
Species richness	1.8	2.7	2.3	4.95	0.009	9.83	0.002		ns
High Mowthorpe 2003									
Group3	0.8	0.5	0.2	3.26	0.047		ns		ns
High Mowthorpe 2004									
Species richness	4.3	4.6	5.5	7.19	0.001		ns	7.11	0.009
High Mowthorpe 2005									
Group2	0.2	0.3	0.1	4.47	0.014	4.69	0.033	8.23	0.005
All weeds	5.9	7.2	3.8	3.74	0.027		ns	7.27	0.008

There was a highly significant effect of herbicide treatment on percent cover of almost all weed species and composite variates analysed (Table 5.9, Table 5.10, Table 5.12 and Appendix 3). Where there was no effect, weed cover was generally very low. Results from each site are considered individually.

Boxworth

In all three years of the study at Boxworth, greatest cover of Groups123 was recorded on untreated plots (a) (Table 5.9) although weed cover was much greater in 2004 than in other years. In 2004, cover of Groups123 (Figure 5.9) was generally greater under single product applications (b, c, d) compared to sequences of herbicides (e – h). A spring application of amidosulfuron (d) left greater weed ground cover than other single herbicide treatments, and the absence of a pre-emergence herbicide (g) left more weed ground cover than other sequences (e, f, h). A similar pattern was observed in 2005, with greater ground cover of Groups123 remaining after single applications or in the absence of a pre-emergence herbicide, but ground cover was overall much less (Table 5.9). The application of herbicide affected individual species differently, as would be expected. In 2004, *S. arvensis* was left uncontrolled only in untreated plots, and where a pre-emergence herbicide alone had been applied (b), whereas relatively high cover of *S. media* remained in all treatments that did not include a pre-emergence herbicide (a, c, d, g) (Figure 5.9). Undesirable species (Group4) were generally more effectively controlled by sequences (e – h) than single herbicide applications (b – d) (Figure 5.10). In 2004, a post-emergence application gave similar levels of control of undesirable species to sequences. This related to control of volunteer beans which was ineffective in the absence of a post-emergence application (Table 5.9).

Overall, both undesirable species and Groups123 species were less effectively controlled by single herbicide applications than by sequences and the spring only treatment generally left highest weed cover. Differences between the effectiveness of single herbicide treatments reflect the species composition and selectivity of the herbicides used.

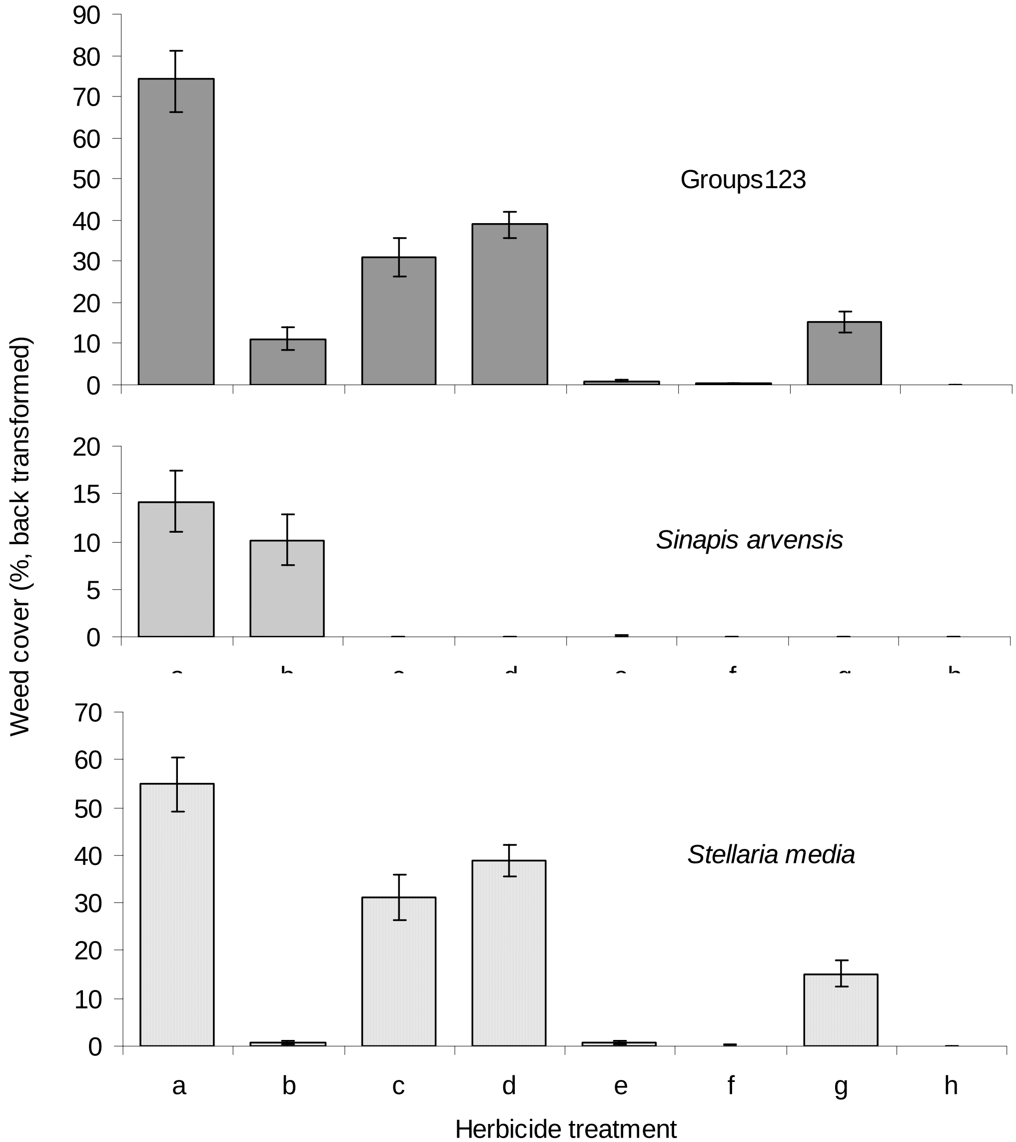

Figure 5.9 The effect of herbicide treatment on the ground cover of the Groups123 weeds, *Stellaria media* and *Sinapis arvensis*: Boxworth, 2004.

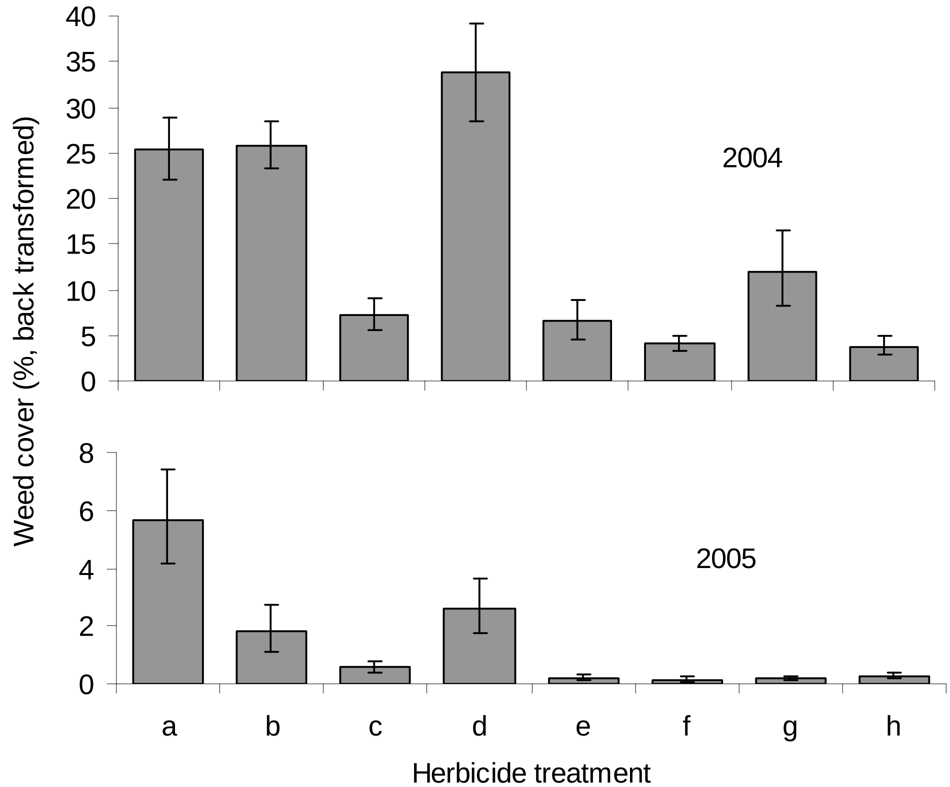

Figure 5.10 The effect of herbicide treatment on groundcover of Group4 weeds: Boxworth, 2004 and 2005.

Table 5.9 The effect of herbicide treatment on weed cover (%) (no interaction between main factors; back transformed means): Boxworth.

	Herbicide									
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***
2003										
Group1	1.7^{a}	0.5^{b}	0.2^{b}	0.7^{b}	0.7^{b}	0.3^{b}	0.2^{b}	0.0^{c}	7.09	<0.001
Groups123	1.8^{a}	0.6^{bc}	0.4^{bc}	0.9^{b}	0.8^{bc}	0.5^{bc}	0.3^{c}	0.0^{d}	9.98	<0.001
Fallopia convolvulus	0.6^{a}	0.1^{b}	0.1^{b}	0.0^{b}	0.2^{ab}	0.1^{b}	0.1^{b}	0.0^{b}	2.44	0.029
2004										
Group1	73.6^{a}	10.9^{c}	31.1^{b}	38.8^{b}	0.9^{d}	0.2^{d}	15.1^{c}	0.1^{d}	91.16	<0.001
Group4	25.4^{a}	25.8^{a}	7.2^{bc}	33.8^{a}	6.6^{bc}	4.1^{c}	12.1^{b}	3.8^{c}	19.92	<0.001
Groups123	74.1^{a}	11.0^{c}	31.1^{b}	38.9^{b}	1.0^{d}	0.2^{d}	15.2^{c}	0.1^{d}	92.48	<0.001
Anisantha sterilis	4.3^{a}	3.2^{a}	5.0^{a}	5.4^{ab}	4.7^{a}	1.6^{a}	11.1^{b}	2.0^{a}	2.90	0.008
Sinapis arvensis	14.1^{a}	10.0^{b}	0.0^{c}	0.0^{c}	0.1^{c}	0.0^{c}	0.0^{c}	0.0^{c}	57.41	<0.001
Stellaria media	54.9^{a}	0.7^{d}	31.1^{b}	38.8^{b}	0.8^{d}	0.2^{d}	15.1^{c}	0.1^{d}	121.04	<0.001
Volunteer bean	18.0^{b}	20.5^{ab}	0.9^{cd}	24.1^{a}	0.8^{cd}	1.5^{c}	0.2^{d}	0.9^{cd}	90.11	<0.001
2005										
Group1	2.8^{a}	0.0^{bc}	0.5^{b}	0.2^{bc}	0.0^{c}	0.0^{c}	0.0^{bc}	0.0^{c}	11.44	<0.001
Group4	5.7^{a}	1.8^{b}	0.6^{c}	2.6^{b}	0.2^{c}	0.2^{c}	0.2^{c}	0.3^{c}	19.45	<0.001
Groups123	2.9^{a}	0.1^{c}	0.6^{b}	0.2^{bc}	0.0^{c}	0.0^{c}	0.1^{c}	0.0^{c}	12.45	<0.001
Galium aparine	3.7^{a}	0.9^{b}	0.2^{c}	0.1^{c}	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	18.42	<0.001

Gleadthorpe

In all three years at Gleadthorpe, weed ground cover was very low on all treatments except untreated and spring-only application (Table 5.10). Ground cover of Group1, Groups123 and individual species analysed were less under spring herbicide applications compared to the untreated in 2003. However, this effect was not consistent in subsequent years Table 5.10) when cover was sometimes similar in untreated and spring herbicide plots e.g. *P. annua* (Figure 5.11).

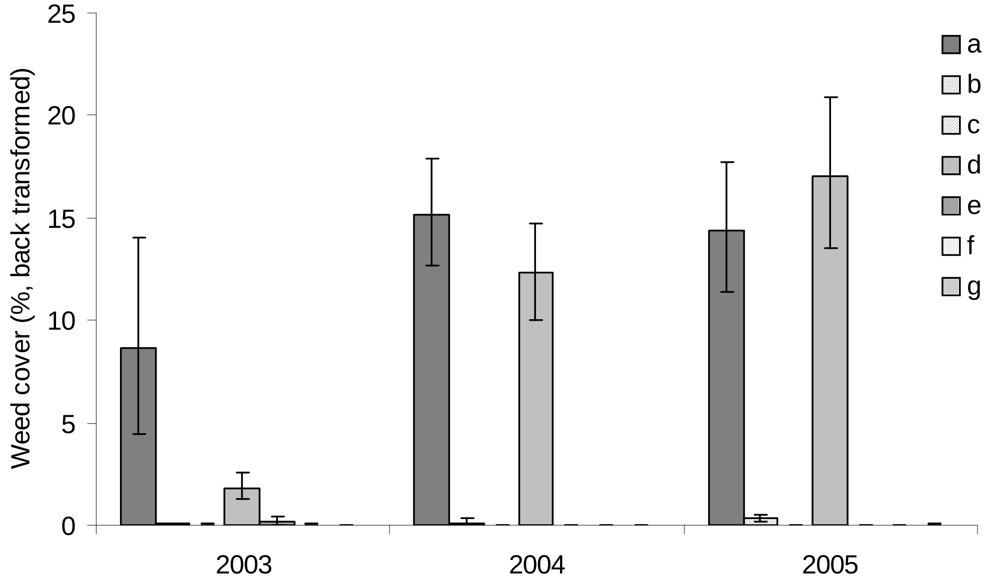

Figure 5.11 The effect of herbicide treatment on ground cover of *Poa annua*: Gleadthorpe.

Ground cover of undesirable species was very low in all three years, although cover was significantly higher on untreated (a) than most other treatments in 2004 and 2005 (Table 5.10).

Table 5.10 The effect of herbicide treatment on weed cover (%) (no interaction between main factors; back transformed means): Gleadthorpe.

	Herbicide								
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***
2003									
Group1	16.9[a]	0.6[c]	1.3[c]	4.7[b]	0.8[c]	0.5[c]	0.1[c]	19.10	<0.001
Groups123	19.8[a]	0.7[c]	1.3[c]	5.7[b]	0.8[c]	0.6[c]	0.1[c]	13.57	<0.001
Fallopia convolvulus	0.9[a]	0.3[b]	0.8[a]	0.3[b]	0.3[b]	0.1[b]	0.1[b]	5.23	<0.001
Poa annua	8.6[a]	0.1[c]	0.0[c]	1.8[b]	0.1[bc]	0.0[c]	0.0[c]	8.61	<0.001
2004									
Group1	15.8[a]	0.2[b]	0.0[b]	12.5[a]	0.0[b]	0.0[b]	0.0[b]	80.35	<0.001
Group4	1.5[a]	0.5[b]	0.2[bc]	0.2[bc]	0.1[bc]	0.1[c]	0.3[bc]	7.08	<0.001
Groups123	17.9[a]	0.2[c]	0.0[c]	13.6[b]	0.0[c]	0.0[c]	0.0[c]	90.83	<0.001
Poa annua	15.2[a]	0.1[b]	0.0[b]	12.3[a]	0.0[b]	0.0[b]	0.0[b]	77.75	<0.001
2005									
Group1	35.5[a]	0.9[c]	0.1[c]	24.8[b]	0.0[c]	0.1[c]	0.1[c]	63.03	<0.001
Group4	0.4[a]	0.2[abd]	0.0[d]	0.1[abcd]	0.0[d]	0.0[bcd]	0.0[cd]	3.81	0.002
Groups123	39.1[a]	0.9[b]	0.1[b]	31.0[a]	0.0[b]	0.1[b]	0.1[b]	85.86	<0.001
Poa annua	14.4[a]	0.3[b]	0.0[b]	17.1[a]	0.0[b]	0.0[b]	0.0[b]	64.22	<0.001
Stellaria media	13.5[a]	0.2[c]	0.0[c]	5.3[b]	0.0[c]	0.0[c]	0.0[c]	18.27	<0.001

In 2003, there was an interaction between herbicide treatment and row spacing/ cultivation for *S. media* ($F = 4.64$; $P < 0.001$; see Appendix 3). Similar to results where there was no interaction between factors, highest percent cover was recorded on untreated (a) followed by a spring application of amidosulfuron (d), however within herbicide treatments highest percent cover was recorded on different row spacing/cultivation treatments.

High Mowthorpe

At High Mowthorpe, there was an interaction between main factors for Group4 in 2005, and for Group1, Groups123 and *P. annua* in all three years (Table 5.11 and Appendix 3). In 2003, percent cover of Group1, Groups123 and *P. annua* was highest on untreated (a) followed by a spring application of amidosulfuron (d), but within herbicide treatments highest percent cover was recorded on WSR in treatment a and Conv in treatment d. Similar effects of treatments were recorded in 2004, however, within herbicide treatments, highest percent cover was recorded on Conv for treatment a and WSR for treatment d. In contrast, in 2005 percent cover of Group1 and *P. annua* was higher on treatment d than treatment a, but similar to results from 2004, highest percent cover was recorded on Conv for treatment a and WSR for treatment d.

Table 5.11 Weed species and groupings for which there was an interaction between herbicide and row spacing/cultivation treatments when % cover was subject to ANOVA: High Mowthorpe.

		Herbicide*Spacing/Cultivation	
Year	**Variate**	***F***	***P***
2003	Group1	3.00	0.004
	Groups123	2.85	0.006
	Poa annua	3.66	<0.001
2004	Group1	2.25	0.017
	Groups123	2.42	0.010
	Poa annua	1.89	0.048
2005	Group1	3.18	<0.001
	Group4	2.35	0.012
	Groups123	2.25	0.017
	Galium aparine	2.35	0.012
	Poa annua	3.24	<0.001

Similarly to results from Gleadthorpe, ground cover of Groups123 was highest on untreated and spring herbicide only plots, with very little cover on any other treatments in 2005 (Appendix 3). In 2004 (Figure 5.12), and to a lesser extent 2003 (Appendix 3), cover of Groups123 was higher under single herbicide applications than sequences.

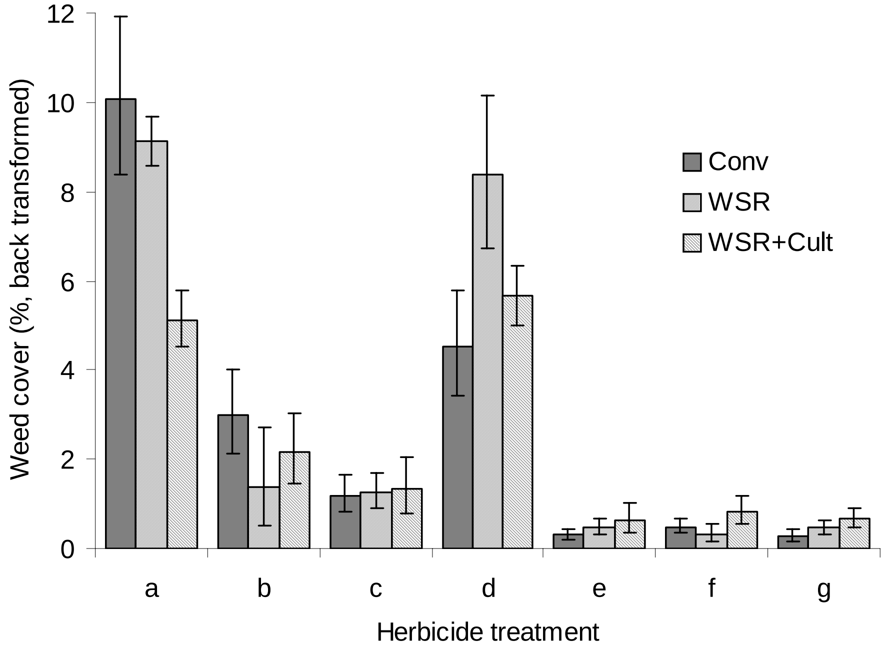

Figure 5.12 The effect of herbicide and row spacing/cultivation on ground cover of Groups123 weeds: High Mowthorpe, 2004.

Ground cover of undesirable species was greater on untreated plots in all three years, although there was an interaction with row spacing/cultivation in 2005 (Table 5.11 and Appendix 3). Highest percent cover was recorded on untreated plots followed by a pre-emergence application of diflufenican + trifluralin (b) in 2005. The interaction between factors was a result of very small differences between row spacing/cultivation treatments on herbicide treatments that had very low percent cover of this species. Generally, ground cover was greater following single herbicide applications compared to sequences (Table 5.12, Figure 5.13). However, in 2003, the spring-only application controlled undesirable species as effectively as the sequences, and in 2004 both the spring-only and the post-emergence only treatments resulted in similar levels of control to the sequences. *G. aparine* was the most common undesirable species at High Mowthorpe in all three years.

Table 5.12 The effect of herbicide treatment on weed cover (%) (no interaction between main factors; back transformed means): High Mowthorpe.

	Herbicide								
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***
2003									
Group4	4.2^{a}	3.1^{ab}	3.3^{ab}	1.3^{bc}	1.3^{bc}	0.5^{c}	0.3^{c}	5.01	<0.001
Sinapis arvensis	1.2^{a}	0.9^{ab}	0.6^{ab}	0.2^{bc}	0.2^{bc}	0.0^{c}	0.0^{c}	3.93	0.003
Volunteer OSR	1.0^{a}	1.2^{a}	0.8^{a}	0.2^{b}	0.2^{b}	0.0^{c}	0.0^{c}	22.23	<0.001
2004									
Group4	5.0^{a}	1.7^{b}	0.9^{bc}	0.7^{c}	0.2^{c}	0.3^{c}	0.3^{c}	19.94	<0.001
Fallopia convolvulus	1.0^{a}	0.3^{b}	0.9^{a}	0.7^{a}	0.2^{b}	0.2^{b}	0.2^{b}	12.44	<0.001
Galium aparine	4.5^{a}	0.9^{b}	0.8^{bc}	0.3^{cd}	0.1^{d}	0.1^{d}	0.2^{d}	23.84	<0.001
Sinapis arvensis	1.5^{a}	1.0^{a}	0.0^{b}	0.1^{b}	0.0^{b}	0.0^{b}	0.0^{b}	24.73	<0.001
2005									
Papaver spp.	12.6^{a}	0.0^{c}	0.2^{bc}	1.0^{b}	0.0^{c}	0.0^{c}	0.0^{c}	23.88	<0.001

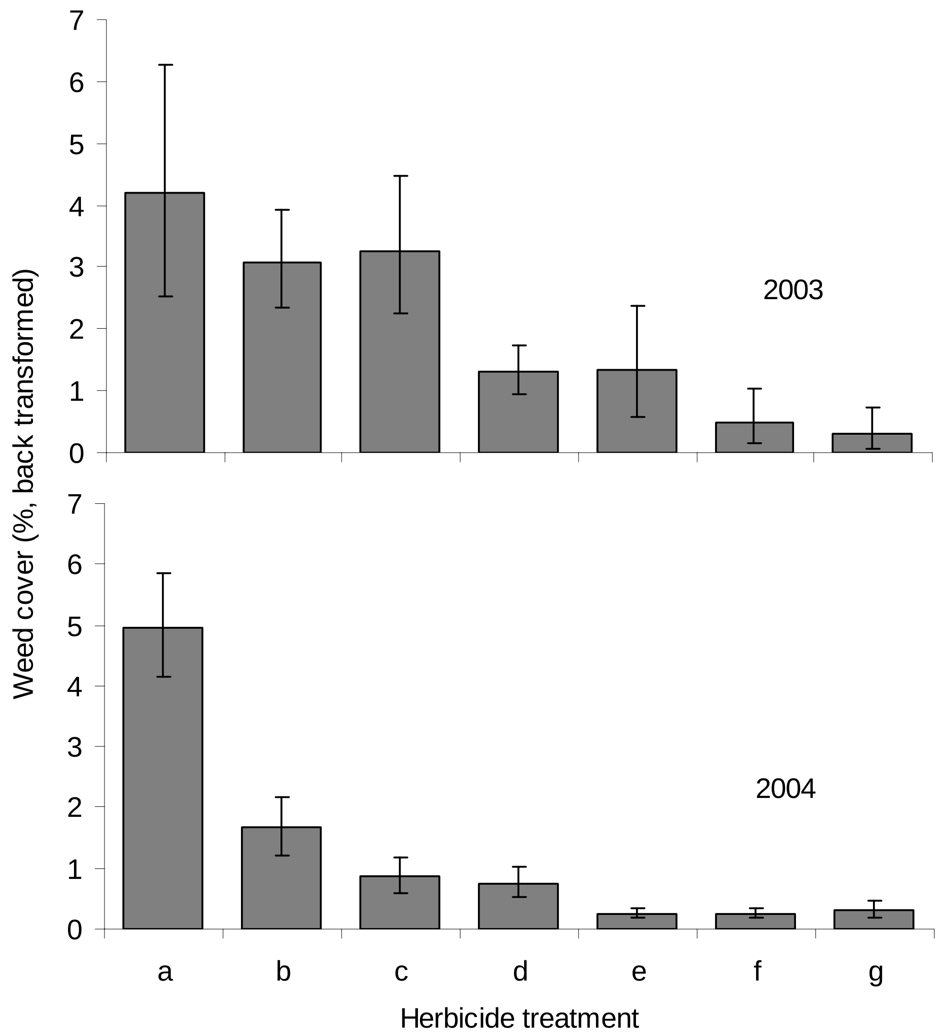

Figure 5.13 The effect of herbicide treatment on ground cover of Group4 weeds: High Mowthorpe, 2003 and 2004.

<u>Species Richness</u>

There was a highly significant effect of herbicide treatment on species richness in all site years (Table 5.13 & Table 5.14). Generally, the pattern of species richness reflected the overall weed cover, with highest species number recorded on untreated plots followed by single herbicide applications followed by sequences (Figure 5.14). Of the single herbicide treatments, species richness was generally higher under spring application of amidosulfuron than under pre-emergence or post-emergence only treatments. At Gleadthorpe in 2004 and 2005 and at High Mowthorpe in 2004, species richness under a post-emergence only application (c) was similar to that for sequences.

Table 5.13 The effect of herbicide treatment on species richness (number of species per plot): Boxworth.

	Herbicide									
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***
2003	5.6^{a}	3.4^{bc}	3.2^{bc}	3.8^{b}	2.9^{bc}	3.0^{bc}	2.0^{c}	0.1^{d}	10.41	<0.001
2004	4.7^{a}	4.8^{a}	3.1^{cd}	3.2^{cd}	4.3^{ab}	3.8^{bc}	3.2^{cd}	2.7^{d}	7.89	<0.001
2005	3.9^{a}	2.5^{b}	2.9^{b}	2.6^{b}	1.2^{c}	0.9^{c}	1.4^{c}	1.4^{c}	14.89	<0.001

Table 5.14 The effect of herbicide treatment on species richness (number of species per plot): Gleadthorpe & High Mowthorpe.

	Herbicide								
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***
Gleadthorpe									
2003	6.3^{a}	3.7^{b}	3.6^{b}	5.1^{a}	2.1^{c}	2.8^{bc}	1.4^{c}	12.67	<0.001
2004	5.5^{a}	2.3^{c}	1.3^{d}	3.8^{b}	0.7^{d}	1.1^{d}	1.2^{d}	29.14	<0.001
2005	4.1^{a}	2.7^{b}	0.6^{c}	3.7^{a}	0.3^{c}	0.8^{c}	0.5^{c}	35.34	<0.001
High Mowthorpe									
2003	9.8^{a}	5.8^{c}	5.0^{c}	7.9^{b}	4.1^{cd}	2.3^{e}	2.9^{de}	21.17	<0.001
2004	8.4^{a}	5.8^{b}	3.4^{c}	6.6^{b}	2.9^{c}	3.3^{c}	3.1^{c}	33.77	<0.001
2005	5.5^{a}	3.1^{bc}	3.5^{b}	5.0^{a}	2.3^{cd}	1.9^{d}	2.2^{cd}	16.92	<0.001

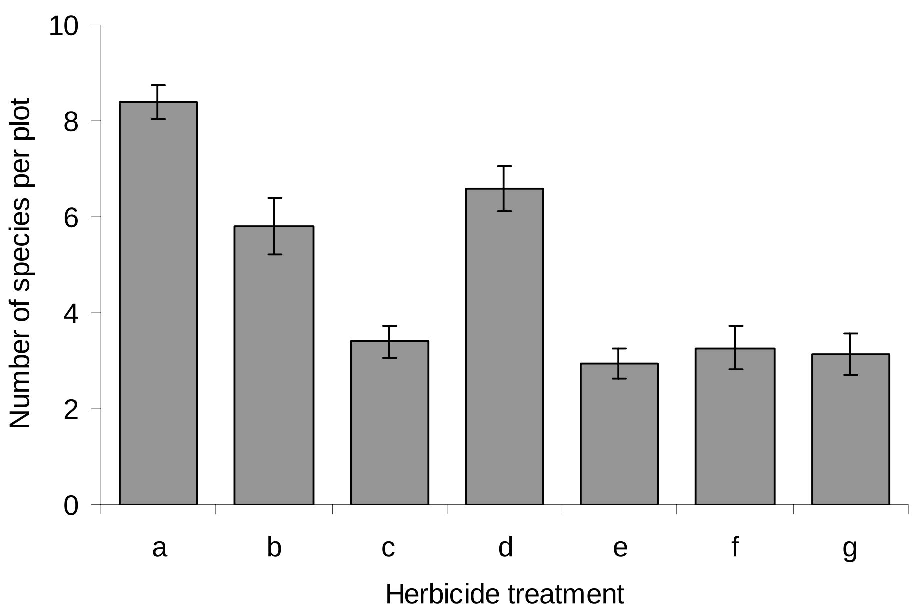

Figure 5.14 The effect of herbicide treatment on species richness (number of species per plot): High Mowthorpe, 2004.

At Boxworth in 2004, the pattern of species richness in response to herbicide treatment did not follow the same pattern as overall weed ground cover (Figure 5.15). This reflects the fact that, although overall ground cover could be high, different species were controlled by each herbicide (Figure 5.9). It is also possible that the small number of species which were present at very high densities outcompeted less abundant species and prevented any germination late in the season.

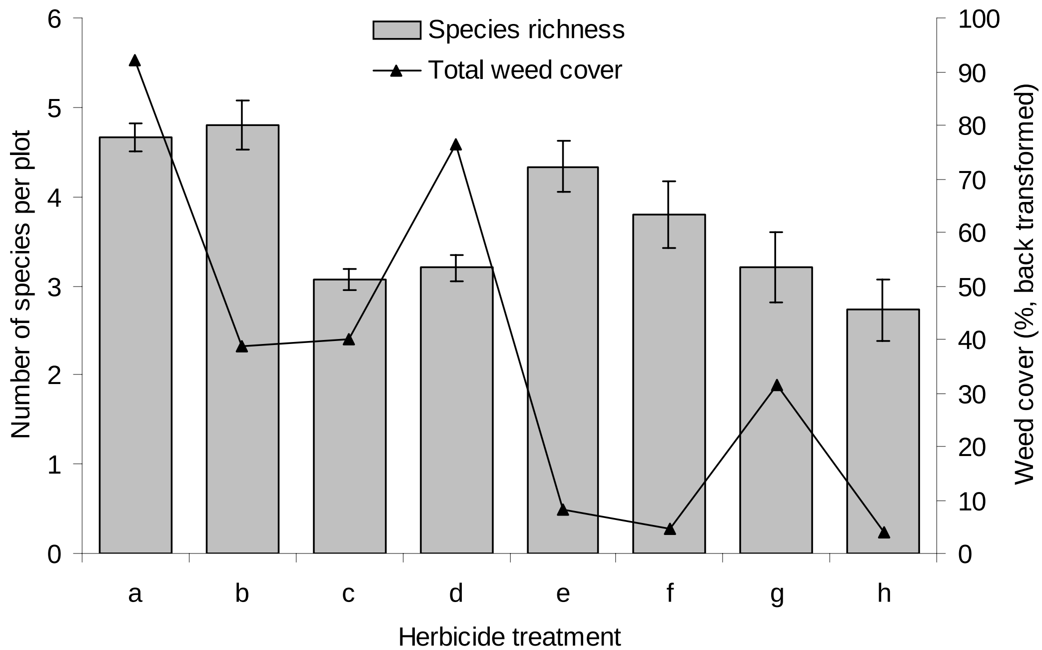

Figure 5.15 The effect of herbicide treatment on species richness: Boxworth, 2004.

<u>Reproductive status</u>

For each site/year, the reproductive status of all species recorded at a mean of >0.5%, or present in 50% of plots, was summarised by herbicide treatment by calculating a relative % for each growth stage (for full results see Appendix 3).

The impact of herbicide treatment on the reproductive status of the weed flora varied with species, although the high level of control under many treatments made it difficult to draw comparisons. At Boxworth in 2004, there were no differences in the reproductive status of *A. sterilis*, but this species was not well controlled by herbicide treatment (Figure 5.16).

However, in the same site/year, *S. media* was effectively controlled by some treatments (Figure 5.17). Where good control was achieved, the weeds that were present in June were at a much earlier growth stage than where control had been ineffective and were much less likely to set seed before harvest.

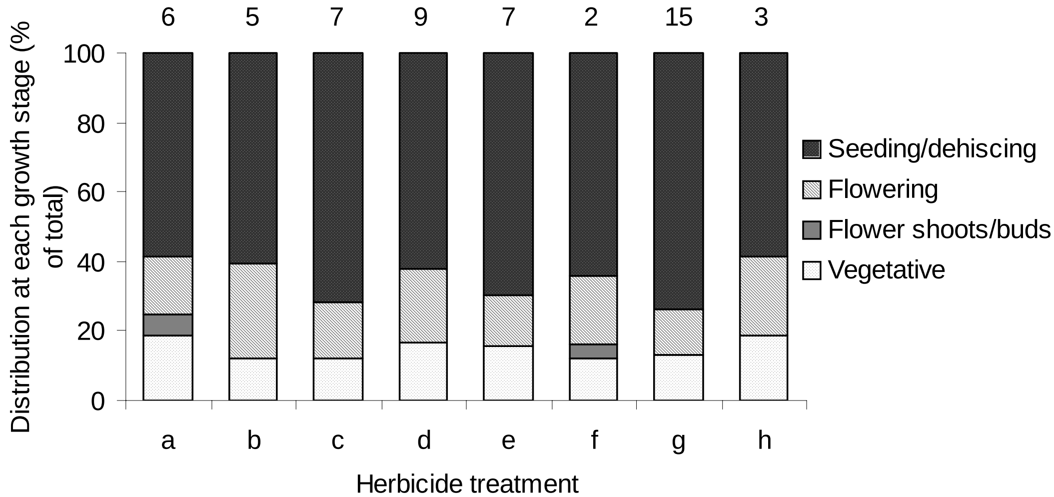

Figure 5.16 Reproductive status of *Anisantha sterilis* under different herbicide treatments (% cover scores above bars): Boxworth, 2004.

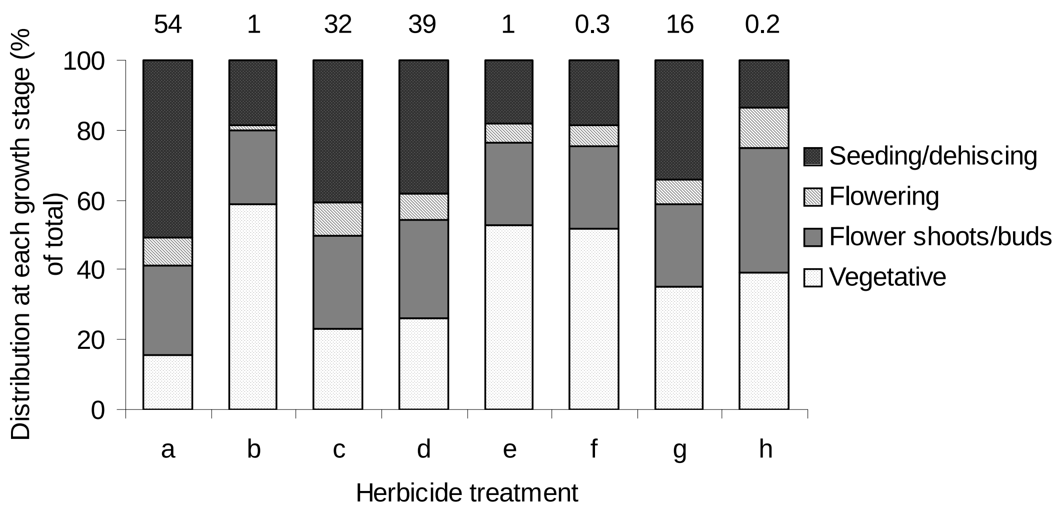

Figure 5.17 Reproductive status of *Stellaria media* under different herbicide treatments (% cover scores above bars): Boxworth, 2004.

At Gleadthorpe in all three years, most weeds were effectively controlled on all treatments other than untreated and amidosulfuron-only. Comparison of the reproductive status of *P. annua* under these treatments indicates that the spring application of amidosulfuron was generally not controlling this species and had no effect on the reproductive status, although there were marked differences between years (Figure 5.18).

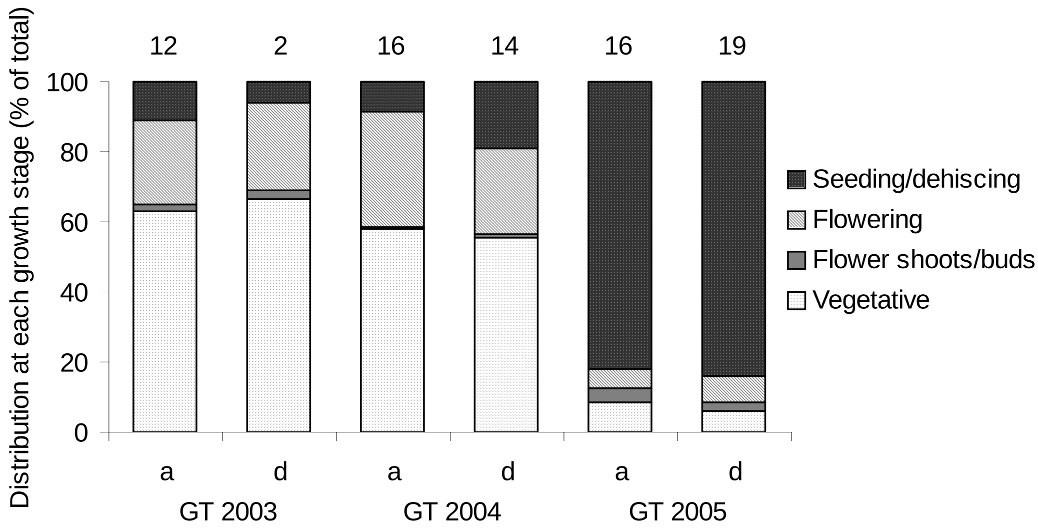

Figure 5.18 Reproductive status of *Poa annua* in untreated (a) and amidosulfuron only (d) treatments in each year. (% cover scores above bars): Gleadthorpe.

At High Mowthorpe, the reproductive status of *G. aparine* was less advanced with later herbicide applications (Figure 5.19). This species can germinate over a relatively long period through autumn and winter (Williams & Morrison, 2003). It is possible that populations remaining in June had germinated after the application of herbicides, and those plants that had received later treatment had less time to mature and set seed. Weed cover was low under many of the herbicide treatments, therefore differences may be influenced by the error associated with small populations. However, at Boxworth in 2005, a relatively advanced growth stage was associated with some very low ground covers of *G. aparine* (see Appendix 3).

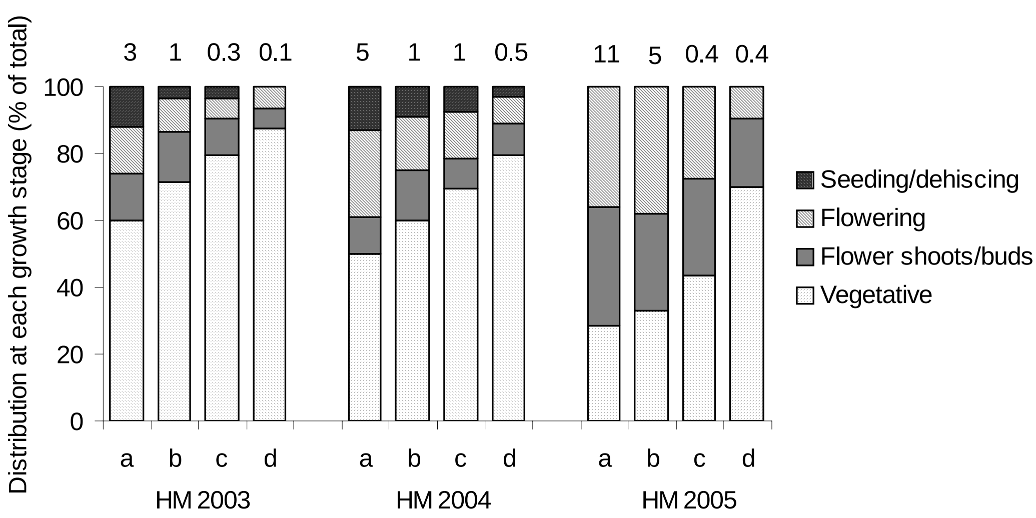

Figure 5.19 Reproductive status of *Galium aparine* in selected treatments, across all years. (% cover scores above bars): High Mowthorpe.

Seed Production

Seed production was measured only on a subset of herbicide treatments, and under conventional row spacing. Both viable and total seeds were assessed. Immature seed may have become viable by the time of harvest and irrespective of viability could still constitute a food source for higher trophic groups. However, seeds assessed as viable are more likely to contribute to farmland biodiversity as a food source or through presence in following crops. Results were generally similar for viable and total seeds, therefore only data for viable seeds are presented here, with those for total seed numbers presented in Appendix 3.

At Boxworth, sampling was restricted to untreated (a), pre-emergence only (b), spring only (d) and full control (h). Where there was an effect of herbicide treatment, differences in viable seed production were usually between the untreated and those that received herbicide (Table 5.15). In 2004, production of *S. arvensis* was higher on treatment b than on d or h, reflecting the higher weed ground cover values recorded in the pre-emergence only treatment (Figure 5.9). Similarly, in 2005, seed production of *G. aparine* was greater under treatment b than either treatment d or h. Weed cover was significantly higher in treatment b than in other treatments where herbicide had been applied, however there were also significant differences between treatment b and the untreated control which did not result in differences in seed production.

Table 5.15 The effect of selected herbicide treatments on production of viable (V) seeds (number of seeds m^{-2}) (conventional spacing only; back transformed means): Boxworth.

	Herbicide					
	a	**b**	**d**	**h**	***F***	***P***
2003						
Group1V	116.5[a]	1.1[b]	0.3[b]	2.0[b]	5.16	0.042
Groups123V	615.6[a]	7.7[b]	5.2[b]	2.0[b]	6.67	0.024
2004						
*Sinapis arvensis*V	2817.4[a]	5010.9[a]	0.8[b]	1.5[b]	52.99	<0.001
*Veronica hederifolia*V	105.2[a]	0.0[b]	199.4[a]	0.0[b]	172.35	<0.001
2005						
Group1V	99.0[a]	3.0[b]	1.7[b]	0.4[b]	10.04	0.001
Groups123V	101.3[a]	3.0[b]	1.7[b]	0.4[b]	10.16	0.001
*Galium aparine*V	74.9[a]	52.7[a]	1.1[b]	1.2[b]	9.27	0.002
*Sinapis arvensis*V	37.9[a]	1.3[b]	0.5[b]	0.0[b]	7.07	0.005

At Gleadthorpe and High Mowthorpe, the untreated (a), spring only (d) and post-emergence followed by mecoprop-p (g) were sampled. At Gleadthorpe, for those groups presented here where there was a significant effect of herbicide, seed production was higher on untreated plots compared to those that received herbicide in 2003. However, in the following two years seed production on untreated and spring only plots was higher than on treatment d (Table 5.16).

Table 5.16 The effect of selected herbicide treatments on production of viable (V) seeds (number of seeds m^{-2}) (conventional spacing only; back transformed means): Gleadthorpe.

	Herbicide				
	a	**d**	**g**	***F***	***P***
2003					
Groups123V	2186.8^{a}	228.1^{b}	10.7^{c}	26.14	0.005
*Poa annua*V	1070.5^{a}	4.0^{b}	0.0^{b}	11.35	0.022
*Fallopia convolvulus*V	82.9^{a}	6.7^{b}	0.0^{c}	35.82	0.003
2004					
Group1V	1411.5^{a}	228.1^{a}	2.7^{b}	21.59	0.007
Groups123V	1478.1^{a}	233.4^{a}	2.7^{b}	22.06	0.007
*Poa annua*V	1411.5^{a}	222.9^{a}	2.7^{b}	21.57	0.007
2005					
Group1V	449.8^{a}	802.5^{a}	0.4^{b}	176.08	<0.001
Groups123V	614.2^{a}	969.5^{a}	1.4^{b}	221.05	<0.001

At High Mowthorpe, results varied with year and the species grouping analysed (Table 5.17). Where there was a significant difference, seed production of undesirable species (Group4) was higher on untreated (a) than where herbicide was applied (d & g). Seed production of highly beneficial species (Group1) was higher on treatments a and d compared to g in 2003 and 2004. Generally, at High Mowthorpe seed production of undesirable species was controlled where herbicides were applied, but the spring-only application allowed beneficial species to produce seeds.

Table 5.17 The effect of selected herbicide treatments on production of viable (V) seeds (number of seeds m^{-2}) (conventional spacing only; back transformed means): High Mowthorpe.

	Herbicide				
	a	**d**	**g**	***F***	***P***
2003					
Group1V	3234.9^{a}	2569.4^{a}	6.6^{b}	26.07	0.005
*Poa annua*V	1777.3^{a}	2453.7^{a}	4.6^{b}	22.93	0.006
Agrostis sp.V	0.0^{a}	0.0^{a}	1046.1^{b}	24.7	0.006
2004					
Group1V	3466.4^{a}	2753.2^{a}	12.5^{b}	14.23	0.015
Group4V	1121.0^{a}	19.0^{b}	18.5^{b}	8.86	0.034
Groups123V	3629.8^{a}	2817.4^{a}	12.5^{b}	14.87	0.014
*Poa annua*V	3234.9^{a}	2753.2^{a}	4.2^{b}	22.43	0.007
*Galium aparine*V	1121.0^{a}	19.0^{b}	18.5^{b}	8.86	0.034
2005					
Group4V	1046.1^{a}	7.3^{b}	4.8^{b}	15.47	0.002
Groups123V	28905.8^{a}	7815.3^{b}	0.2^{c}	448.84	<0.001
Papaver spp.V	3387.4^{a}	37.9^{ab}	0.2^{b}	7.74	0.013
Poa spp.V	1478.1^{a}	3387.4^{a}	0.0^{b}	36.83	<0.001
*Galium aparine*V	1046.1^{a}	0.6^{b}	1.2^{b}	29.31	<0.001

Crop cover

There was a consistent effect of spacing/cultivation on crop cover across all sites and all years (*P* < 0.001 except at Boxworth in 2005 where *P* = 0.035). Crop cover was consistently greater under Conv compared to WSR (*P* < 0.001 except at Boxworth in 2005 and Gleadthorpe in 2003 where *P* = 0.042 and 0.007 respectively). Crop cover under WSR and WSR+Cult was not different except at Boxworth in 2004 (*P* = 0.021). The full analyses can be found in Appendix 3. Data for Boxworth 2003 are presented in Figure 5.20. Bare ground viewed from above the canopy was higher in WSR compared to Conv in all sites/years when it was measured, reflecting the lower crop cover under WSR (Appendix 3).

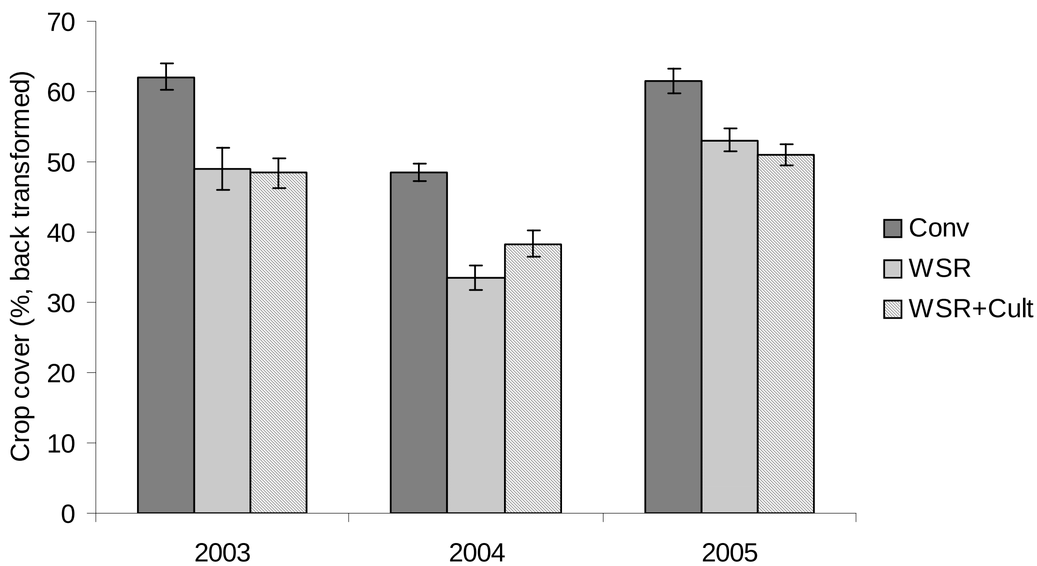

Figure 5.20 The effect of spacing/cultivation treatment on crop cover (mean of all herbicide treatments): Boxworth.

Herbicide treatment only affected crop cover on two occasions, in two out of the three site years with highest weed cover. At High Mowthorpe in 2005, crop cover on the untreated was lower than those treatments that had received herbicide application. At Boxworth in 2004, crop cover was lower on the untreated plots compared to all other treatments and was also lower under single applications applied either pre-emergence (b) or in spring (d) compared to other plots that received herbicide (Figure 5.21).

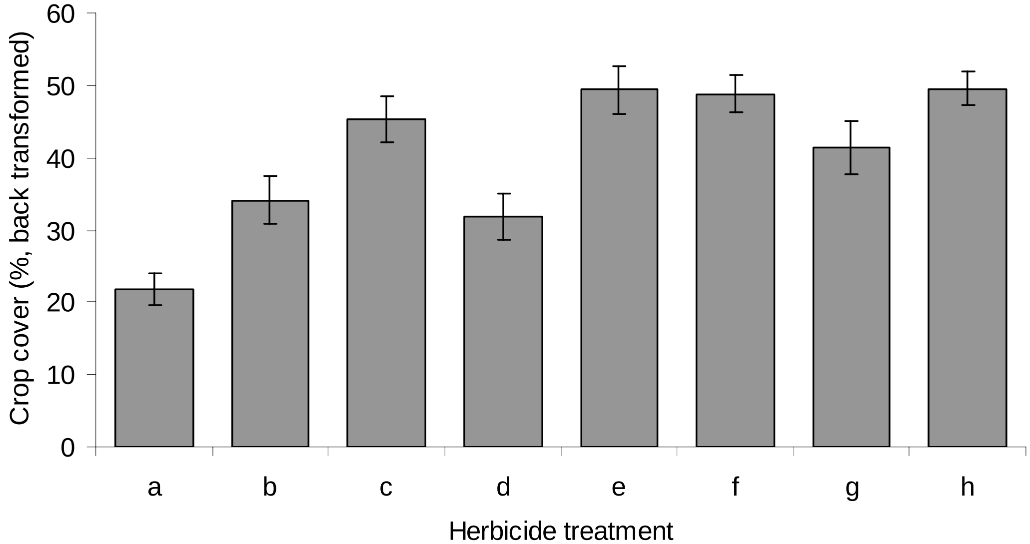

Figure 5.21 The effect of herbicide treatment on crop cover (mean of all row spacing/cultivations): Boxworth, 2004.

1.4.2.4 Impact of Weeds on Crop Cover and Yield

Regression analysis of weed cover, crop cover and yield indicated that relationships varied between sites and years (Table 5.18; conventional spacing only). At Boxworth there were highly significant relationships between all variates analysed in both 2004 and 2005, although crop cover accounted for a higher percentage of the variation in yield than weed cover. At Gleadthorpe there was a significant relationship between crop cover and yield in all three years and a significant effect of weed cover on yield in 2005, although this accounted for only a small proportion of the variation. At High Mowthorpe, all comparisons were significant in 2005, with weed cover accounting for 76% of the variability in yield. Generally, crop cover accounted for a greater proportion of the variation in yield than weed cover.

Table 5.18 Results of regression analysis of weed and crop % cover and yield (t ha^{-1}) (conventional spacing only).

	Weed/crop		Weed/yield		Crop/yield	
	P	**r^2**	***P***	**r^2**	***P***	**r^2**
Boxworth						
2004	<0.001	60.4	<0.001	68.6	<0.001	83.5
2005	<0.001	33.6	0.001	22.2	<0.001	39.7
Gleadthorpe						
2003	0.350		0.545		0.026	19.5
2004	0.644		0.484		<0.001	41.5
2005	0.056		0.027	12.1	<0.001	45.1
High Mowthorpe						
2003	0.500		0.758		0.246	
2004	0.436		0.748		0.274	
2005	0.002	23.1	<0.001	76.0	0.018	13.3

Weeds generally influenced yield in sites/years of greater weed cover (see Figure 5.5). However, high weed cover of certain species apparently had little effect on yield, presumably because they did not compete so effectively with the crop and thereby reduce crop cover. At Boxworth in 2004, relatively high cover of *S. media* did not influence crop yield (treatment c), whereas similar weed cover of volunteer beans and *S. arvensis* (treatment b) led to a significant yield reduction (Figure 5.22). Similarly, 20% cover of *P. annua* at High Mowthorpe in 2005, had no effect on yield (Figure 5.23 & Appendix 2).

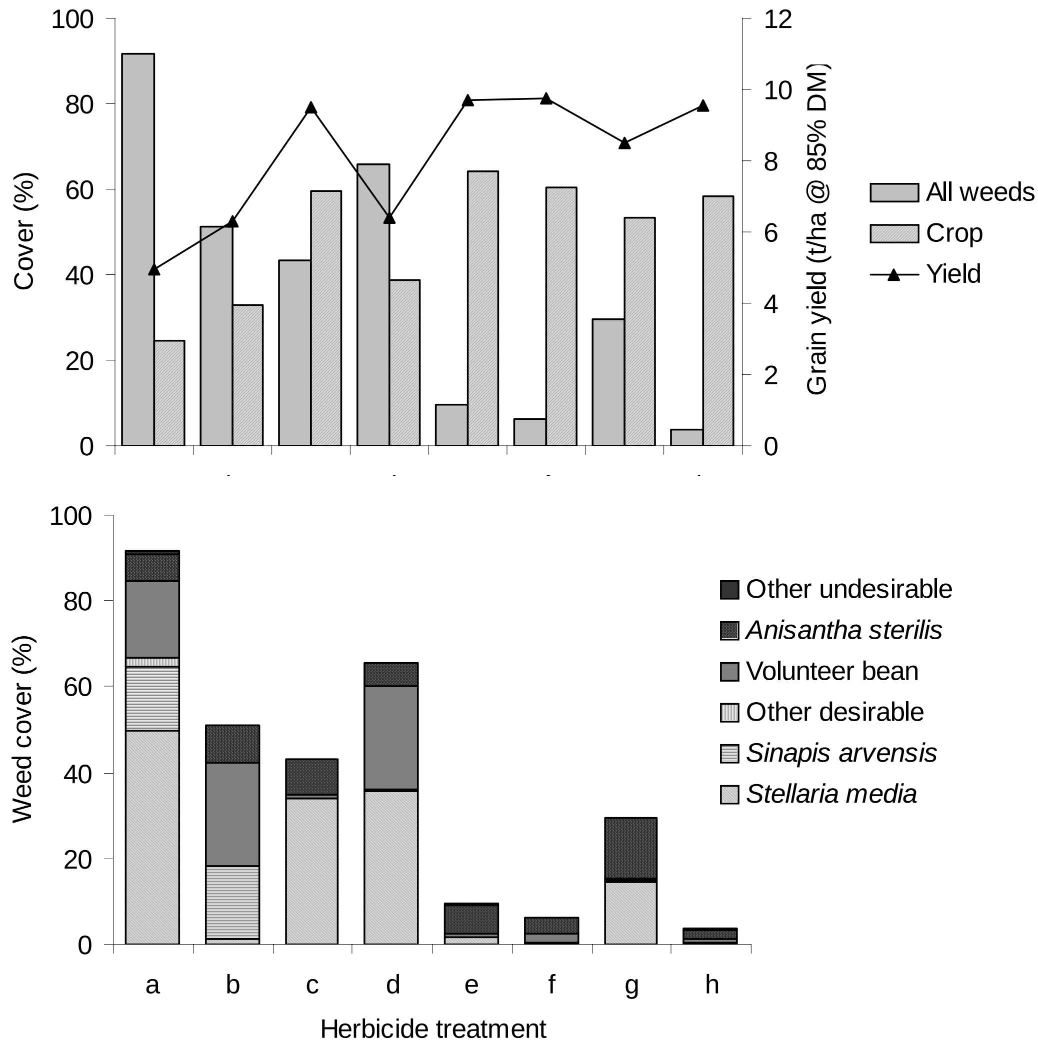

Figure 5.22 Crop and weed cover and crop yield (conventional spacing only): Boxworth, 2004.

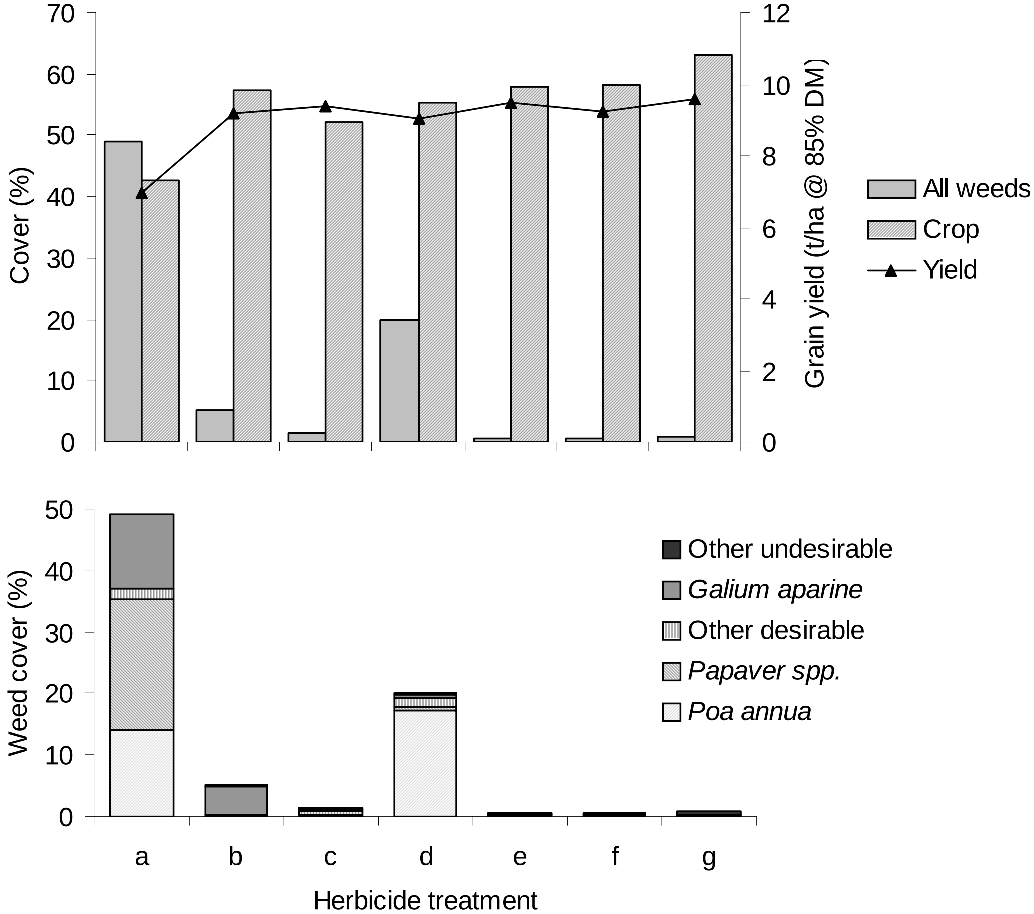

Figure 5.23 Crop and weed cover and yield (conventional spacing only): High Mowthorpe, 2005.

1.4.3 Arthropods

Arthropod abundance and community composition varied between both sites and years. In general the abundance of invertebrates was linked to weed cover; when weed cover was particularly low sampling was restricted to sites with visible weed cover. The sub-sample of treatments for arthropod collection is shown in Table 5.19.

Table 5.19 Arthropod sampling regime for each site and year.

		a	b	c	d	e	f	g	h	Conv	WSR	WSR+ Cult
2003	Boxworth	✓								✓		✓
	High Mowthorpe	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Gleadthorpe	✓		✓	✓	✓				✓	✓	✓
2004	Boxworth	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	High Mowthorpe	✓	✓	✓	✓					✓	✓	✓
	Gleadthorpe	Not sampled in this year										
2005	Boxworth	✓	✓	✓	✓					✓		
	High Mowthorpe	✓	✓	✓	✓					✓	✓	✓
	Gleadthorpe	✓	✓	✓	✓					✓	✓	✓

Abundance of arthropods was generally low; in most cases the majority of the catch was composed of omnivores, after which the predators formed the greatest part.. Herbivores and nectar feeders formed a small proportion of the catch. Figure 5.24, Figure 5.25 and Figure 5.26, show annual differences between crop active invertebrates sampled by suction sampler at the three experimental sites.

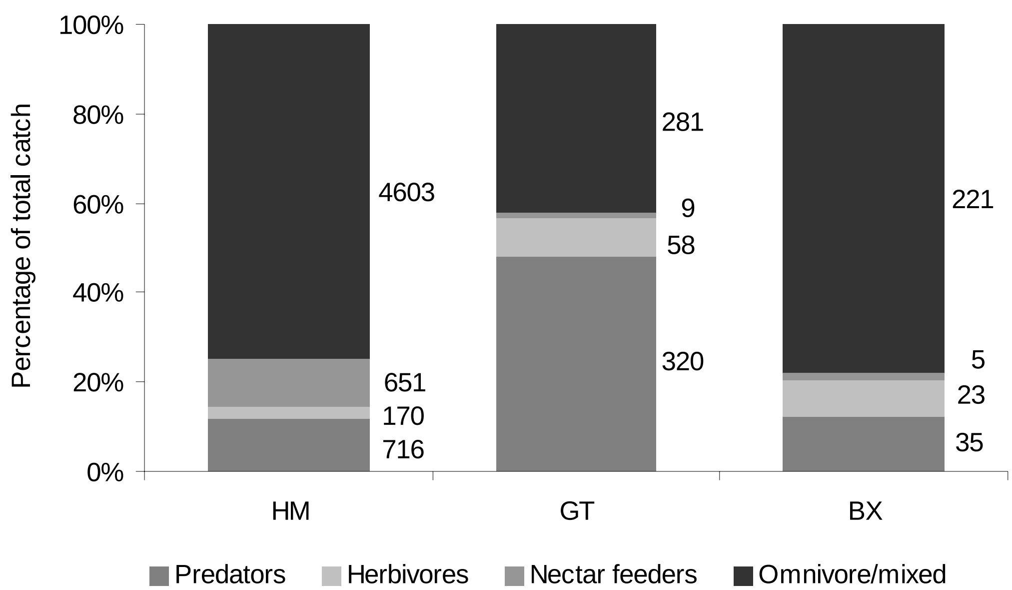

Figure 5.24 Total arthropod catch at each site 2003. Y axis represents proportion of catch; absolute abundance of each group is shown on the bars.

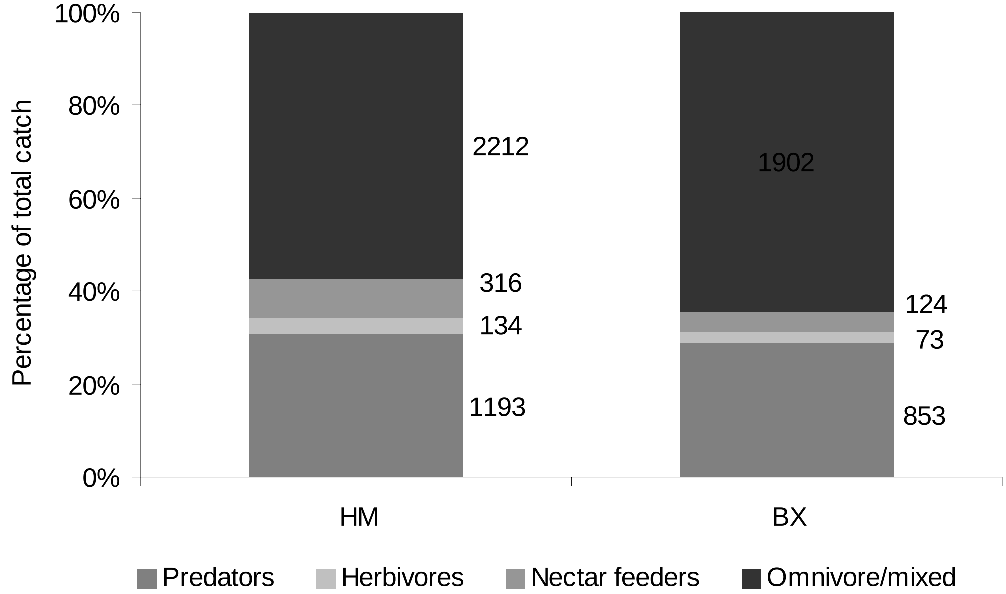

Figure 5.25 Total arthropod catch at each site 2004. Y axis represents proportion of catch; absolute abundance of each group is shown on the bars. (Gleadthorpe was not sampled in 2004)

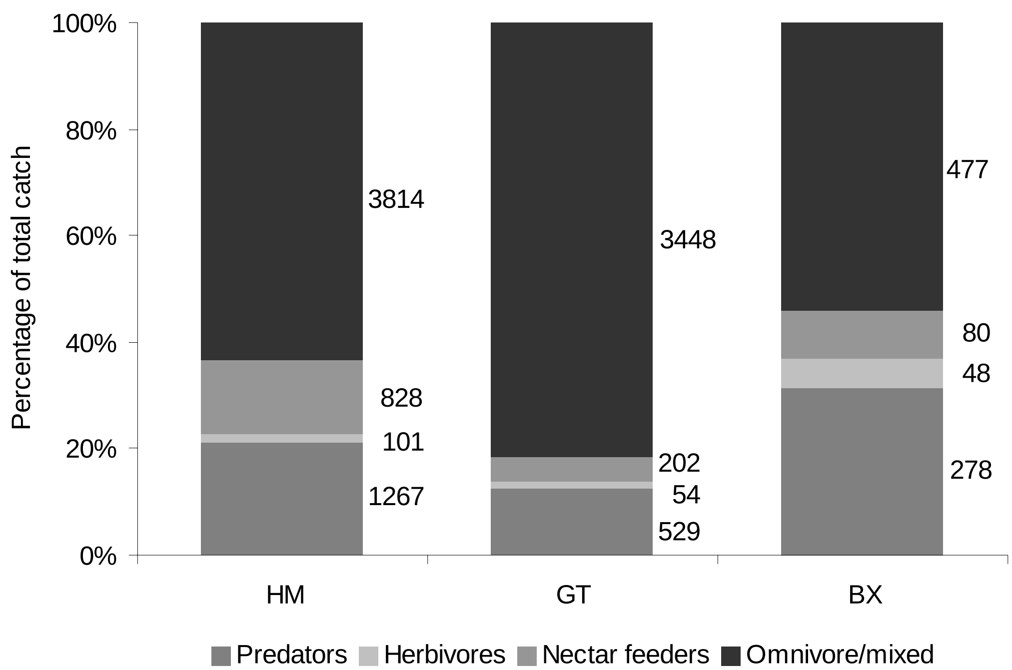

Figure 5.26 Total arthropod catch at each site 2005. Y axis represents proportion of catch; absolute abundance of each group is shown on the bars.

Of the arthropod groups analysed, twelve did not respond to either of the main treatments or the interaction between them. These included some groups of flies (Brachycera, Tipulidae and Calyptera), groups of beetles (Cantharidae, Carabidae and Staphylinidae), harvestmen, sawflies, bugs (Homoptera) and the composite group of ‘predatory arthropods’ as well as the Chick Food Index. Table 5.20 shows the 21 groups which responded to at least one of the experimental treatments at each site and in each year. Nematocera (not including Tipulids), Heteroptera, total Araneae and the composite group ‘skylark food items’ responded most frequently and so were the most sensitive to the effect of herbicide on vegetation and/or cultivation. Lepidoptera larvae, Neuroptera larvae and Chrysomelidae responded only once and in each case abundance of the group was low.

Table 5.20 Overall response of arthropod groups to experimental treatments at High Mowthorpe (HM), Gleadthorpe (GT) and Boxworth (BX).

	2003			2004		2005		
	HM	GT	BX	HM	BX	HM	GT	BX
Groups that responded								
Flies								
Aschiza	✓					✓		
Acalypterae	✓					✓		
Calyptera				✓			✓	
Nematocera (no Tipulidae)		✓		✓	✓	✓		✓
Diptera larvae				✓				
Total Diptera				✓	✓	✓		
Beetles								
Chrysomelidae			✓					
Curculionidae					✓			
Elateridae						✓		
Other coleoptera					✓			
Total coleoptera	✓				✓	✓		
Bugs								
Heteroptera	✓				✓	✓	✓	
Butterflies								
Lepidoptera adults	✓				✓			
Lepidoptera larvae							✓	
Neuroptera								
Neuroptera larvae							✓	
Spiders								
Total Araneae		✓	✓			✓	✓	
Functional groups								
Omnivores					✓	✓		
Herbivores					✓			
Nectar feeders	✓					✓		
Skylark food items				✓	✓	✓	✓	
Total arthropods					✓	✓	✓	

Groups that didn't respond	
Flies	**Sawflies**
Brachycera	Symphyta adults
Tipulidae	Symphyta larvae
Calyptera	**Harvestmen**
Beetles	Total Opiliones
Cantharidae	**Totals**
Carabidae	Total diptera
Staphylinidae	**Functional Groups**
True Bugs	Predators
Homoptera	Chick Food Index

1.4.3.1 Effect of WSR and Cultivation independent of herbicide application

There was little consistent independent effect of the WSR or cultivation treatments on arthropod abundance. Of those that were affected, flies and beetles were the most responsive orders (Appendix 4). Not all groups responded in the same way; a treatment which led to an increase in one group, could also lead to a decrease in another. For example, WSR increased the total abundance of Coleoptera at High Mowthorpe in 2003 with no effect of additional cultivation (Figure 5.27), however, cultivation did benefit Elateridae (click beetles) at the same site in 2005 (Figure 5.28). In contrast, 'other' beetles were reduced by cultivation at Boxworth in 2004 (Figure 5.29).

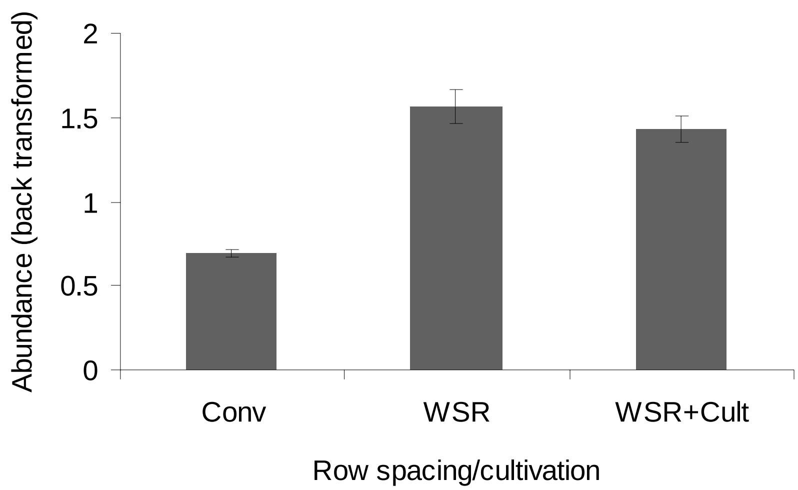

Figure 5.27 The effect of row width and cultivation on the mean abundance (per 0.5 m^2) of all Coleoptera: High Mowthorpe, 2003.

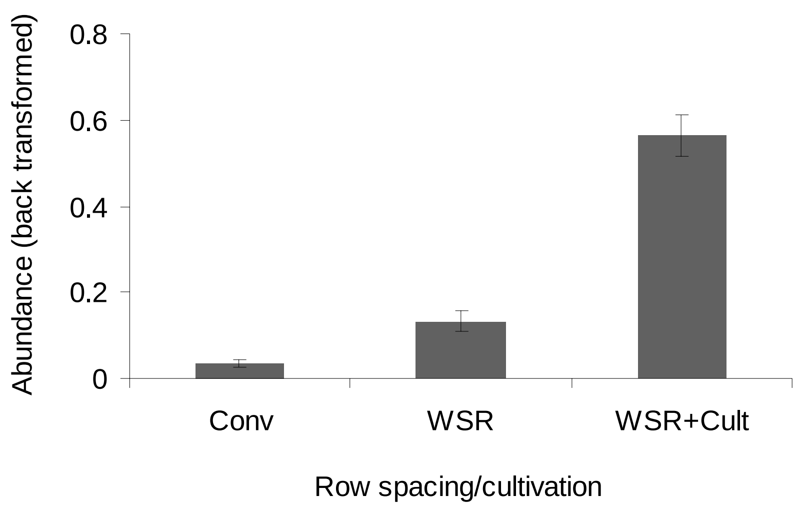

Figure 5.28 The effect of row width and cultivation on the mean abundance (per 0.5 m^2) of Elateridae (click beetles): High Mowthorpe, 2005.

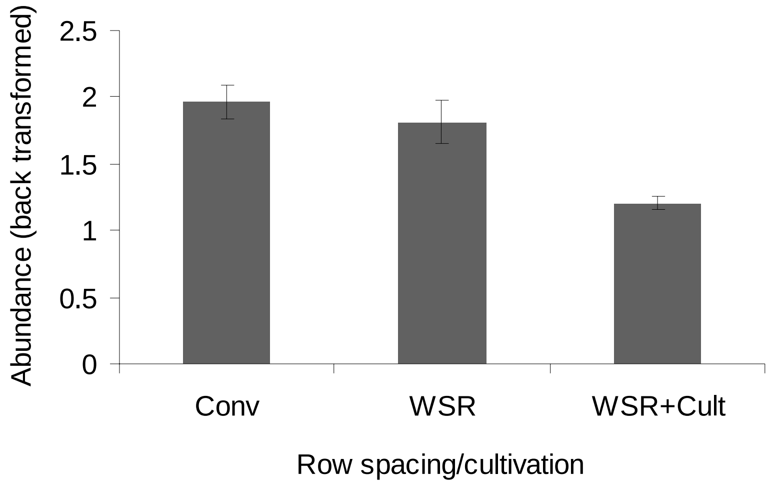

Figure 5.29 The effect of row width and cultivation on the mean abundance (per 0.5 m^2) of Coleoptera (others): Boxworth, 2004.

WSR led to a reduction in the abundance of Nematocera (not including Tipulids) at High Mowthorpe in 2004 (Figure 5.30) and although there was no effect of cultivation in 2004, in 2005 both Nematocera and Aschiza were reduced by WSR+Cult rather than WSR alone (Figure 5.31). Predatory species and Araneae were reduced by WSR in 2003 at Gleadthorpe (Figure 5.32). It is worth noting that the predator group was dominated by the abundance of predatory flies.

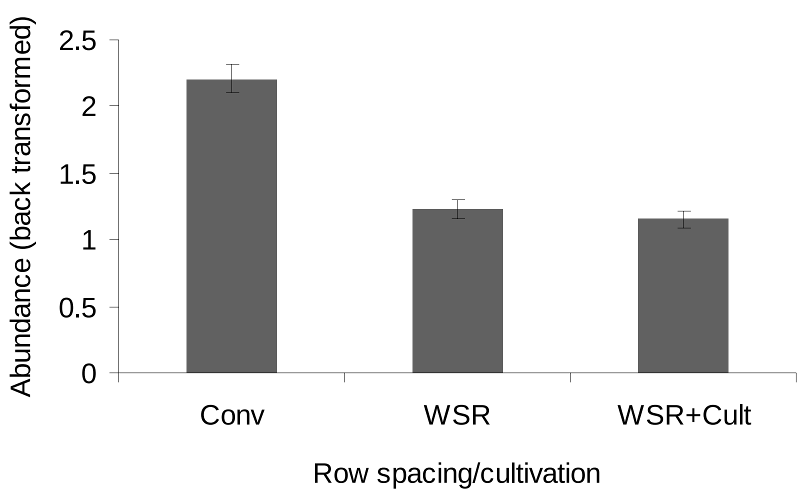

Figure 5.30 The effect of row width and cultivation on the mean abundance (per 0.5 m^2) of Nematocera (not including Tipulids): High Mowthorpe, 2004.

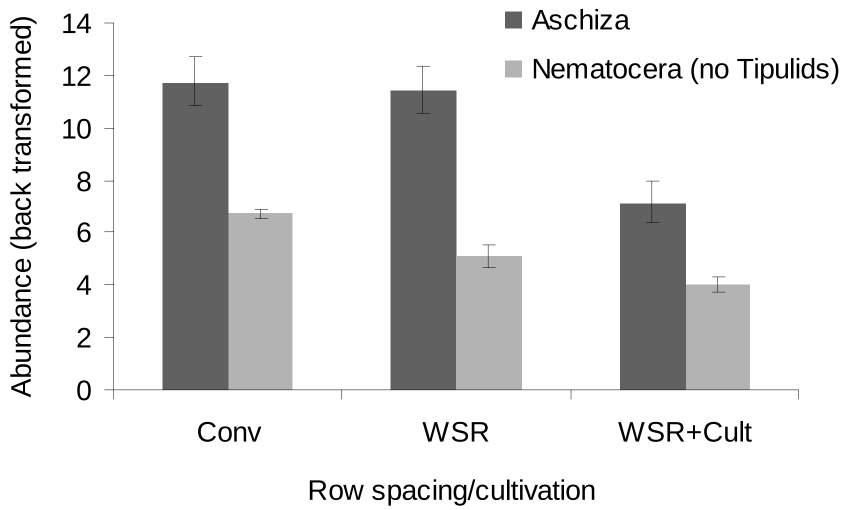

Figure 5.31 The effect of row width and cultivation on the mean abundance (per 0.5 m^2) of Aschiza and Nematocera: High Mowthorpe, 2005.

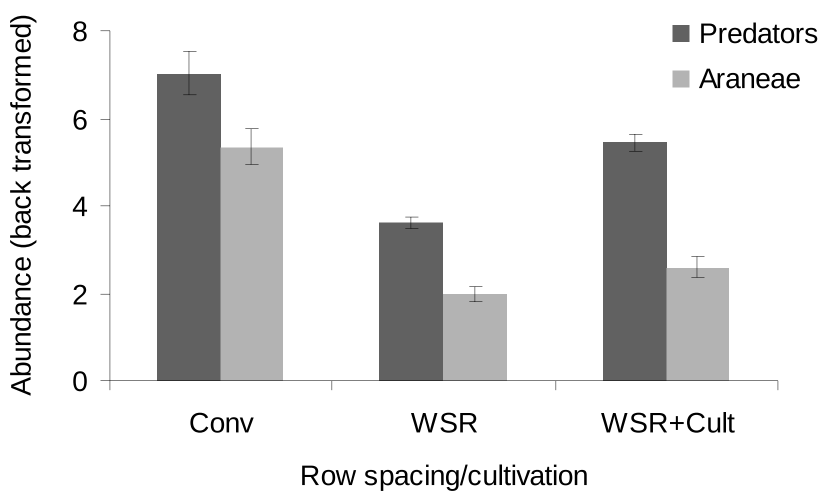

Figure 5.32 The effect of row width and cultivation on the mean abundance (per 0.5 m^2) of predators and Araneae (spiders): Gleadthorpe, 2003.

The only other group to respond was the Skylark food Item (SFI) group comprising those families which are known to be part of the Skylark diet. At Gleadthorpe in 2005, there was a greater abundance of SFI in WSR although cultivation had no additional effect (Figure 5.33).

In summary, flies were likely to be reduced by the WSR and cultivation treatments whilst beetles were more likely to increase in abundance. On one occasion, SFI was increased by WSR.

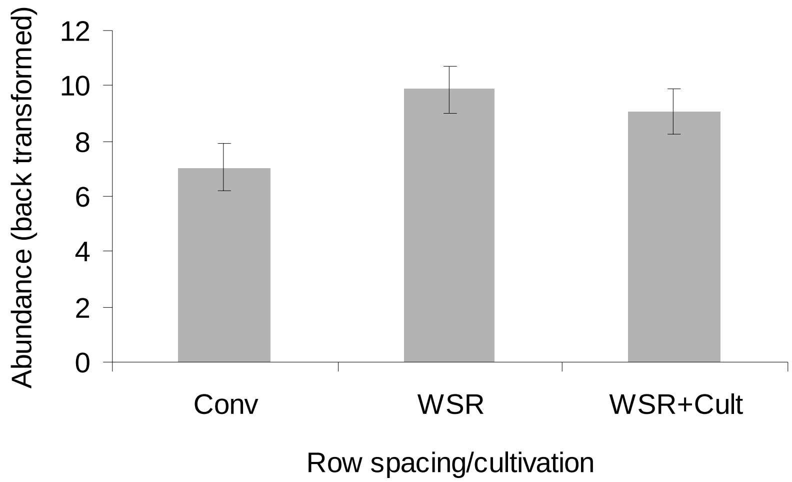

Figure 5.33 The effect of row width and cultivation on the mean abundance (per 0.5 m^2) of SFI: Gleadthorpe, 2005.

1.4.3.2 Herbicide application independent of row width and cultivation

The independent effect of herbicide varied across site and year. Full data are tabulated in Appendix 4. Each site is reported separately, by year.

Boxworth

2003
In 2003, sampling was restricted to untreated herbicide plots and those from conventional row width and WSR+Cult, therefore no results are presented.

2004
Samples were taken from all herbicide treatments and a number of arthropod groups responded to herbicide treatment independent of row width and cultivation; these are shown in Table 5.21. In all cases, except that of Nematocera (no Tipulids), the untreated control plots supported the greatest number of arthropods. Indirectly, any application of herbicide led to a reduction in arthropod abundance. There was some variation in the degree to which groups of invertebrates were affected by the different herbicide regimes. In general, there were fewer arthropods on plots treated with sequences of herbicides than where there were on plots treated with single applications, although a single application of post-emergence diflufenican + isoproturon also had a negative effect on arthropod abundance.

Table 5.21 The effect of herbicide on arthropod mean abundance (per 0.5 m^2, independent of row width and cultivation; back transformed). Multiple comparisons were carried out with Duncan's multiple range test (significant at 0.05). Boxworth 2004.

	Herbicides									
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***
Order/sub-order										
Curculionidae	0.7^{a}	0.6^{ac}	0^{b}	0.3^{c}	0.1^{b}	0^{b}	0.1^{b}	0.1^{b}	5.14	<0.001
Heteroptera	0.8^{a}	0.1^{b}	0.1^{b}	0.1^{b}	0.1^{b}	0^{b}	0.1^{b}	0.1^{b}	6.76	<0.001
Lepidoptera Adults	0.1^{ac}	0.2^{bc}	0^{a}	0.1^{ac}	0^{a}	0^{a}	0^{ac}	0^{ac}	2.12	0.050
Nematocera (no Tipulidae)	4.5^{ab}	5.4^{abe}	1.6^{cf}	3.4^{cd}	1.4^{ce}	0.9^{ef}	1.6^{c}	1.2^{ad}	7.15	<0.001
Other Coleoptera	5.6^{a}	3.0^{b}	1.2^{c}	2.9^{b}	1.1^{c}	0.6^{c}	0.5^{c}	1.0^{c}	10.61	<0.001
Total Coleoptera	10.0^{a}	7.7^{b}	4.2^{c}	7.4^{b}	4.1^{c}	3.5^{c}	3.2^{c}	4.8^{c}	7.60	<0.001
Total Diptera	49.6^{a}	23.4^{bc}	18.1^{cd}	28.4^{b}	17.7^{d}	14.6^{d}	18.6^{cd}	16.5^{cd}	11.27	<0.001
Composite **group**										
Herbivores	2.1^{a}	1.0^{b}	0.3^{cd}	1.0^{be}	0.7^{bcd}	0.1^{cd}	0.6^{bcd}	0.3^{bcd}	5.25	<0.001
Omnivore / Mixed	46.0^{a}	19.3^{c}	11.8^{b}	21.6^{c}	9.2^{b}	7.9^{b}	11.4^{b}	8.1^{b}	14.93	<0.001
Skylark Food Items	17.5^{a}	15.8^{ab}	9.9^{c}	15.4^{ab}	11.5^{bc}	9.5^{c}	8.8^{c}	11.0^{c}	5.66	<0.001
Total Invertebrates	64.0^{a}	35.8^{c}	23.7^{b}	38.7^{c}	24^{b}	19.8^{b}	23.6^{b}	23.3^{b}	13.74	<0.001

Figure 5.34 and Figure 5.35 demonstrate that although there may be some differences between particular arthropod groups, the general trend is similar. A single application of amidosulfuron in March (treatment d) was the least detrimental arthropod abundance, followed by a pre-emergence treatment of pendimethalin + flufenacet.

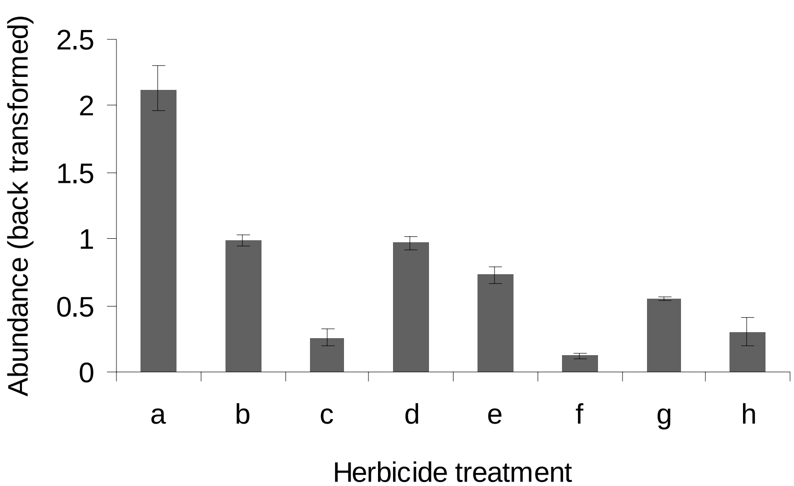

Figure 5.34 The effect of herbicide treatment on herbivores, mean abundance per 0.5 m^2: Boxworth, 2004.

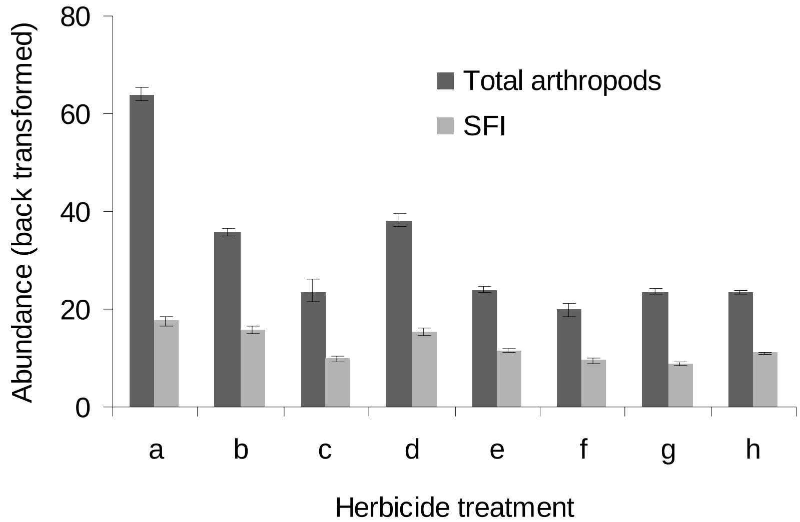

Figure 5.35 The effect of herbicide treatment on Skylark food items (SFI) and total Arthropods, mean abundance per 0.5 m^2: Boxworth, 2004.

2005

In 2005, sampling was limited to four herbicide treatments (a–d) in conventionally spaced rows. Two groups responded, of these Heteroptera only occurred in the untreated control plots. Nematocera (no Tipulids) were significantly fewer where there was a post-emergence application of pendimethalin + flufenacet (treatment c) (Figure 5.36).

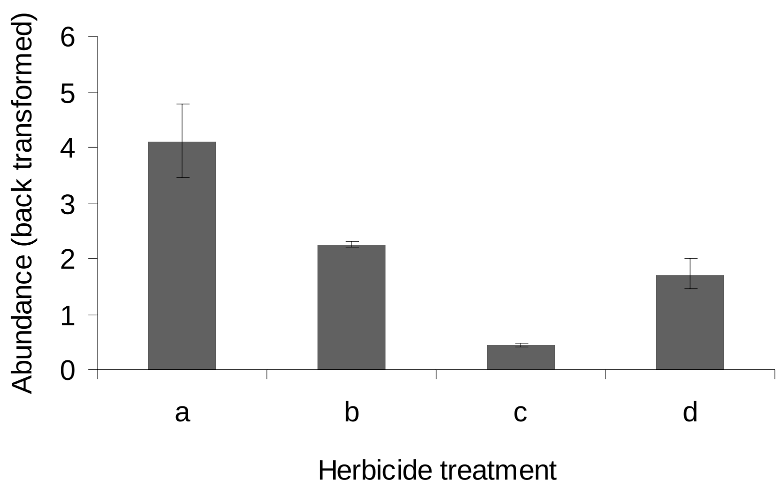

Figure 5.36 The effect of herbicide treatment on Nematocera (not including Tipulids), mean abundance per 0.5 m^2: Boxworth, 2005.

In summary, at Boxworth, arthropods were most abundant where herbicide was restricted to a single application, particularly in the case of a pre-emergence application of pendimethalin + flufenacet or a March application of amidosulfuron.

High Mowthorpe

2003

All treatments were sampled in 2003; three groups of arthropods were affected. Acalypterae (Figure 5.37) were least abundant when amidosulfuron was applied in March (treatment d), however the abundance of this group was also low in treatment b (a pre-emergence application of diflufenican + trifluralin) and treatment f (a post-emergence application of diflufenican + isoproturon with a March application of florasulam).

Aschiza, and a wider group of nectar feeders (Figure 5.38), were fewest in treatment g (post emergence diflufenican + isoproturon and a March application of mecoprop-p). Overall within the treated areas, arthropods were most abundant under Treatment c (a post emergence application of diflufenican + isoproturon).

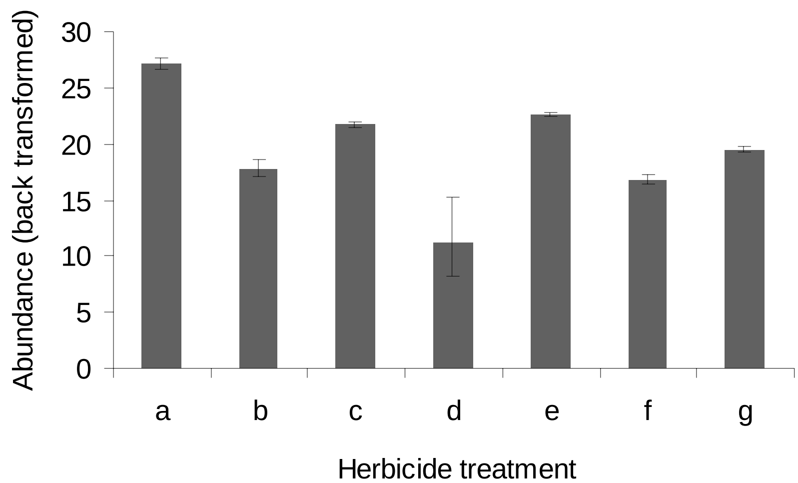

Figure 5.37 The effect of herbicide treatment on Acalypterae, mean abundance per 0.5 m^2: High Mowthorpe, 2003.

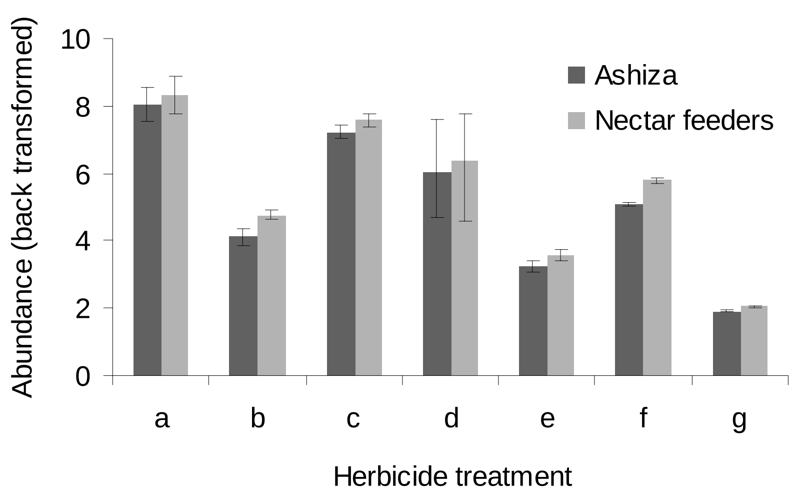

Figure 5.38 The effect of herbicide treatment on Aschiza and Nectar feeders, mean abundance per 0.5 m^2: High Mowthorpe, 2003.

2004
In 2004, sampling was restricted to treatments a to d, and for most arthropod groups there was no effect of treatment, except that the abundance of Skylark food items was least under treatment d (March application of amidosulfuron) (Figure 5.39).

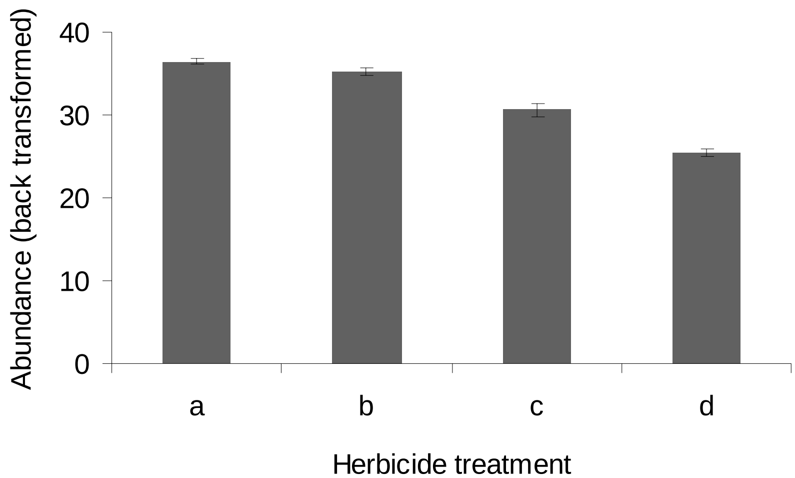

Figure 5.39 The effect of herbicide treatment on Skylark food items (SFI), mean abundance per 0.5m^2: High Mowthorpe, 2004.

2005
Sampling was restricted to treatments a to d; more arthropod groups responded in than in 2003 or 2004 (Table 5.22). Treatment d (a March application of amidosulfuron) was the least detrimental. The data for the composite groups followed similar trends (Figure 5.40 & Figure 5.41) and the arthropods with comprised these groups occurred in fewer numbers on plots treated withthe pre and post-emergence herbicides (treatments b and c respectively).

Table 5.22 The effect of herbicide on mean arthropod abundance (independent of row width and cultivation; back transformed means per 0.5 m^2). Multiple comparisons were carried out with Duncan's multiple range test (significant at 0.05): High Mowthorpe, 2005.

	Herbicides								
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***
Order/sub-order									
Acalypterae	39.6^{a}	25.4^{b}	31.4^{ab}	31.8^{ab}	-	-	-	3.93	0.010
Aschiza	16.4^{a}	7.2^{b}	6.4^{b}	12.2^{a}	-	-	-	7.36	<0.001
Nematocera					-	-	-		
(no Tipulidae)	7.6^{a}	4.6^{bc}	3.6^{bc}	5.5^{ac}				3.81	0.020
Total Diptera	91.9^{a}	58.4^{b}	65.5^{bc}	75.6^{ac}	-	-	-	5.14	0.004
Total Coleoptera	8.2^{a}	4.1^{bc}	3.2^{b}	6.6^{ac}	-	-	-	5.39	0.002
Heteroptera	0.2^{a}	0.2^{a}	0.1^{a}	1.2^{b}	-	-	-	9.80	<0.001

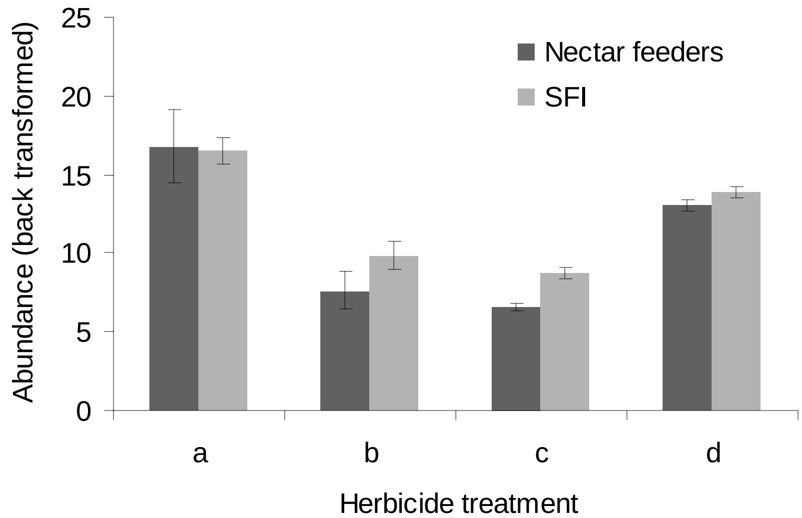

Figure 5.40 The effect of herbicide treatment on Nectar feeders and Skylark food items (SFI), mean per 0.5 m^2: High Mowthorpe, 2005.

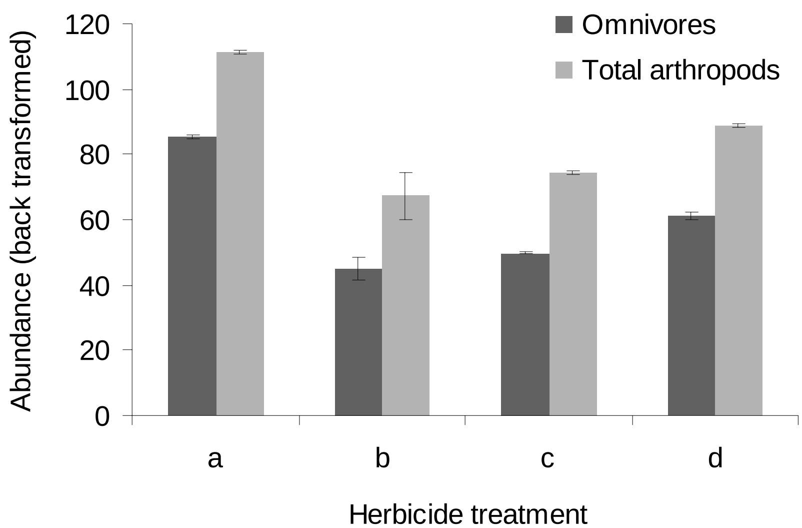

Figure 5.41 The effect of herbicide treatment on Omnivores and Total Arthropods, mean per 0.5 m^2: High Mowthorpe, 2005.

To summarise, at High Mowthorpe there was between-year variation in the arthropod groups that responded to herbicide treatment, and variation in the direction of that effect. In 2004, there were negligible differences between the herbicide treatments. The abundance of flies, Acalypterae and Aschiza, and Nectar feeders differed between the herbicide treatments in both 2003 and 2005. However, in 2003 arthropod abundance was lowest in treatment d, whereas in 2005 it was lowest in treatments b and c. In 2005, this trend was evident across all groups; there was no significant difference between treatment d (a March application of amidosulfuron) and the untreated control.

Gleadthorpe

Gleadthorpe was not sampled in 2004 and sampling was restricted in both 2003 and 2005.

2003
In 2003, sampling was restricted to treatments a, c, d and e, and only one group responded to herbicide application. The abundance of Nematocera (excluding Tipulids) was lowest in treatments d (March application of amidosulfuron) and e (post-emergence application of diflufenican + isoproturon + spring application of amidosulfuron (Figure 5.42).

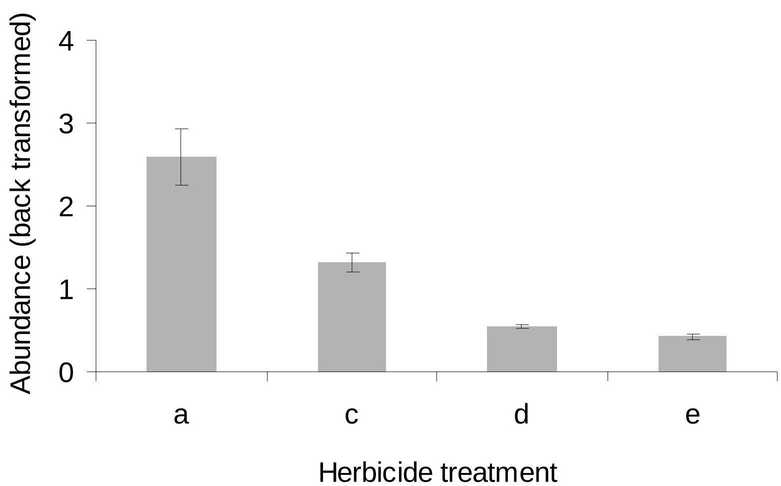

Figure 5.42 The effect of herbicide treatment on Nematocera (excluding Tipulids): Gleadthorpe, 2003.

2005
Treatments a to d were sampled in 2005, and two arthropod groups were affected; Heteroptera and SFI. The abundance of both groups was significantly reduced by treatment c (post-emergence diflufenican + isoproturon) while treatments b (pre-emergence diflufenican + trifluralin) and d (March application of amidosulfuron) had no effect (Figure 5.43).

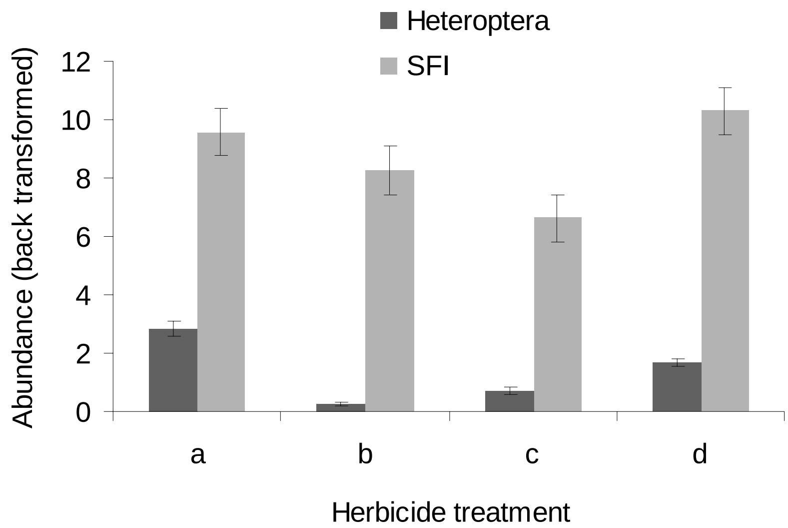

Figure 5.43 The effect of herbicide treatment on Heteroptera and Skylark food items (SFI): Gleadthorpe, 2005.

Overall there were few effects of herbicide treatment at Gleadthorpe and results were inconsistent between years. In 2003 a post-emergence application of diflufenican + isoproturon (treatment c) was not detrimental to Nematocera, however, in 2005 this same treatment had a negative impact on the abundance of Heteroptera and SFI.

1.4.3.3 Interaction between Cultivation and Herbicide application

In some cases there was an interaction between the effects of cultivation and herbicide on arthropod abundance (Table 5.23). There was little consistency in the response of groups to interactions, although Araneae responded at each site once, however, the year in which the group responded varied between sites and there was no consistent trend. The highest number of groups to be affected by an interaction between treatments at any one site was four (Gleadthorpe 2003) out of a possible 33 groups and consequently the effect of interactions can be considered negligible for the majority of arthropod groups. Full analyses are shown in Appendix 4.

Table 5.23 Summary of arthropod groups affected by an interaction between cultivation and herbicide.

Site	Group	*F*	*P*
Boxworth 2004	Araneae	1.89	0.043
	Chrysomelidae	4.19	<0.001
High Mowthorpe 2003	Heteroptera	3.63	0.001
	Lepidoptera Adults	2.74	0.008
High Mowthorpe 2004	Calyptera	4.14	0.002
	Diptera Larvae	15.99	<0.001
	Total Diptera	2.29	0.052
High Mowthorpe 2005	Araneae	2.36	0.046
Gleadthorpe 2003	Acalyptera	2.70	0.041
	Staphylinidae	2.31	0.050
	Other Coleoptera	6.83	<0.001
	Total Coleoptera	3.55	0.013
Gleadthorpe 2005	Araneae	3.25	0.019
	Calyptera	2.90	0.018
	Lepidoptera Larvae	4.17	0.002
	Neuroptera Larvae	3.71	0.005

1.4.4 Trophic linkages: Vegetation – Arthropod

Regression analyses showed that total weed cover was related to arthropod abundance at Boxworth in 2004 and High Mowthorpe in 2005; the strongest association was at High Mowthorpe (Table 5.24).

Table 5.24 Significant relationships between weed cover and arthropod abundance as determined using linear regression.

	% variation explained by weed cover	*F*	*P*
Boxworth 2004	7.8	7.98	0.006
High Mowthorpe 2005	25.8	21.54	<0.001

1.4.4.1 Community composition

In order to compare the effect of treatment on the species assemblage of both the weed and arthropod communities, the data was analysed using a two-way crossed ANOSIM (see section 5.3.3). ANOSIM calculates the test statistic R which is a comparative measure of the degree of separation (i.e. difference in species assemblage) between groups (in this case, treatments). When comparing the treatments at a particular site, the Global R statistic indicates whether there are some significant differences between each possible pair of treatments. An R statistic is also generated for each pair-wise comparison between treatments so that it becomes clear where the differences lie. R usually lies between 0 and 1; 0 = no difference between groups; 1 = complete dissimilarity. Occasionally, when R is low, although R is statistically significant, it may be considered biologically insignificant as in reality, there is very little difference between the groups. Table 5.25 shows that the species assemblage of the weed community differed between herbicide regimes at all sites but that cultivation had no effect. In contrast, the arthropod community responded to both herbicide and cultivation at the majority of sites, with the exception of High Mowthorpe in 2003 and in 2005. However, Global R was low in several cases, so that although the difference between treatments was significant, it was of minimal consequence biologically.

Table 5.25 ANOSIM results for weeds and arthropods.

		Weeds		Arthropods	
		Global R	***P***	**Global R**	***P***
Boxworth 2004	Cultivation	0.009	0.397	0.940	0.013
	Herbicide regime	0.386	0.001	0.200	0.001
High Mowthorpe 2003	Cultivation	0.069	0.823	0.053	0.190
	Herbicide regime	0.279	0.010	0.136	0.050
High Mowthorpe 2004	Cultivation	0.020	0.312	0.082	0.031
	Herbicide regime	0.491	0.001	0.076	0.036
High Mowthorpe 2005	Cultivation	0.017	0.337	-0.003	0.498
	Herbicide regime	0.447	0.001	0.152	0.001
Gleadthorpe 2003	Cultivation	0.022	0.398	0.265	0.010
	Herbicide regime	0.368	0.001	0.222	0.009
Gleadthorpe 2005	Cultivation	-0.050	0.883	0.690	0.049
	Herbicide regime	0.318	0.100	0.660	0.051

Pair-wise comparisons indicated differences between individual treatments; the strength of the dissimilarity is indicated by the R value. Significant comparisons are shown in the tables below and in Appendix 5.

Row width and Cultivation

The effect of cultivation on community composition was restricted to arthropods. Table 5.26 shows the significant pair-wise comparisons. At Gleadthorpe and Boxworth there were significant differences between WSR+Cult and both conventional crop spacing and WSR. At High Mowthorpe in 2004 the differences lay between the conventional row spacing and both WSR and WSR+Cult.

Table 5.26 Significant differences in arthropod community composition between row-spacing and cultivation treatments.

	Row space / cultivation	**R**	***P***
Gleadthorpe 2003	Conv, WSR+Cult	0.384	0.015
	WSR, WSR+Cult	0.301	0.039
Gleadthorpe 2004	Conv, WSR+Cult	0.115	0.026
	WSR, WSR+Cult	0.092	0.059
Boxworth 2004	Conv, WSR+Cult	0.118	0.032
	WSR, WSR+Cult	0.177	0.003
High Mowthorpe 2004	Conv, WSR	0.164	0.021
	Conv, WSR+Cult	0.078	0.09

The pair-wise dissimilarity between the groups was low; only at Gleadthorpe in 2003 was there a result approaching biological significance. The differences were accounted for by a proportional increase in some groups, 50% of this difference was accounted for by increased numbers of 'other Coleoptera', Heteroptera, and Brachycera in plots with additional cultivation (Table 5.27). Abundance of Araneae was highest in the conventional plots when compared with WSR but additional cultivation increased those numbers.

Table 5.27 Pair-wise differences in arthropod community composition between row spacing and cultivation treatments: Gleadthorpe, 2003.

	Average abundances			
	Conv	**WSR+Cult**	**Contrib%**	**Cum.%**
Coleoptera 'others'	0.00	1.29	13.49	13.49
Heteroptera	0.91	1.34	13.41	26.90
Araneae	5.31	2.55	13.03	39.94
Brachycera	1.51	2.39	12.47	52.41
Homoptera	0.58	0.41	10.27	62.68
Nematocera	1.40	0.82	9.84	72.52
Acalypterae	0.82	0.62	9.10	81.62
Chrysomelidae	0.35	0.07	4.59	86.21
Staphylinidae	0.15	0.12	4.08	90.29
	WSR	**WSR+Cult**	**Contrib%**	**Cum.%**
Coleoptera 'others'	0.48	1.29	19.65	19.65
Araneae	1.95	2.55	13.27	32.92
Heteroptera	0.58	1.34	12.42	45.34
Brachycera	1.19	2.39	11.16	56.49
Nematocera	1.00	0.82	10.84	67.34
Homoptera	0.78	0.41	9.49	76.83
Acalypterae	0.66	0.62	7.30	84.13
Staphylinidae	0.20	0.12	3.56	87.69
Carabidae	0.12	0.10	3.28	90.97

1.4.4.2 Herbicide application

Results are reported by site and by year.

<u>Boxworth 2004</u>

Weed Community
There were many significant pair-wise comparisons of weed community composition at Boxworth 2004. Complete lists of significantly different pairs are detailed in Appendix 5, and Table 5.28 shows the significant pair-wise comparisons. Figure 5.44 shows the community composition of each treatment and from this it is apparent that treatments b, d, e and g supported very simple communities whereas treatments a (the control) and h supported a relatively complex weed spectrum. Despite

similarity in complexity, treatments a and h were very different in terms of community composition. The majority of the distinction between groups was accounted for by differences in the relative proportion of *P. annua, G. aparine, S. arvensis, Veronica persica, Fallopia convolvulus* and *Veronica hederifolia* (species breakdown of significant differences can be found in Appendix 5). *P. annua* dominated the community in treatments a and c; treatment b was significantly different from both a and c and was more similar to the sequence regimes.

Table 5.28 Pair-wise comparisons of weed community composition between herbicide treatments: Boxworth, 2004.

Herbicide	**R Statistic**	***P***
a, b	0.734	0.001
a, c	0.378	0.001
a, d	0.469	0.001
a, e	0.680	0.001
a, f	0.347	0.001
a, h	0.861	0.001
b, c	0.705	0.001
b, f	0.510	0.001
b, h	0.227	0.021
c, d	0.378	0.001
c, e	0.602	0.001
c, f	0.503	0.001
c, h	0.806	0.001
d, f	0.253	0.004
e, f	0.348	0.004
f, h	0.455	0.001
a, d	0.284	0.016

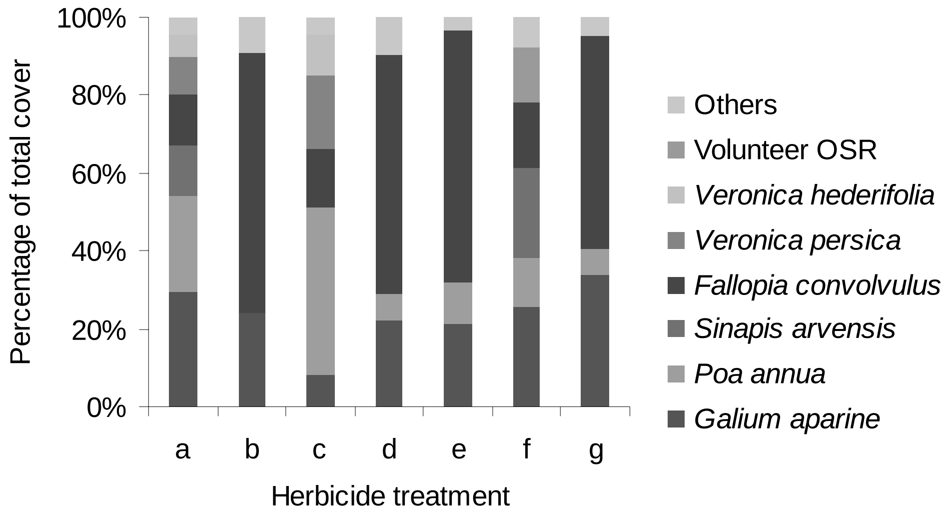

Figure 5.44 Species composition of the weed community sampled in each herbicide treatment: Boxworth, 2004.

Arthropod community

There were also many pair-wise differences in arthropod community composition associated with herbicides, however, it is apparent from Table 5.29 and Figure 5.45 that there was less differentiation than in the weed community (see R values in Table 5.29) and most of the dissimilarity was between treatments a (the control) and other treatments, especially the sequence regimes. The least significant differences were between treatments a & d and d & h. Differences in the relative abundance of Diptera (Acalypterae, Tipulidae, Cantharidae, Aschiza, Nematocera (no Tipulids), Brachycera), Coleoptera (others) and Heteroptera accounted for the distinction between herbicides. Notably, the control plots supported a relatively high abundance of Acalyptera; full pair-wise comparisons of significant differences are shown in Appendix 5.

Table 5.29 Pair-wise comparisons of arthropod community composition between herbicide treatments: Boxworth, 2004.

Herbicide	**R Statistic**	***P***
a, b	0.253	0.015
a, c	0.396	0.001
a, d	0.191	0.011
a, e	0.667	0.002
a, f	0.559	0.001
a, h	0.597	0.001
b, e	0.333	0.008
b, f	0.201	0.021
b, h	0.281	0.015
d, e	0.302	0.005
d, h	0.191	0.031
e, h	0.267	0.029

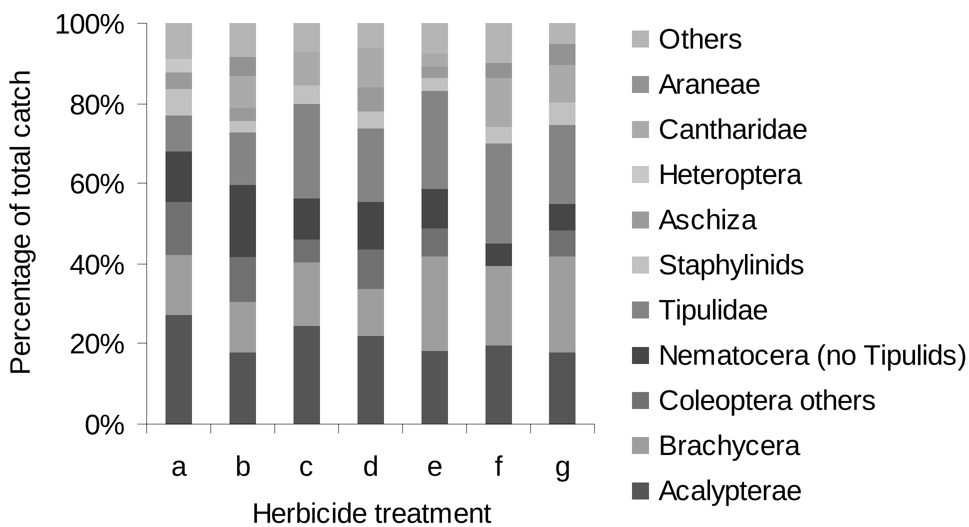

Figure 5.45 Species composition of the arthropod community sampled in each herbicide treatment: Boxworth, 2004.

RELATE was used to correlate the similarity matrices of weed and arthropod abundance; there was a significant correlation (Rho = 0.144; $P = 0.013$). The BEST routine was used to determine which components of the weed spectrum best explained the arthropod community composition i.e. which were the most influential species. The BEST correlation was 0.243, and the influential species were *F. convolvulus*, *Elytrigia repens* and volunteer OSR.

High Mowthorpe 2003

Weed community

The weed community species composition differed between a number of the treatments, particularly treatment a (the control) and the sequence regimes. Treatments a and d were not significantly different from each other but Table 5.30 shows that there was a difference between treatment d and b, c, e & g. Treatment g was dominated by *G. aparine* resulting in a very simple weed community. In all cases up 80% of the differences between herbicides were accounted for by changes in the relative abundance of the following species: *P. annua, Papaver* spp*., G. aparine* and *Fumaria officinalis.* Tables showing differences between each treatment are located in Appendix 5.

Table 5.30 Pair-wise comparisons of weed community composition between herbicide treatment: High Mowthorpe, 2003.

Herbicide	**R Statistic**	***P***
a, e	0.642	0.003
a, f	0.346	0.016
a, g	0.685	0.004
a, b	0.370	0.038
c, d	0.420	0.011
d, e	0.543	0.003
d, b	0.630	0.005
a, b	0.809	0.001

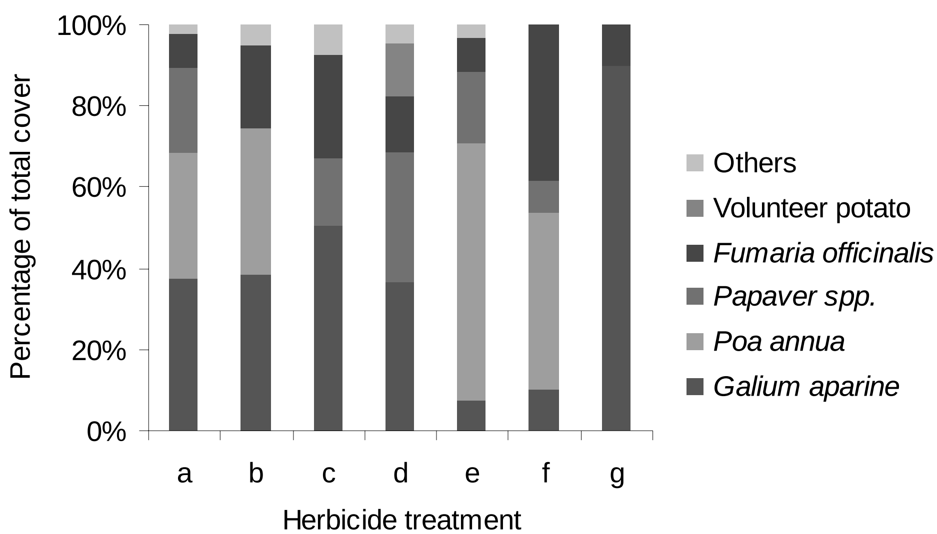

Figure 5.46 Species composition of the weed community sampled in each herbicide treatment: High Mowthorpe, 2003.

Arthropod community

There were fewer significant differences in arthropod community composition when compared with the weed community composition. Treatment a (the control) was distinguished from treatments b, c and g and treatment b was significantly different to g (Table 5.31). The pairwise difference between treatments a and g was the greatest when compared to the others.

The majority of the variation in arthropod community between herbicides was accounted for by the relative abundance of Diptera (Aschiza, Brachycera, Calyptera and Nematocera (not including Tipulids)), Araneae and Hemiptera (Figure 5.47). Full tables are in Appendix 5.

Table 5.31 Pair-wise comparisons of arthropod composition between herbicide treatments: High Mowthorpe, 2003.

Herbicide	**R Statistic**	***P***
a, c	0.333	0.029
a, g	0.667	0.001
a, b	0.481	0.005
g, b	0.605	0.003

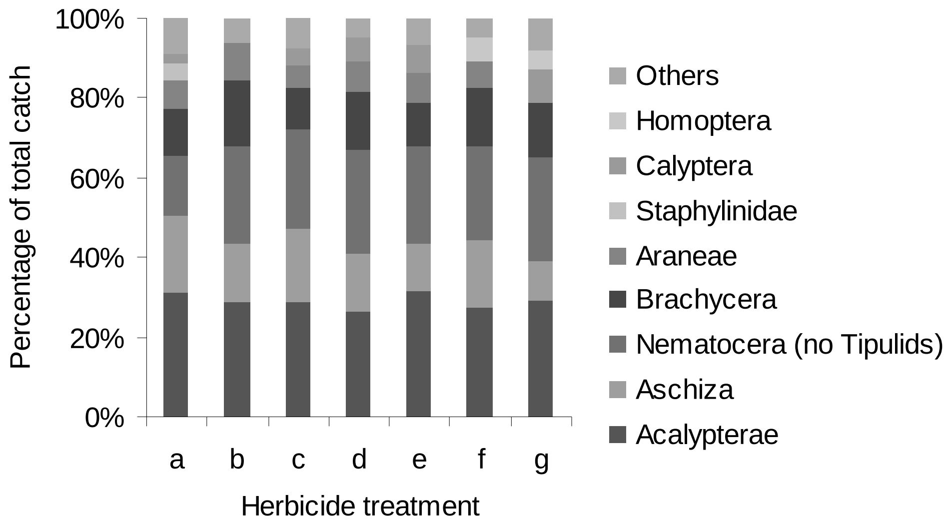

Figure 5.47 Species composition of the arthropod community sampled in each herbicide treatment: High Mowthorpe, 2003.

There was no correlation between the weed and arthropod community composition (Rho = -0.114; $P = 0.966$).

<u>High Mowthorpe 2004</u>

Weed community

There were pair-wise differences in weed community composition between most of the herbicides with the exception of the control (a) and treatment d (Table 5.32). The greatest difference was between treatments a and b followed by treatments b and c. The differences were accounted for by the relative abundances of *P. annua*, *F.*

convolvulus, *S. arvensis, G. aparine* and *E. repens*. Figure 5.48 shows that treatment b was dominated by *G. aparine*.

Table 5.32 Pair-wise comparisons of weed composition between herbicide treatments: High Mowthorpe, 2004.

Herbicide	**R Statistic**	***P***
a, b	0.845	0.001
a, c	0.143	0.028
b, c	0.671	0.001
b, d	0.427	0.001
c, d	0.318	0.001

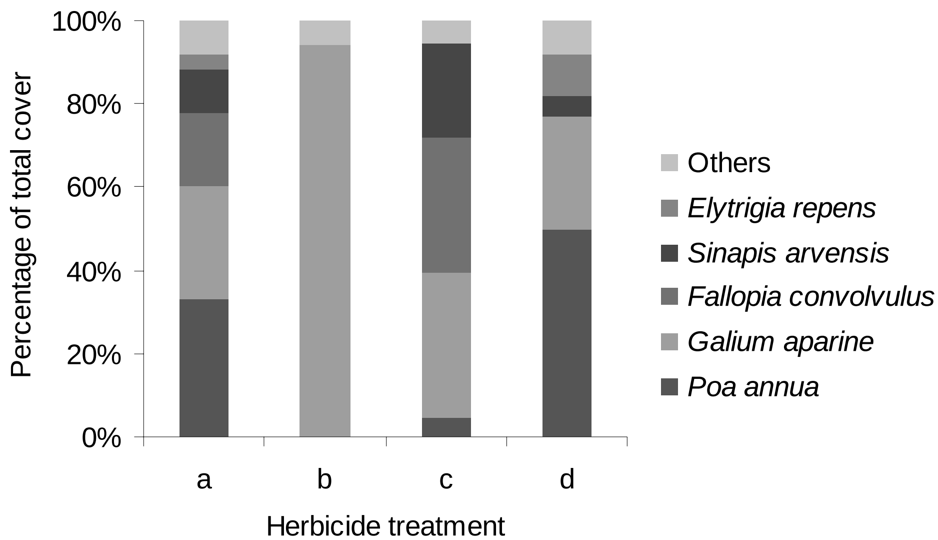

Figure 5.48 Species composition of the weed community sampled in each herbicide treatment: High Mowthorpe, 2004.

Arthropod community

In contrast, there were few significant pair-wise comparisons between arthropods sampled from each herbicide treatment when compared with the results of the weed community; only treatment b was distinguished from both the control (treatment a) and treatment d (Table 5.33). The R statistic is low in both cases and the species determining the differences detected were numerous and followed no consistent trend; this is illustrated in Figure 5.49 and in the full analyses are in Appendix 5.

Table 5.33 Pair-wise comparisons of arthropod composition between herbicide treatments: High Mowthorpe, 2004.

Herbicide	**R Statistic**	***P***
a, b	0.204	0.008
b, d	0.179	0.005

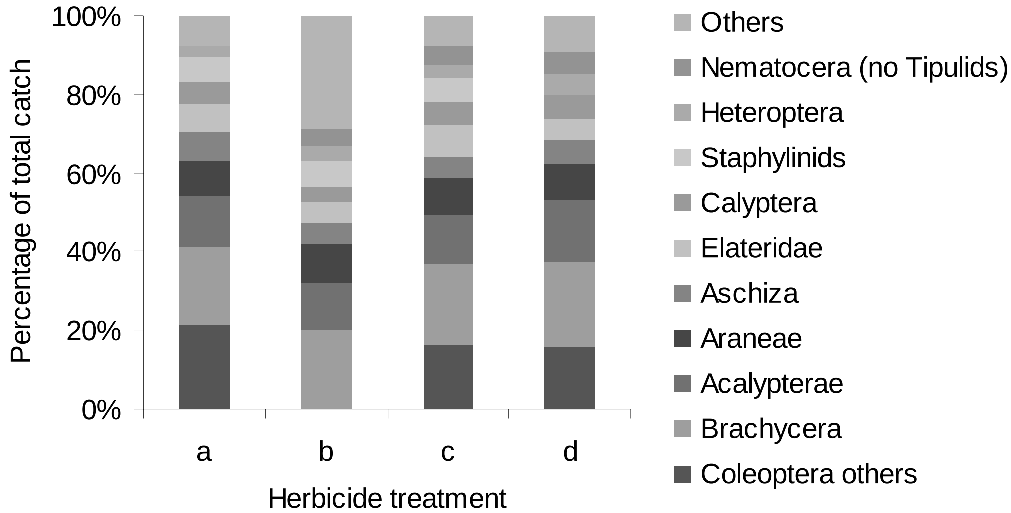

Figure 5.49 Species composition of the arthropod community sampled in each herbicide treatment: High Mowthorpe, 2004.

There was no correlation between the weed and invertebrate community composition (Rho = 0.028; P = 0.310).

<u>High Mowthorpe 2005</u>

Weed community
As demonstrated in other years and at other sites, treatment a, the control, was most likely to be distinguished from other groups, however, the greatest contrast at High Mowthorpe in2005 was that between treatments b and d (Table 5.34) where b was dominated by *G. aparine* and d was dominated by *P. annua* (Figure 5.50).

Table 5.34 Pair-wise comparisons of weed composition between herbicide treatments: High Mowthorpe, 2005.

Herbicide	**R Statistic**	***P***
a, c	0.544	0.001
a, d	0.364	0.001
a, b	0.589	0.001
c, d	0.461	0.001
d, b	0.663	0.001

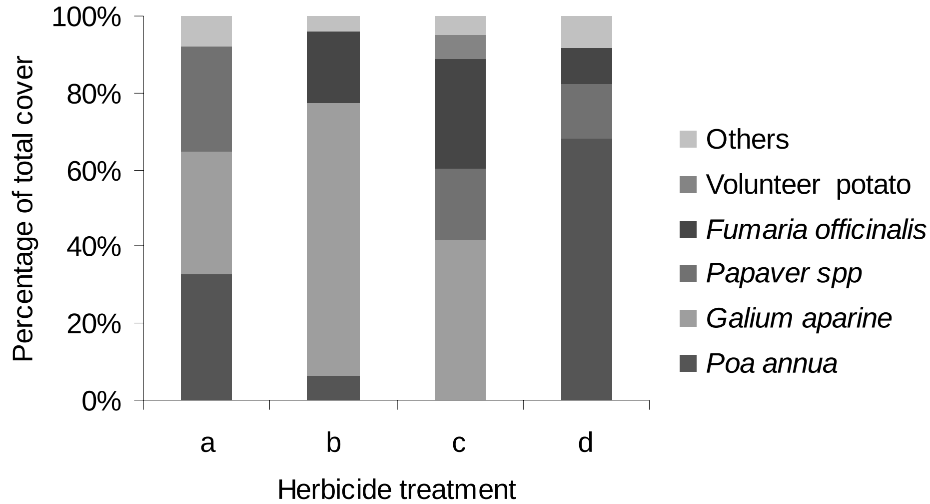

Figure 5.50 Species composition of the weed community sampled in each herbicide treatment: High Mowthorpe, 2005.

Arthropod community
As in 2004, the R statistic was low for most comparisons, only the difference between the control and treatment b approached biological significance (Table 5.35). This was due to the increased number of Diptera and 'other Coleoptera' that were recorded on the control plots (Figure 5.51, Appendix 4).

Table 5.35 Pair-wise comparisons of arthropod composition between herbicide treatments: High Mowthorpe, 2005.

Herbicide	**R Statistic**	***P***
a, c	0.177	0.021
a, d	0.151	0.015
a, b	0.303	0.001
d, b	0.199	0.017

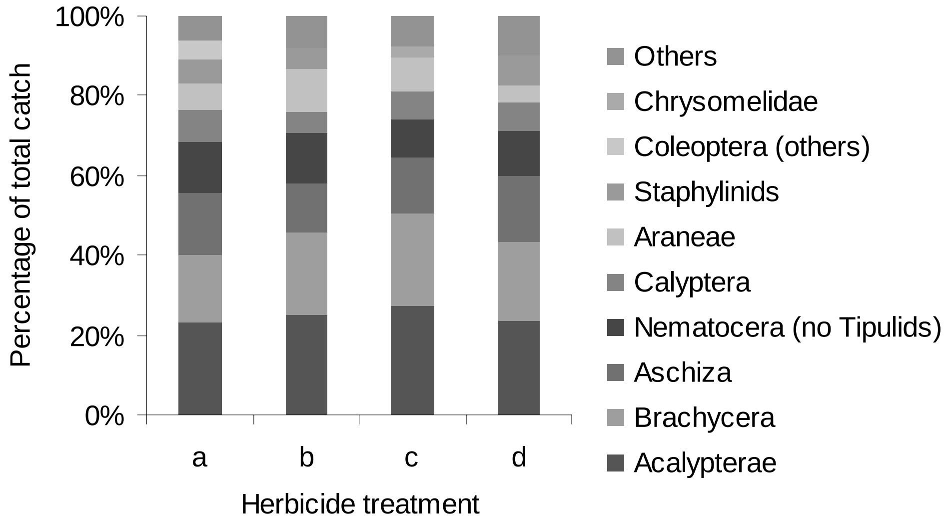

Figure 5.51 Species composition of the arthropod community sampled in each herbicide treatment: High Mowthorpe, 2005.

There was no correlation between the weed and invertebrate community composition (Rho=0.62, *P* = 0.152).

<u>Gleadthorpe 2003</u>

Weed community

At Gleadthorpe in 2003 there was a significant difference between all herbicide treatments with the exception of b and d (Table 5.36). The greatest difference was that between treatments a and b, which was due to much higher ground cover of *P. annua* and *S. media* on the control plots. Differences are illustrated in Figure 5.52 and a table of differences is presented in Appendix 5.

Table 5.36 Pair-wise comparisons of weed composition between herbicide treatments: Gleadthorpe, 2003.

Herbicide	**R Statistic**	***P***
a, b	0.679	0.004
a, c	0.148	0.072
a, d	0.494	0.006
b, c	0.531	0.009
c, d	0.370	0.021

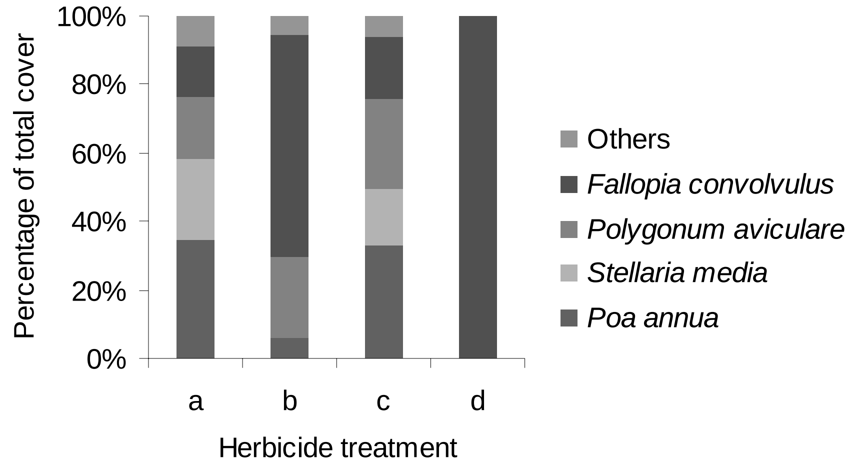

Figure 5.52 Species composition of the weed community sampled in each herbicide treatment: Gleadthorpe, 2003.

Arthropod community

Within the arthropod community, the significant differences lay between treatment b and all other treatments (Table 5.37) and was due to differences in the relative abundance of Nematocera (no Tipulids), Araneae and 'other' Coleopetera (Figure 5.53, Appendix 5).

Table 5.37 Pair-wise comparisons of arthropod composition between herbicide treatments: Gleadthorpe, 2003.

Herbicide	R Statistic	*P*
a, b	0.333	0.017
b, c	0.494	0.007
b, d	0.358	0.029

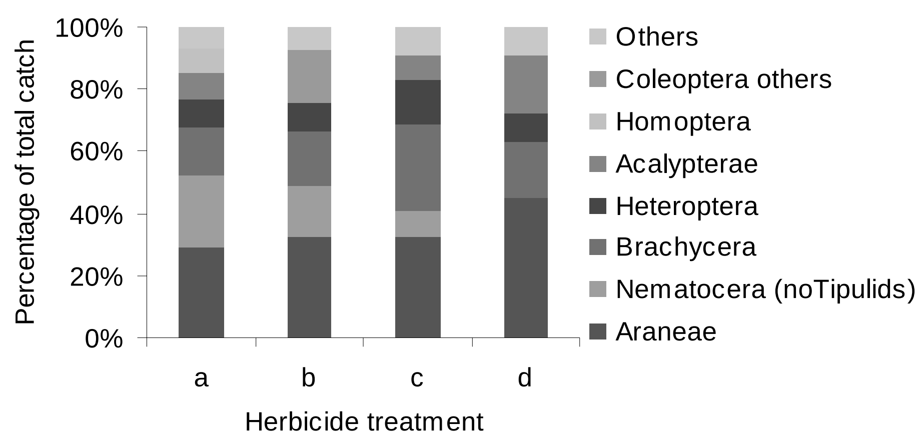

Figure 5.53 Species composition of the arthropod community sampled in each herbicide treatment: Gleadthorpe, 2003.

There was no correlation between the weed and arthropod communities (Rho = -0.023, *P* = 0.615)

Gleadthorpe 2005

Weed community
Significant pair-wise differences in weed community composition between herbicides are shown in Table 5.38. Treatment c was dominated by *Polygonum aviculare* and was different from all other treatments. Treatment d was not distinguished from the control (Figure 5.54).

Table 5.38 Pair-wise comparisons of weed community composition between herbicide treatments: Gleadthorpe, 2005.

Herbicide	**R Statistic**	***P***
a, c	0.423	0.001
a, b	0.487	0.001
c, d	0.468	0.001
c, b	0.142	0.022
d, b	0.447	0.001

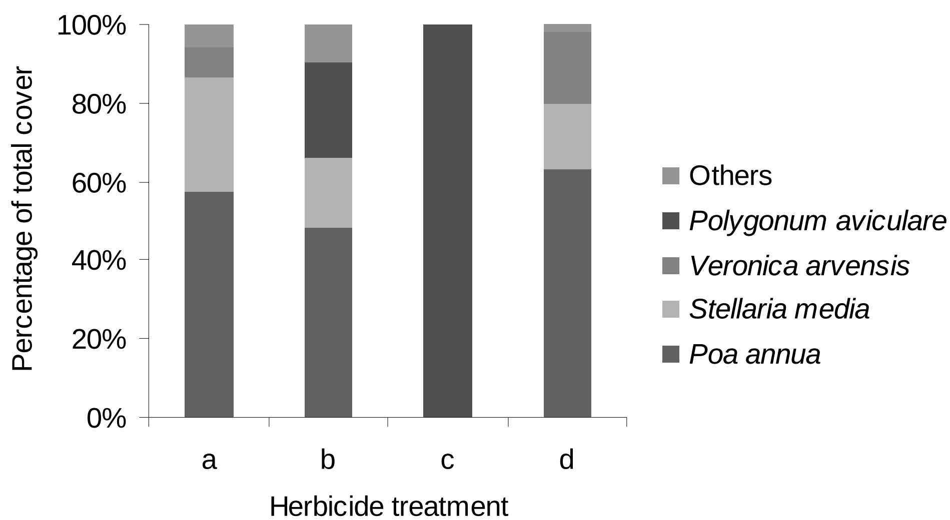

Figure 5.54 Species composition of the weed community sampled in each herbicide treatment: Gleadthorpe, 2005.

Arthropod community
Only one comparison of arthropod species assemblage was significantly different. Treatment b was distinct from treatment c (Table 5.39). The difference was accounted for by the relative abundance of Other Nematocera, Acalypterae, Aschiza and Coleoptera (others) (Figure 5.55, Appendix 5).

Table 5.39 Pair-wise comparisons of arthropod community composition between herbicide treatments: Gleadthorpe, 2005.

Herbicide	**R Statistic**	***P***
c, b	0.172	2.4

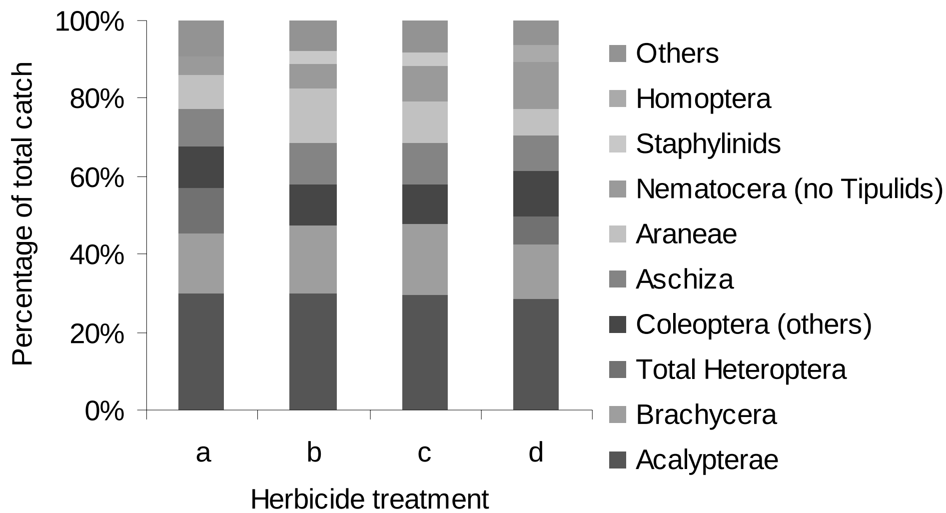

Figure 5.55 Species composition of the arthropod community sampled in each herbicide treatment: Gleadthorpe, 2005.

There was no correlation between the weed and arthropod communities (Rho=0.085, P = 0.158).

In summary, the community analysis showed that the weed species assemblage was more affected by herbicide regime than was the assemblage of arthropods; there were more significant differences between groups and the strength of disassociation was stronger. This is because arthropods respond indirectly to herbicide application but weeds are directly affected. The weed community was relatively simple and was largely driven by differences in *P. annua, G. aparine* and *F. convovulus,* all three of which species may be expected to benefit arthropods. However, there was very little relationship between species assemblage of weeds and arthropods; only at Boxworth in 2004 was there a significant correlation where the arthropod species assemblage was determined by the abundance of *F. convovulus*, *E. repens* and volunteer OSR. In most cases weed cover and arthropod abundance was too low to detect the relationship between them. In general, the difference in arthropod species assemblage between herbicide treatments was largely driven by flies, spiders and small beetles such as Cantharids and those assigned as ‘other Coleoptera’.

1.5 DISCUSSION

1.5.1 Effect of row spacing and cultivation

Crop cover was consistently lower under WSR compared to conventional spacing. Overall, WSR reduced yield, however effects were not significant across all sites/years.

There were few effects of cultivation/spacing on vegetation and where significant differences were recorded, the effects were not consistent across sites, although there were many interactions between cultivation/spacing and herbicide at High Mowthorpe. At High Mowthorpe, the reduction in cover of the neutral (Group3) species in 2003 and all weeds in 2005, suggest that the cultivation was acting as a cultural weed control technique in certain circumstances. This reflects the results of Wilson et al. (1993) who reported that *G. aparine* biomass was significantly reduced by a spring cultivation between rows. There was no suggestion that a spring cultivation encouraged the emergence of spring germinating species. In all sites/years the vegetation was dominated by autumn germinating weeds or those that can germinate over a long period of time. Species such as *P. aviculare* and *F. convolvulus*, which have a discrete period of germination in the spring and early summer (Williams & Morrison, 2003), were recorded in the study, but at very low levels. Also, species richness was greater with cultivation in only one site year (High Mowthorpe 2004). This suggests that spring cultivation does not promote significant germination, that the advanced state of the crop canopy limits growth, or that these species are only present at very low densities in the seed bank. Ultimately, a spring cultivation in winter wheat crops did not increase cover of spring germinating species. WSR did not appear to allow increased in weed cover through reduced canopy cover. No consistent effects were recorded on untreated plots, indicating that the lack of effect on weed cover was not due solely to herbicide use.

Row spacing and additional spring cultivation had a limited effect on arthropod abundance. Where an effect was shown, beetles responded positively to the wider rows, with and without cultivation, but flies responded negatively. The minimal interaction between herbicide application and row spacing/cultivation demonstrated that opening up the crop and introducing soil disturbance did not consistently mitigate the effect of herbicide application; only Araneae (spiders) responded to the interaction more frequently than to each treatment regime independently. This was probably because they respond to changes in habitat architecture. The species assemblage of the arthropod community was affected by row spacing/cultivation independently of the weed community; weed species assemblage was unaffected thus emphasising the importance of overall cover and structure as a driver for the distribution of invertebrate species (which are mobile and able to respond quickly). Weed species assemblage is likely to be strongly influenced by site and year differences which could mask any small-scale effect of row width/cultivation on relative abundance.

In conclusion, the effect of the row spacing/cultivation treatment was inconsistent. Weed cover was rarely affected, and there was no evidence that lower competition between the rows or cultivation in spring encouraged beneficial species to germinate. In general, the arthropod groups affected were not important bird food species, nor were they threatened arable species. There were also yield penalties in some sites/years to both WSR and cultivation. Manipulating row spacing/cultivation is therefore not recommended for commercial application.

1.5.2 Effect of herbicide treatment

Herbicide treatment consistently affected cover of all weed species and composite groups analysed, except in sites/years of very low weed cover. Some effects were consistent throughout the study, others were specific to sites and/or years.

Generally, as would be expected, weed ground cover was greatest on untreated plots. Comparison of treatments which received herbicide indicated that weed cover and species richness was higher in treatments involving single herbicide applications than following sequences of herbicide applications. Multiple applications simply allowed the use of different products to target a wider range of species at different timings, effectively minimising weed populations. Generally, all sequences gave similar levels of weed control, although at Boxworth in 2004, *A. sterilis* and *S. media* were not fully controlled in the absence of a pre-emergence application (treatment g).

The most beneficial herbicide treatment for wider biodiversity was a single spring application of amidosulfuron (d), which consistently allowed greater weed populations to develop, in terms of cover and species number, than other treatments. At High Mowthorpe, where *G. aparine* was the main problem weed species, amidosulfuron was effective in controlling this species and control of undesirable species was similar to that achieved by sequences. However, where problem grass species were present, herbicide treatments that left beneficial species did not always control these noxious species fully. At Boxworth in 2004, a relatively high ground cover of *S. media* in treatment d (spring only application) was accompanied by high cover of undesirable species, although these were largely volunteer beans.

The effects of herbicides on seed production were similar to those for weed cover, with greatest seed production where weed cover was greatest. Weed reproductive status was least advanced where herbicides had been effective in controlling weeds. Weeds which survived herbicide application may have been stunted by the treatment, or weeds may have germinated post treatment, but without sufficient time to reproduce. It was not possible to distinguish between these scenarios in this study.

There was no consistent effect of weed cover on crop yield. Crop ground cover was generally more closely related to crop yield than to weed ground cover. However, in sites/years of high weed cover, there was a competitive effect with the crop of some, but not all, weed species.

This study suggests that there is scope to manipulate herbicide inputs to allow some increase in weed populations that would be beneficial for wider farmland biodiversity and would not compromise productivity. However, results varied depending on site and year and this approach would necessarily be site specific and dynamic in order to avoid expansion of weed populations to detrimental levels. Weed species vary in their competitive ability (Wilson & Wright, 1990), therefore some species can be tolerated at higher populations than others, but very high populations of most species are likely to lead to a yield penalty and for less competitive species this is unlikely to occur within a growing season if the herbicide regime is reactive. However, where high populations of undesirable species already exist, this approach will involve greater risk and manipulation of herbicide inputs is probably inappropriate were there is evidence of herbicide resistance in the weed population.

Arthropod response to herbicide treatment varied between groups; a number of important groups (e.g. Heteroptera, total Coleoptera, total Araneae, Skylark food items and total arthropods) differed between the treatments, mostly in the years with higher weed cover. In years with low weed cover, responsive groups tended to be limited to flies or those composite groups dominated by fly abundance. The effects of the herbicides on arthropods were assumed to be indirect i.e. arthropod response was mediated by the effect of herbicides on weed cover; there is little evidence to suggest that herbicides are toxic to arthropods (Brust, 1990; Samsoe-Petersen, 1995). Likewise many other studies conducted along field margins showed that arthropods and especially those important in the diet of the grey partridge were always higher in unsprayed plots compared to those treated with herbicides (Sotherton et al., 1985; 1988; Chiverton & Sotherton, 1991; Moreby & Southway, 1998; reviewed by Frampton, 2003). Leaving unsprayed strips around the outer edge of cereal fields increased the supply of arthropods sufficiently to raise the chick survival rate (Rands & Sotherton, 1986). The value of unsprayed field margins has since been demonstrated for a variety of farmland wildlife including butterflies, small mammals and songbirds (Sotherton, 1991; de Snoo, 1999). Leaving unsprayed field margins was, however, found to be agronomically unacceptable and instead selective herbicide regimes were tested and recommended (Boatman, 1991, 1992; Boatman & Bain, 1992). Even so a single herbicide application in the autumn was sufficient to have a substantial impact on arthropods (Moreby & Southway, 1998). A greater challenge exists when trying to manipulate the flora of field interiors because of the difficulties in managing pernicious weeds, the larger areas involved and the potential impact on crop yields.

The abundance of arthropods was usually highest where no herbicides were applied, although in some cases similar levels were found on treated plots. At Boxworth in 2004, there was high weed cover and arthropod abundance was highest in plots treated with a March application of amidosulfuron. This is the current recommendation for control of cleavers in conservation headlands (Anon, 2005). In general, the sequences of herbicides led to the fewest arthropods, although a post-emergence application of flupyrsulfuron-methyl also had a negative effect. At Boxworth in 2005, only Heteroptera and Nematocera (no Tipulids) responded to the treatments, however, the same trend was shown (although the sequence regimes were not sampled).

At High Mowthorpe and Gleadthorpe, the effect of herbicide application varied between years. In plots receiving a March application of amidosulfuron, which was the least damaging at Boxworth, there was a lower abundance of Acalypterae (High Mowthorpe in 2003), Skylark food items (High Mowthorpe in 2003) and Nematocera (no Tipulids) (Gleadthorpe in 2003). However, the same treatment contained high numbers of Skylark food items at Gleadthorpe in 2005 and Acalypterae, SFI, Nectar feeders, Omnivores and total Arthropods at High Mowthorpe in 2005. A post-emergence application of diflufenican + isoproturon was the least damaging herbicide treatment at High Mowthorpe in 2003, however this was not so in the following two years. In 2005, both the pre-emergence application and post-emergence application of diflufenican + isoproturon had significantly lower numbers of arthropods when compared with the control and, in many cases, with a March application of amidosulfuron.

Across groups and years, the abundance of the composite group comprising Skylark food items was usually highest following a March application of amidosulfuron.

The species assemblage of the weed community was affected by herbicide application in each year, at each site. Most differences were found at Boxworth 2004 and High Mowthorpe in 2005 when weed cover was high. The arthropod species assemblage varied less than the weed community, and where there were differences, these tended to be fewer when compared with the weed community and the dissimilarity was weaker. There was little relationship between the weed and invertebrate community composition; a significant correlation was found at Boxworth at 2004, but otherwise no relationship was shown. In addition, total weed cover and total arthropod numbers were only related at Boxworth in 2004 and High Mowthorpe in 2005, demonstrating that the relationship is dependent on there being sufficient weed cover. If there is insufficient weed cover, arthropod communities cannot establish. Further analysis of the relationship between weeds and invertebrates is needed to identify the key determinants of arthropod abundance and diversity; possible factors include cover of broadleaf weeds, grass weeds, crop, bare ground and litter. In addition, analyses are needed to determine whether a weed threshold can be identified beyond which acceptable levels of arthropods occur. The grey partridge chick food index is a robust indicator that could be used for assessing acceptable levels because the relationship between chick survival and arthropod abundance been quantified. The diet of partridge chicks is similar to that of other farmland birds, providing a broader indication of bird food supplies (Holland et al., 2006).

This study showed that where there is sufficient weed cover it is possible to maintain a healthy invertebrate population by the careful selection of herbicide type and timing of applications. Encouraging arthropods through a reduction in herbicide inputs would, however, only be prudent if there were no pernicious weeds and the density of other weeds did not compromise crop yield or inhibit crop harvest. In some sites and years, even in the untreated plots, weed levels remained very low (<5% cover in 2003, 10% cover in 2005 at Boxworth) but in other years reached almost 100% cover revealing the risk involved in such an approach. Even so, there was evidence in this study that there is scope to reduce herbicide inputs within fields. Such an approach would benefit arthropods; we have demonstrated that higher arthropod abundances were associated with a selective herbicide programme involving a single herbicide treatment when compared to sequential applications. Arthropods important in the diet of farmland birds were often most abundant in plots receiving the March application of amidosulfuron.

1.6 CONCLUSIONS AND RECOMMENDATIONS

Weed cover often remained within acceptable levels when herbicide inputs were reduced, suggesting that there is scope for many farmers to reduce herbicide inputs.

However, undesirable species were sometimes associated with increases in desirable species and there was evidence that weed cover could reach levels which impacted on crop yield and also potentially affect subsequent crops because of increased levels of weed seed production and return to the soil.

Herbicide programmes to encourage beneficial species must therefore be carefully tailored to the soil type and weed spectrum present at any particular site and circumstances and impacts on subsequent crops must be considered.

Herbicide inputs have an impact on the abundance of arthropods, particularly those taxa important in the diet of farmland birds.

The abundance of arthropods important in the diet of farmland birds was usually greatest where there was a single herbicide treatment in March.

A relationship between weed and arthropod abundance was identified but requires further exploratory analyses.

It is possible to increase weed cover by the use of selective herbicides and this can result in positive benefits for wider farmland biodiversity. Farmers and their advisors should be made more aware of the importance of weeds in determining arthropod abundances and the subsequent impact on the survival of farmland bird chicks. The potential to reduce herbicide inputs within fields without pernicious weeds should also be highlighted, both as a way to increase biodiversity and reduce herbicide costs. However, this should only be considered where the weed spectrum is known to be suitable, and herbicide programmes should preferably be planned with advice from a BASIS qualified agronomist to ensure that crop health and productivity is safeguarded.

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1.8 REFERENCES

Anon, (2005). Entry Level Stewardship Handbook. London: DEFRA.

Ball, D.A. & Miller, S.D. (1989) A comparison of techniques for estimation of arable soil seed banks and their relationship to weed flora. *Weed Research* **29**, 365-373.

Boatman, N.D. (1991) Selective control of cleaver in Conservation Headlands with quinmerac. *1991 British Crop Protection Conference – Weeds,* pp. 669-677. BCPC, Farnham.

Boatman, N.D. & Bain, A.B. (1992) Evaluation of quinmerac and fluroxypyr against hedgerow flora and uncommon arable weeds. Tests of Agrochemicals and Cultivars. *Annals of Applied Biology* **120** [Supplement], 42-43.

Boatman, N.D. (1992) Improvement of field margin habitat by selective control of annual weeds. *Aspects of Applied Biology* **29**, 431-436.

Brust, G.E. (1990) Direct and indirect effects of four herbicides on the activity of carabid beetles (Coleoptera: Carabidae). *Pesticide Science* **30**, 309-320.

Chiverton, P.A. & Sotherton, N.W. (1991) The effects on beneficial arthropods of the exclusion of herbicides from cereal crop edges. *Journal of Applied Ecology* **28**, 1027-1039.

de Snoo, G.R. (1999) Unsprayed field margins: effects on environment, biodiversity and agricultural practice. *Landscape and Urban Planning* **46**, 151-160.

Frampton, G.K.F. (2003) The role of unsprayed crop headlands for the protection of non target arthropods within arable fields. Defra project PN0939.

Hald, A.B. (1999) The impact of changing the season in which cereals are sown. *Journal of Applied Ecology* **22**, 491-501.

Holland, J.M., Hutchison, M.A.S., Smith, B. & Aebischer, N.J. (2006) A review of invertebrates and seed bearing plants as food for farmland birds in Europe. *Annals of Applied Biology* **148**, 49-71.

Marshall, E.J.P., Brown, V.K., Boatman, N.D., Lutman, P.J.W., Squire, G.R. & Ward, L.K. (2003) The role of weeds in supporting biological diversity within crop fields. *Weed Research* **43**, 77-89.

Moreby, S.J. & Southway, S.E. (1998) Influence of autumn applied herbicides on summer and autumn food available to birds in winter wheat fields in southern England. *Agriculture, Ecosystems and Environment* **72**, 285-297.

Pain, D.J. & Pienkowski, M.W. (Eds). (1997) *Farming and Birds in Europe. The Common Agricultural Policy and its Implications for Bird Conservation*. London, Academic Press.

Rands, M.R.W. (1985) Pesticide use on cereals and the survival of Grey Partridge chicks: a field experiment. *Journal of Applied Ecology* **22**, 49-54.

Samsoe-Petersen, L. (1995) Effects of 67 herbicides and plant growth regulators on the rove beetle Aleochara bilineata (Col: Staphylinidae) in the laboratory. *Entomophaga* **40**, 95-104.

Sotherton, N.W., Rands, M.R.W. & Moreby, S.J. (1985) Comparison of herbicide treated and untreated headlands on the survival of game and wildlife. *1985 British Crop Protection Conference – Weeds,* pp. 991-998. BCPC, Farnham.

Sotherton, N.W., Dover, J.W. & Rands, M.R.W. (1988) The effects of pesticide exclusion strips on faunal populations in Great Britain. *Ecological Bulletins* **39**, 197-199.

Sotherton, N.W. (1991) Conservation Headlands: a practical combination of intensive cereal farming and conservation. In: *Ecology of temperate cereal fields* (eds Firbank L. G., Carter N., Darbyshire J. F. & Potts G. R.), pp. 373-397. Blackwell Scientific Publications, Oxford.

Williams, J.B. & Morrison, J.R. (2003). A colour atlas of weed seedlings. Manson Publishing, London.

Wilson, B.J. & Wright, K.J. (1990) Predicting the growth and competitive effects of annual weeds in wheat. *Weed Research* **30**, 201-211.

Wilson, B.J., Wright, K.J. & Butler, R.C. (1993) The effect of different frequencies of harrowing in the autumn or spring on winter wheat, and on the control of *Stellaria media* (L.) vill., *Galium aparine* L. and *Brassica napus* L.. *Weed Research* **33**, 501-506.

APPENDIX 1 – CROP MANAGEMENT DETAILS

Table 5.A1 Agronomic inputs 2002/03.

2002/03	ADAS Boxworth	ADAS Gleadthorpe	ADAS High Mowthorpe
Field	17 Acres	Top Kingston	Warren
Soil Type	Calc. Clay Loam (Hanslope Series)	Loamy medium sand (Cuckney Series)	
Previous cropping			
1999	Set-aside	Potatoes	-
2000	Winter wheat	Winter wheat	-
2001	Winter wheat	Carrots (strawed over winter and lifted spring 2002)	-
2002	Winter oilseed rape	Spring oilseed rape	Spring beans
Cultivations			
	7/08/02 pig tail cultivated 23/08/02glyphosate 360g ai/l @ 2 l/ha 23/08/02 mole drained 5/9/02 ploughed and furrow pressed followed by rolling 1/10/02 power Harrowed 3/10/02 rolled	12/09/02 sub-soiled 13/09/02 chisel ploughed 28/10/02 ploughed and furrow pressed	24/09/02 plough /press 03/10/02 surrounding crop drilled: 20/10/02 power harrow:
Drilling date	8/10/02	05/11/02	20/10/2002
Variety	Claire	Equinox	Hereward
Seed rate (kg/ha) (Normal row spacing)	150	214	141
Seed rate (kg/ha) (Double row spacing)	50 This was the highest seed rate we could achieve	172 This was the highest seed rate we could achieve	145

2002/03	ADAS Boxworth	ADAS Gleadthorpe	ADAS High Mowthorpe
Fertiliser	27/02/03 400 l/ha 7:21:0:0 liquid fertiliser	06/02/03 96 kg/ha P_2O_5, as triple super phosphate.	
	29/03/03 300 l/ha Nuram 37 liquid fertiliser.	13/02/03 96 kg/ha K_2O, as muriate of potash.	15/01/2003, 0:20:30, 574 kg/ha
	26/04/03.200 l/ha Nuram 37 liquid fertiliser.	21/02/03 40 kg/ha N plus 10.3 kg/ha S as Sulphur Gold.	14/03/2003, Ammonium nitrate, 123 kg/ha
		28/02/03 5.0 kg/ha $MnSO_4$	01/05/2003, Nitram, 617 kg/ha
		20/03/03 52 kg/ha N as ammonium nitrate (34.5% N)	25/06/2003, Nufol, 209 kg/ha
		09/05/03 113 kg/ha N as ammonium nitrate (34.5% N)	
Fungicide	15/4/03 Fortress @ 0.1 l/ha	07/05/03 Landmark 0.5 l/ha + Fortress 0.1 l/ha	07/05/2003, Opus, 0.54 l/ha
	7/05/03 Landmark @ 0.5 l/ha		07/05/2003, Erysto, 0.43 l/ha
	30/05/03 Opera @ 0.75 l/ha	27/05/03. Landmark 0.5 l/ha + Opus 0.25 l/ha	27/05/2003, Landmark, 0.47 l/ha
			14/06/03, Amistar-Pro, 0.24 l/ha 14/06/03, Folicur, 0.24 l/ha
PGR	15/4/03 3C Cycocel @ 1.5 l/ha 7/05/03 3C Cycocel @ 0.75 l/ha	None	22/04/2003, Chlormequat 720, 2.47 l/ha
Insecticides	24/02/03 Cypermethrin @ 246 ml/ha.	None	None

2002/03	ADAS Boxworth	ADAS Gleadthorpe	ADAS High Mowthorpe
Herbicide treatments	31/10/02 Crystal @ 3 or 4 l/ha depending on treatment. Crop emerging, GS 09/10. 5/11/02 Avadex @ 15 kg/ha to treatments using pepper pot shakers 20/12/02 Crop at GS21.Hawk @ 2.5 l/ha + Lexus @20 g/ha to required plots 20/03/03 Crop @ GS 22-23.Eagle @ 40 g/ha, OR Boxer @ 0.15 l/ha to desired treatments.	07/11/02 Ardent @ 2.5 l/ha to treatments 9, 20 and 31. 07/11/02 Terbutryn @ 3.0 l/ha to treatments 11, 22 and 33. 15/11/02 Avadex @ 15 kg/ha to treatments 10, 21 and 32. 09\12/02Crop fully emerged, GS 11.Fenpath @ 2.0 l/ha to treatments 2, 4-7, 13, 15-18, 24, 26-29 and 34-36. 10/12/02 Ardent @ 2.5 l/ha to treatments 8, 19 and 30.	31/10/2002, Crop pre-emergence, Treatments 9,20,31, Ardent @ 2.5l 31/10/2002 Treatments 11,22,33, Alpha Terbutryne 50SC @ 5.6l 31/10/2002Treatments 10,21,32, Avadex Excel 1 @ 15kg 18/12/2002, , Treatments 2,4,5,6,7,13,15, 16,17,18,24 ,26,27,28,29,34, 35, 36, Panther @ 2.0l 18/12/2002 Crop @ GS 12, Treatments 8,19,30, Ardent @ 2.5l
	9/5/03 Crop @ GS 32.Ally @ 30g/ha plus Starane @ 2.0 l/ha OR Starane @ 2.0 l/ha OR Duplosan (CMPP-p) @ 2.0 l/ha to required treatments	26/03/03Eagle @ 40 g/ha to treatments 3, 4, 14, 15, 25, 26, and 35.	19/03/2003, Crop @ GS22, Treatments 3,4,14,15,25,26,35, Eagle @ 40g/ha
		26/03/03Boxer @ 0.15 l/ha to treatments 5, 16 and 27. 26/03/03Ally @ 30g/ha plus Starane @ 2.0 l/ha to treatment 34. 26/03/03CMPP @ 5.6 l/ha to treatment 36. 16/04/03Crop at GS 30.CMPP @ 5.6 l/ha to treatments 6, 17 and 28. 16/04/03Starane @ 2.0 l/ha to treatments 7, 18 and 29.	19/03/2003, Crop @ GS22, Treatments 5,16,27, Boxer @ 0.15l 19/03/2003, Treatments 34, Ally @ 30g + Starane @ 1.0l 19/03/2003, Treatment 36, Compitox Plus @ 2.0l 15/05/2003, Crop @ GS32, Treatments 6,17,28, Compitox Plus @ 2.0l 15/05/2003, Treatments 7,18,29, Starane 2 @ 1.0l
Hoe treatments	21/3/03Crop @ GS 22-23.Hoed treatments 34-36 using a multi-tined weeder.	20/03/03Crop at GS 22/23.Hoed treatments 34-36 using a multi-tined weeder. 11/04/03Crop not yet at GS 30.Hoed treatments 23-33 using multi-tined weeder as before.	14/03/2003, Crop @ GS22, Treatments 34,35,36, Einbock weeder tines 17/04/2003, Hoe, Treatments 23,24,25,26,27,28,29,30,31,32,33, Einbock weeder tines
Trial harvested	8&9/08/03	08/08/03.	

Table 5.A2 Agronomic inputs 2003/04.

2003/04	**ADAS Boxworth**	**ADAS Gleadthorpe**	**ADAS High Mowthorpe**
Field	Pamplins North	Tenter Field	Warren
Soil Type	Calc. Clay Loam (Hanslope Series)	Loamy medium sand (Cuckney series)	
Previous cropping			
2000	Winter oil seed rape		Winter wheat
2001	Winter wheat		Winter wheat
2002	Winter wheat	Carrots (strawed over winter and lifted spring 2003)	Spring beans
2003	Winter beans	Spring oil seed rape	Winter wheat
Cultivations	22/08/03 glyphosate 360g ai/l @ 4 l/ha + 0.5 l/ha tallow amine 29/08/03 mole drained 6/09/03 Flat lifted 6/09/03 Rolled 8/09/03 Power Harrowed 24/09/03 rolled	29/09/03 Trial area ploughed and furrow pressed.	01/09/2003 Roundup 360 4.0 Lt 07/10/2003 Plough/press 10/10/2003 Roll
Drilling date	23/09/03 Trial drilled with 3m Sulky drill @ 3.5cm depth	07/10/03	13/10/2003
Variety	Solstice	Access	Napier
Seed rate (kg/ha) (Normal row spacing)	170	147	184
Seed rate (kg/ha) (Double row spacing)	170	147	186
Fertiliser	3/03/04 400 l/ha 7:21:0:0 liquid fertiliser 30/03/04 260 l/ha Nuram 37 liquid fertiliser. 14/05/04 260 l/ha Nuram 37 liquid fertiliser.	24/11/03 3.0 kg/ha $MnSO_4$ 23/02/04 135 kg/ha Muriate of Potash 17/03/04 100 kg/ha Ammonium Sulphate 20/03/04 100 kg/ha Ammonium Nitrate 08/04/04 303 kg/ha Ammonium Nitrate 15/04/04 3.0 kg/ha $MnSO_4$ 07/05/04 156 kg/ha Ammonium Nitrate	29/09/2003 Farmyard Manure 300.0 t/ha 09/03/2004 Ammonium Nitrate 208.3 Kg/ha 09/04/2004 0.20.30 228.2 Kg/ha 22/04/2004 Ammonium Nitrate 396.8 Kg/ha

2003/04	ADAS Boxworth	ADAS Gleadthorpe	ADAS High Mowthorpe
Fungicide	16/04/04 Bravo @ 1.0 l/ha 12/05/04 Opus @ 0.2 l/ha + Landmark @ 0.5 l/ha 30/05/04 Landmark @ 0.70 l/ha	31/03/04 1.0 l/ha Chlorothalonil. 02/05/04 0.6 l/ha Landmark. 02/05/04 1.0 l/ha Chlormequat. 24/05/04 0.5 l/ha Landmark. 24/05/04 0.25 l/ha Opus. 24/05/04 0.3 l/ha Tern 750Ec.	02/05/2004 Landmark 0.5 l/ha 06/06/2004 Bravo 500 1 l/ha 06/06/2004 Landmark 0.7 l/ha 22/06/2004 Folicur 0.3 l/ha
PGR	16/04/04 3 C Cycocel @ 2.3 l/ha	15/04/04 2.0 l/ha Chlormequat. 24/05/04 1.0 l/ha Terpal.	22/04/2004 New Cycocel 2.1 l/ha
Insecticides	24/10/03 Draza @ 3.5 kg/ha broadcast 6/12/03 Cypermethrin @ 0.25 l/ha applied 30/05/04 Cypermethrin @ 0.25 l/ha	31/03/04 0.25 l/ha Cypermethrin.	21/11/2003 Cyperkill 0.25 l/ha
Herbicide treatments	30/9/03 Crystal @ 3 or 4 l/ha depending on treatment. Crop not emerged; but first cotyledons seen for various weeds. 9/02/04 Crop at GS21. Hawk @ 2.5 l/ha + Lexus @20 g/ha to required plots 25/03/04 Crop @ GS 22-23. Eagle @ 30 g/ha,	31/03/04 2.0 l/ha CMPP-p to treatments 6,13 and 20. 06/11/03 2.0 l/ha Fernpath Ipex, post emergence, to treatments 2,4,5,6,9,11,12,13,16,18,19 and 20. 31/03/04 30 g/ha Eagle to treatments 3,4,10,11,17 and 18. 31/03/04 0.75 l/ha Boxer to treatments 5,12 and 19.	21/12/03 Ardent to required plots 28/11/03 Panther to required plots 13/04/04 Eagle, Boxer, CMPP-p to required plots
Hoe treatments	15/04/04 Crop @ GS 31. Hoed treatments 17-24 using a multi-tined weeder.	16/04/04 Spring hoeing treatment applied to treatments 15-21.	25/04/04 Hoe treatments using Einbock weeder
Pre-Harvest treatment	11/08/04 Glyphosate 360g ai/l @ 2.5 l/ha	02/08/04 Applied 2.0 l/ha Glyphosate pre harvest	
Trial harvested	7/09/04	28/08/04	29&30/08/2004

Table 5.A3 Agronomic inputs 2004/05.

2004/05	**ADAS Boxworth**	**ADAS Gleadthorpe**	**ADAS High Mowthorpe**
Field	Thorofare	Top Kingston (West)	Kirby Field West
Soil Type	Calc. Clay Loam (Hanslope Series)	Loamy medium sand (Cuckney series)	
Previous cropping			
2001			Spring oilseed rape
2002			Winter wheat
2003		Carrots (strawed over winter and lifted spring 2004)	Spring beans
2004		Spring oilseed rape	Winter wheat
Cultivations		8-9/10/04 ploughed and furrow pressed	
Drilling date	16/11/04	12/10/04	24/09/04
Variety		Access	Hereward
Seed rate (kg/ha) (Normal row spacing)		162	154
Seed rate (kg/ha) (Double row spacing)			155
Fertiliser		25/11/04 Manganese sulphate 3.25 kg/ha 03/03/05 Muriate of potash 135 kg/ha 07/03/05 Axax fertiliser (27N9SO3) 149 kg/ha (40 kg/ha N) 01/05/05 Ammonium nitrate 213 kg/ha 08/04/05 Ammonium nitrate spread overall 264 kg/ha	11/04/05, Ammonium Nitrate, 289.6 kg/ha 27/04/05, Ammonium Nitrate, 315.32 08/07/05, Protol-L Nitrogen, 0.24 t/ha

2004/05	ADAS Boxworth	ADAS Gleadthorpe	ADAS High Mowthorpe
Fungicide		21/04/05 chlorothalonil 1 l/ha plus Opus 0.5 l/ha 17/5/05 chlorothalonil 0.75 l/ha plus Opus 0.75 l/ha	22/04/ 05, Agrig Chlorothalonil, 1.03 l/ha 11/05/ 05, Agrig Chlorothalonil, 0.991 l/ha 11/05/ 05, Proline, 0.399 l/ha 07/06/ 05, Comet, 0.26 l/ha 07/06/ 05, Epoxyconazole A, 0.71 l/ha 07/06/ 05, Instinct-Tern, 0.29 l/ha 26/06/ 05, Amistar, 0.26 l/ha 26/06/ 05, Icon Folicur, 0.32 l/ha
PGR		21/04/05 chlormequat 2 l/ha	22/04/ 05, Chlormequat 720, 2.32 l/ha
Insecticides		25/11/04 Cypermethrin 0.25 l/ha	11/11/ 04, Toppel 10, 0.26 l/ha 18/10/ 04, Rivet Slug P, 2.6 kg/ha 11/05/ 05, Frigate, 0.4 l/ha
Herbicide treatments	13/01/05 T1 - Peri-em sprays at GS 10, Crystal @ 3 or 4 l/ha. 8/2/05 T2 – post-em sprays at GS 12, Topik & Esterol or Topik, Lexus & Esterol 25/03/05 T3 - Eagle @ 30 g/ha at GS 24 to Treatments 2, 5, 8, 10, 13, 16, 18, 21 & 24	18/10/04 Ardent @ 2.5 l/ha to treatments 7, 14 and 21 23/11/04 Fenpath Ipex @ 2.0 l/ha to treatments 2, 4-6, 9, 11-13, 16 and 18-20 18/03/05 Eagle @ 30g/ha to treatments 3, 4, 10, 11, 17 and 18 18/03/05 Boxer @ 75ml/ha to treatments 5, 12 and 19 18/03/05 CMPP-p @ 2 l/ha to treatments 6, 13 and 20	29/09/04 Pre emergence herbicides applied, Ardent @ 2.5 l/ha 20111/04 Panther, GS 12 01/04/05 Eagle @ 30g/ha to treatments 3, 4, 10, 11, 17 and 18 01/04/05 Boxer @ 75ml/ha to treatments 5, 12 and 19 01/04/05 CMPP-p @ 2 l/ha to treatments 6, 13 and 20
Hoe treatments	19/04/05 Mechanically hoed	07/04/05 Spring hoeing treatment	29/04/05 Hoe treatment Einbock
Pre-Harvest treatment	-		
Trial harvested	30/08/05	17&18/8/05	29&30/08/05

APPENDIX 2 – AGRONOMIC ANALYSES

Subjected to Duncan's multiple range test, letters omitted where not significant

Table 5.A4 Boxworth 2003.

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 60																			
Yield (t/ha @ 85% DM)	8.8	9.0	9.2	9.1	9.2	9.2	9.5	9.0	1.95	0.078	9.2	9.2	9.0	1.58	0.225	0.08	0.782	2.67	0.108
Specific weight (kg/jhl)	73.0	73.0	73.2	73.3	73.4	73.1	73.2	73.3	0.71	0.662	73.2	73.2	73.2	0.04	0.963	0.01	0.928	0.03	0.858

Table 5.A5 Boxworth 2004.

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 106																			
Yield (t/ha @ 85% DM)	4.9^{a}	6.8^{b}	9.0^{c}	6.5^{b}	9.3^{c}	9.4^{c}	8.9^{c}	9.3^{c}	56.94	<0.001	8.1	7.9	8.0	0.42	0.656	0.82	0.369	0.37	0.546
Specific weight (kg/jhl)	74.7	74.6	74.8	74.8	74.8	74.7	75.0	74.8	0.07	0.999	74.9	74.6	74.8	0.24	0.789	0.40	0.529	0.31	0.579
Fertile tillers (/m^2)	140^{a}	162^{b}	200^{c}	164^{b}	199^{c}	206^{c}	192^{c}	215^{c}	12.06	<0.001	218	166	170	40.02	<0.001	64.84	<0.001	0.42	0.517

Table 5.A6 Boxworth 2004 Thousand grain weight interaction.

	Herbicide								Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; Space*Herb df = 14; resid df = 92															
Conv	53.1	54.0	54.0	56.0	52.3	54.0	54.9	53.6	0.49	0.842	**Spacing**	0.22	0.803	2.17	0.015
WSR	53.6	54.2	56.7	52.3	55.7	53.3	53.9	54.6			**Conv vs WSR**	0.44	0.509		
WSR+Cult	55.1	54.0	52.6	54.6	54.5	53.0	55.3	53.9			**WSR vs WSR+Cult**	0.14	0.711		

Table 5.A7 Boxworth 2005.

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 106																			
Yield (t/ha @ 85% DM)	8.7^{a}	9.2^{b}	9.2^{b}	9.2^{b}	9.4^{b}	9.4^{b}	9.1^{b}	9.1^{b}	2.94	0.008	9.5	9.2	8.8	19.36	<0.001	7.12	0.009	12.49	<0.001
Specific weight (kg/jhl)	75.0	74.9	75.0	74.5	75.0	74.9	75.0	75.1	0.71	0.668	74.9	75.1	74.8	1.05	0.355	1.01	0.318	1.97	0.163
Thousand grain weight (g)	41.8	41.3	41.5	41.9	41.8	42.2	42.0	41.7	0.79	0.595	41.7	41.4	42.0	1.46	0.238	0.40	0.528	2.85	0.094
Fertile tillers (/m²)	320	322	341	325	328	326	334	313	1.33	0.243	485	250	246	953.3	<0.001	1422.5	<0.001	0.04	0.846

Table 5.A8 Gleadthorpe 2003.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 52																		
Yield (t/ha @ 85% DM)	7.2	7.4	6.4	6.6	6.9	7.1	6.4	1.04	0.410	7.4	6.7	6.4	3.46	0.390	3.83	0.560	0.30	0.589
Thousand grain weight (g)	49.9	51.9	50.0	49.9	49.6	51.1	48.9	0.72	0.637	49.9	50.8	49.9	0.52	0.595	0.78	0.382	0.79	0.377
Fertile tillers (/m²)	300	306	284	294	301	302	286	0.87	0.526	201	345	342	195.05	<0.001	299.66	<0.001	0.18	0.676

Table 5.A9 Gleadthorpe 2003 Specific weight interaction.

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; Space*Herb df = 12; resid df = 40														
Conv	76.7	70.3	77.0	77.1	76.3	77.1	76.8	13.27	<0.001	**Spacing**	6.59	0.003	10.35	<0.001
WSR	76.4	75.4	76.9	77.2	77.6	77.1	76.8			**Conv vs WSR**	9.82	0.003		
WSR+Cult	74.7	77.5	74.1	77.7	77.6	77.8	78.0			**WSR vs WSR+Cult**	0.00	0.985		

Table 5.A10 Gleadthorpe 2004.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Yield (t/ha @ 85% DM)	8.6[a]	8.7[a]	8.8[a]	8.8[a]	9.2[b]	8.7[a]	8.9[ab]	2.25	0.045	9.2	8.8	8.3	35.69	<0.001	13.73	<0.001	22.31	<0.001
Thousand grain weight (g)	48.7	49.0	48.7	49.7	48.9	49.1	49.8	1.65	0.141	49.0	49.4	48.9	1.41	0.250	1.46	0.230	2.60	0.110
Fertile tillers (/m²)	505	538	516	529	542	550	522	1.56	0.168	591	500	495	43.88	<0.001	61.54	<0.001	0.26	0.610

Table 5.A11 Gleadthorpe 2005.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Yield (t/ha @ 85% DM)	8.1	8.3	8.5	8.2	8.1	8.1	8.3	0.58	0.742	8.6	8.2	7.9	7.80	<0.001	5.47	0.022	2.52	0.116
Specific weight (kg/jhl)	73.2	73.0	73.1	72.9	72.5	72.9	73.3	1.33	0.251	72.9	72.9	73.3	2.45	0.920	0.60	0.962	3.59	0.061
Thousand grain weight (g)	44.2	43.7	44.1	44.5	42.5	43.0	44.2	1.76	0.116	43.9	43.4	43.9	0.66	0.520	0.83	0.364	1.12	0.293
Fertile tillers (/m²)	440	419	432	425	463	427	411	1.57	0.165	499	411	383	48.08	<0.001	50.80	<0.001	5.15	0.026

Table 5.A12 High Mowthorpe 2003.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 52																		
Yield (t/ha @ 85% DM)	9.5	9.5	9.7	9.7	9.5	9.5	9.3	0.40	0.874	9.5	9.5	9.6	0.32	0.728	0.00	0.990	0.49	0.488
Specific weight (kg/jhl)	80.7	80.4	80.8	80.7	80.7	80.8	81.0	1.20	0.321	80.8	80.9	80.6	1.58	0.216	0.57	0.452	3.14	0.082
Thousand grain weight (g)	49.3	49.1	48.8	48.8	48.8	49.4	49.3	0.76	0.606	49.2	49.0	49.0	0.17	0.843	0.15	0.702	0.04	0.851
Fertile tillers (/m²)	497	518	521	510	511	519	513	0.33	0.916	550	493	494	12.11	<0.001	18.13	<0.001	0.00	0.995

Table 5.A13 High Mowthorpe 2004.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Yield (t/ha @ 85% DM)	5.8^{a}	6.1^{abc}	6.1^{abc}	5.9^{ab}	6.2^{bc}	6.4^{c}	6.0^{abc}	2.52	0.027	6.1	6.1	6.0	0.97	0.382	0.00	0.970	1.41	0.238
Specific weight (kg/jhl)	64.1^{a}	65.5^{b}	66.2^{b}	65.8^{b}	66.6^{b}	66.7^{b}	66.3^{b}	5.07	<0.001	65.5	66.0	66.1	1.37	0.266	1.64	0.204	0.06	0.806
Thousand grain weight (g)	42.8	42.6	42.5	42.7	42.9	42.7	43.2	0.59	0.740	42.4	42.7	43.2	3.37	0.039	1.22	0.273	2.20	0.141
Fertile tillers (/m²)	337^{ab}	372^{abcd}	322^{a}	409^{cd}	406^{bcd}	441^{d}	364^{abc}	3.45	0.004	375	384	378	0.09	0.916	0.17	0.681	0.07	0.786

Table 5.A14 High Mowthorpe 2005.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Yield (t/ha @ 85% DM)	6.8^{a}	9.0^{b}	9.2^{b}	8.9^{b}	9.3^{b}	9.3^{b}	9.2^{b}	26.68	<0.001	8.9	8.8	8.7	0.91	0.406	1.15	0.286	0.03	0.865
Specific weight (kg/jhl)	43.5^{a}	47.3^{b}	47.7^{b}	47.9^{b}	47.6^{b}	48.0^{b}	47.4^{b}	16.14	<0.001	46.7	46.8	47.6	3.40	0.038	0.07	0.787	4.46	0.038
Thousand grain weight (g)	77.3^{a}	79.6^{b}	79.8^{b}	79.4^{b}	79.9^{b}	79.9^{b}	79.7^{b}	29.34	<0.001	79.2	79.3	79.7	5.43	0.006	0.93	0.339	5.06	0.027
Fertile tillers (/m²)	417	477	460	476	470	464	476	1.76	0.115	609	391	389	144.15	<0.001	214.71	<0.001	0.01	0.919

APPENDIX 3 – VEGETATION ANALYSES

Table 5.A15 Effect of herbicide and spacing/cultivation treatments on vegetation cover at Boxworth in 2003 (back transformed means; no interaction between main factors).

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	b	c	d	e	f	g	h	*F*	*P*	Conv	WSR	WSR +Cult	*F*	*P*	*F*	*P*	*F*	*P*
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 60																			
Group1	1.7^{a}	0.5^{b}	0.2^{b}	0.7^{b}	0.7^{b}	0.3^{b}	0.2^{b}	0.0^{c}	7.09	<0.001	0.5	0.3	0.5	0.63	0.535	1.08	0.302	0.79	0.377
Group3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.70	0.127	0.0	0.0	0.0	0.35	0.708	0.63	0.432	0.38	0.537
Group4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.81	0.102	0.0	0.0	0.0	0.93	0.399	1.77	0.189	0.88	0.351
Groups12	1.8^{a}	0.5^{b}	0.3^{b}	0.7^{b}	0.7^{b}	0.4^{b}	0.2^{b}	0.0^{c}	7.49	<0.001	0.5	0.4	0.5	0.62	0.541	1.10	0.298	0.72	0.399
Groups123	1.8^{a}	0.6^{bc}	0.4^{bc}	0.9^{b}	0.8^{bc}	0.5^{bc}	0.3^{c}	0.0^{d}	9.98	<0.001	0.6	0.4	0.6	0.90	0.414	1.79	0.186	0.54	0.467
All weeds	1.9^{a}	0.6^{bc}	0.4^{bc}	0.9^{b}	0.8^{bc}	0.5^{bc}	0.3^{c}	0.0^{d}	10.23	<0.001	0.7	0.4	0.6	0.97	0.386	1.93	0.170	0.58	0.448
Broadleaved species	1.9^{a}	0.6^{bc}	0.4^{bc}	0.9^{b}	0.8^{bc}	0.5^{bc}	0.3^{c}	0.0^{d}	10.19	<0.001	0.6	0.4	0.5	0.91	0.406	1.83	0.181	0.49	0.488
Grasses	0.0^{a}	0.0^{bc}	0.0^{bc}	0.0^{ac}	0.0^{bc}	0.0^{bc}	0.0^{bc}	0.0^{c}	2.44	0.028	0.0	0.0	0.0	0.39	0.677	0.26	0.612	0.78	0.381
Bare below	74.9	74.4	75.4	75.6	76.5	77.3	74.7	77.2	1.24	0.298	74.7	76.1	76.4	2.02	0.142	2.44	0.123	0.10	0.756
Litter	2.2	2.4	2.3	2.5	2.3	2.5	2.5	2.4	0.28	0.958	2.9	2.3	2.0	9.83	<0.001	8.22	0.006	2.24	0.140
Crop	56.5	52.4	53.7	53.4	51.3	54.0	52.0	52.4	0.42	0.889	62.0	49.1	48.4	25.58	<0.001	36.41	<0.001	0.10	0.758
Fallopia convolvulus	0.6^{a}	0.1^{b}	0.1^{b}	0.0^{b}	0.2^{ab}	0.1^{b}	0.1^{b}	0.0^{b}	2.44	0.029	0.1	0.1	0.1	0.27	0.761	0.39	0.535	0.43	0.513
Species richness	5.6^{a}	3.4^{bc}	3.2^{bc}	3.8^{b}	2.9^{bc}	3.0^{bc}	2.0^{c}	0.1^{d}	10.41	<0.001	3.3	2.5	3.2	1.88	0.162	3.27	0.076	2.27	0.137

Table 5.A16 Effect of herbicide and spacing/cultivation treatments on % cover of Group 2 species at Boxworth in 2003 (back transformed means; interaction of main factors).

	Herbicide								Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; Space*Herb df = 14; resid df = 46															
Group2															
Conv	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	3.04	0.010	**Spacing**	0.27	0.767	2.46	0.011
WSR	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0			**Conv vs WSR**	0.04	0.848		
WSR+Cult	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0			**WSR vs WSR+Cult**	0.50	0.484		

Table 5.A17 Effect of herbicide and spacing/cultivation treatments on vegetation cover at Boxworth in 2004 (back transformed means; no interaction between main factors).

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult.**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 106																			
Group1	73.6[a]	10.9[c]	31.1[b]	38.8[b]	0.9[d]	0.2[d]	15.1[c]	0.1[d]	91.16	<0.001	15.5	17.5	12.5	2.45	0.092	0.73	0.395	4.81	0.030
Group2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.00	0.436	0.0	0.0	0.0	1.00	0.371	1.50	0.223	1.50	0.223
Group3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.32	0.941	0.0	0.0	0.0	1.98	0.143	3.11	0.081	0.01	0.933
Group4	25.4[a]	25.8[a]	7.2[bc]	33.8[a]	6.6[bc]	4.1[c]	12.1[b]	3.8[c]	19.92	<0.001	12.8	14.4	12.2	0.57	0.566	0.54	0.464	1.08	0.300
Groups12	73.6[a]	10.9[c]	31.1[b]	38.8[b]	0.9[d]	0.2[d]	15.1[c]	0.1[d]	91.18	<0.001	15.5	17.5	12.5	2.45	0.091	0.73	0.394	4.83	0.030
Groups123	74.1[a]	11.0[c]	31.1[b]	38.9[b]	1.0[d]	0.2[d]	15.2[c]	0.1[d]	92.48	<0.001	15.9	17.6	12.8	2.31	0.104	0.52	0.470	4.47	0.037
Groups1234	92.3[a]	38.8[c]	39.9[c]	76.6[b]	8.1[d]	4.5[d]	31.4[c]	4.0[d]	95.19	<0.001	33.9	37.7	31.5	1.75	0.179	1.30	0.258	3.44	0.067
Broadleaved spp.	88.1[a]	33.6[c]	32.6[c]	66.3[b]	2.3[e]	2.3[e]	15.9[d]	1.2[e]	119.44	<0.001	25.0	29.4	21.8	3.73	0.027	2.45	0.121	7.41	0.008
Grasses	4.4[a]	3.3[a]	5.2[ab]	5.5[ab]	4.9[a]	1.8[a]	11.1[b]	2.0[a]	2.87	0.009	4.6	4.8	4.0	0.17	0.840	0.03	0.873	0.33	0.569
Bare below	29.7[a]	83.2[e]	54.0[c]	39.5[b]	87.6[e]	89.0[e]	71.8[d]	89.1[e]	77.43	<0.001	72.2	66.3	71.1	3.36	0.039	5.96	0.016	3.89	0.051
Litter	4.0[a]	3.4[ab]	1.9[c]	3.9[a]	2.6[abc]	2.1[bc]	2.7[abc]	2.2[bc]	3.52	0.002	2.9	3.0	2.5	1.10	0.337	0.10	0.755	1.99	0.161
Crop	21.8[a]	34.1[b]	45.3[cd]	31.8[b]	49.4[d]	48.7[cd]	41.4[c]	49.6[d]	17.90	<0.001	48.5	33.4	38.3	25.95	<0.001	50.02	<0.001	5.52	0.021
Anisantha sterilis	4.3[a]	3.2[a]	5.0[a]	5.4[ab]	4.7[a]	1.6[a]	11.1[b]	2.0[a]	2.90	0.008	4.4	4.7	4.0	0.14	0.866	0.02	0.875	0.27	0.602
Sinapis arvensis	14.1[a]	10.0[b]	0.0c	0.0c	0.1c	0.0c	0.0c	0.0[c]	57.41	<0.001	1.1	1.0	0.6	1.49	0.230	0.01	0.920	2.08	0.152
Stellaria media	54.9[a]	0.7[d]	31.1[b]	38.8[b]	0.8[d]	0.2[d]	15.1[c]	0.1[d]	121.04	<0.001	11.0	13.1	9.7	2.17	0.119	1.53	0.219	4.28	0.041
Volunteer bean	18.0[b]	20.5[ab]	0.9[cd]	24.1[a]	0.8[cd]	1.5[c]	0.2[d]	0.9[cd]	90.11	<0.001	5.5	6.0	4.6	1.47	0.235	0.43	0.515	2.89	0.092
Species richness	4.7[a]	4.8[a]	3.1[cd]	3.2[cd]	4.3[ab]	3.8[bc]	3.2[cd]	2.7[d]	7.89	<0.001	3.9	3.8	3.5	1.95	0.147	0.09	0.759	2.36	0.127

Table 5.A18 Effect of herbicide and spacing/cultivation treatments on % cover of bare ground viewed from above at Boxworth in 2004 (back transformed means; interaction of main factors).

	Herbicide								**Herbicide**		**Spacing/Cultivation**			**Spacing*Herbicide**	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; Space*Herb df = 14; resid df = 92															
Bare above															
Conv	5.4	11.1	17.7	11.5	22.9	28.9	18.8	31.7	44.17	<0.001	**Spacing**	27.18	<0.001	2.08	0.020
WSR	3.4	32.8	24.5	12.6	42.2	50.1	26.4	44.8			**Conv vs WSR**	33.00	<0.001		
WSR+Cult	9.1	33.6	30.8	11.1	44.1	49.4	27.1	44.5			**WSR vs WSR+Cult**	1.28	0.261		

Table 5.A19 Effect of herbicide and spacing/cultivation treatments on vegetation cover at Boxworth in 2005 (back transformed means; no interaction between main factors).

	Herbicide										**Spacing/Cultivation**					**Conv vs WSR**		**WSR vs WSR+Cult**	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 96																			
Group1	2.8^{a}	0.0^{bc}	0.5^{b}	0.2^{bc}	0.0^{c}	0.0^{c}	0.0^{bc}	0.0^{c}	11.44	<0.001	0.2	0.1	0.2	0.10	0.903	0.14	0.720	0.17	0.690
Group2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.58	0.151	0.0	0.0	0.0	0.46	0.648	0.20	0.664	0.92	0.367
Group3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.25	0.285	0.0	0.0	0.0	3.61	0.076	4.69	0.062	0.09	0.777
Group4	5.7^{a}	1.8^{b}	0.6^{c}	2.6^{b}	0.2^{c}	0.2^{c}	0.2^{c}	0.3^{c}	19.45	<0.001	0.9	1.2	0.8	0.44	0.661	0.50	0.501	0.78	0.403
Groups12	2.9^{a}	0.1^{bc}	0.5^{b}	0.2^{bc}	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	12.48	<0.001	0.2	0.1	0.2	0.14	0.869	0.21	0.663	0.22	0.650
Groups123	2.9^{a}	0.1^{c}	0.6^{b}	0.2^{bc}	0.0^{c}	0.0^{c}	0.1^{c}	0.0^{c}	12.45	<0.001	0.2	0.2	0.2	0.13	0.876	0.08	0.790	0.27	0.619
Groups1234	10.7^{a}	2.0^{bc}	1.4^{c}	3.1^{b}	0.3^{d}	0.2^{d}	0.4^{d}	0.3^{d}	27.64	<0.001	1.5	1.6	1.3	0.11	0.898	0.01	0.915	0.20	0.666
Broadleaved spp.	8.7^{a}	1.1^{b}	1.0^{b}	0.4^{bc}	0.1^{c}	0.0^{c}	0.1^{c}	0.0^{c}	28.16	<0.001	0.7	0.7	0.6	0.02	0.981	0.02	0.892	0.00	0.964
Grasses	1.0^{b}	0.5^{bc}	0.3^{c}	2.3^{a}	0.1^{c}	0.1^{c}	0.1^{c}	0.2^{c}	8.39	<0.001	0.3	0.6	0.4	1.27	0.332	2.15	0.181	1.62	0.239
Bare above	35.5	38.9	40.5	37.5	40.4	40.3	40.6	40.7	1.47	0.187	32.8	41.2	44.0	5.88	0.027	6.12	0.038	0.67	0.437
Bare below	82.7	83.9	84.4	82.5	84.7	84.7	83.3	83.8	1.57	0.154	82.6	84.2	84.5	1.83	0.222	2.33	0.166	0.06	0.820
Litter	1.4	1.3	1.3	1.3	1.3	1.3	1.5	1.3	0.66	0.707	1.6	1.2	1.2	1.93	0.207	3.22	0.110	0.04	0.845
Crop	52.5	55.2	55.3	56.6	55.1	55.8	55.4	55.5	0.49	0.839	61.5	53.1	50.9	5.23	0.035	5.86	0.042	0.41	0.538
Galium aparine	3.7^{a}	0.9^{b}	0.2^{c}	0.1^{c}	0.0^{c}	0.0^{c}	0.0^{c}	0.0^{c}	18.42	<0.001	0.2	0.3	0.2	0.15	0.862	0.22	0.654	0.24	0.640
Species richness	3.9^{a}	2.5^{b}	2.9^{b}	2.6^{b}	1.2^{c}	0.9^{c}	1.4^{c}	1.4^{c}	14.89	<0.001	1.8	2.1	2.4	3.35	0.088	2.11	0.184	1.27	0.292

Table 5.A20 Effect of herbicide and spacing/cultivation treatments on vegetation cover at Gleadthorpe in 2003 (back transformed means; no interaction between main factors).

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 52																		
Group1	16.9[a]	0.6[c]	1.3[c]	4.7[b]	0.8[c]	0.5[c]	0.1[c]	19.10	<0.001	1.1	3.2	2.4	3.43	0.040	6.59	0.013	0.70	0.406
Group2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.95	0.090	0.0	0.0	0.0	0.13	0.879	0.01	0.908	0.24	0.629
Group3	0.5	0.0	0.0	0.4	0.0	0.0	0.0	2.01	0.081	0.0	0.0	0.1	0.10	0.904	0.03	0.872	0.08	0.778
Group4	0.2	0.3	0.2	0.0	0.1	0.0	0.0	1.68	0.145	0.0	0.1	0.1	2.84	0.068	4.09	0.048	0.01	0.937
Groups12	17.5[a]	0.7[c]	1.3[c]	4.8[b]	0.8[c]	0.5[c]	0.1[c]	17.91	<0.001	1.2	3.2	2.5	3.06	0.055	5.80	0.020	0.51	0.479
Groups123	19.8[a]	0.7[c]	1.3[c]	5.7[b]	0.8[c]	0.6[c]	0.1[c]	13.57	<0.001	1.3	3.4	2.9	2.09	0.133	3.74	0.059	0.15	0.700
Groups1234	20.1[a]	1.0[c]	1.5[c]	5.8[b]	0.9[c]	0.6[c]	0.2c	13.21	<0.001	1.4	3.8	3.3	2.56	0.087	4.51	0.039	0.15	0.704
Grasses	10.3[a]	0.1[cde]	0.1[cde]	2.6[bd]	0.2[bcde]	0.1[de]	0.0[e]	6.85	<0.001	0.4	1.1	1.0	0.63	0.536	1.12	0.295	0.04	0.844
Bare below	51.6[a]	76.0[b]	76.3[b]	67.3[b]	75.0[b]	75.0[b]	75.3[b]	6.42	<0.001	72.3	70.7	70.7	0.17	0.846	0.26	0.615	0.00	0.992
Litter	4.3	4.2	3.4	4.9	4.1	4.3	3.4	0.58	0.746	5.3	3.7	3.4	5.10	0.010	6.18	0.016	0.24	0.625
Crop	29.2	29.7	29.2	33.4	31.5	34.5	29.2	0.79	0.581	36.2	29.6	27.2	8.04	<0.001	7.87	0.007	1.17	0.285
Fallopia convolvulus	0.9[a]	0.3[b]	0.8[a]	0.3[b]	0.3[b]	0.1[b]	0.1[b]	5.23	<0.001	0.3	0.3	0.5	1.91	0.159	0.28	0.601	1.87	0.178
Poa annua	8.6[a]	0.1[c]	0.0[c]	1.8[b]	0.1[bc]	0.0[c]	0.0[c]	8.61	<0.001	0.3	0.9	0.7	0.66	0.522	1.28	0.263	0.16	0.688
Species richness	6.3[a]	3.7[b]	3.6[b]	5.1[a]	2.1[c]	2.8[bc]	1.4[c]	12.67	<0.001	3.1	4.0	3.6	1.70	0.193	3.36	0.072	0.57	0.454

Table 5.A21 Effect of herbicide and spacing/cultivation treatments on % cover of broadleaved species and *Stellaria media* at Gleadthorpe in 2003 (back transformed means; interaction between main factors).

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; Space*Herb df = 12; resid df = 40														
Broadleaved spp.														
Conv	3.7	0.6	0.7	2.0	0.4	0.3	0.0	35.66	<0.001	**Spacing**	8.66	<0.001	2.12	0.037
WSR	11.6	0.9	2.1	5.2	0.5	0.5	0.1			**Conv vs WSR**	17.00	<0.001		
WSR+Cult	7.3	1.1	1.6	1.7	0.4	0.6	0.6			**WSR vs WSR+Cult**	2.48	0.123		
Stellaria media														
Conv	0.9	0.0	0.0	0.3	0.0	0.0	0.0	27.15	<0.001	**Spacing**	9.96	<0.001	4.64	<0.001
WSR	8.7	0.0	0.0	3.6	0.0	0.0	0.0			**Conv vs WSR**	15.32	<0.001		
WSR+Cult	1.8	0.0	0.0	0.0	0.0	0.0	0.0			**WSR vs WSR+Cult**	14.54	<0.001		

Table 5.A22 Effect of herbicide and spacing/cultivation treatments on vegetation cover at Gleadthorpe in 2004 (back transformed means; no interaction between main factors).

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Group1	15.8^{a}	0.2^{b}	0.0^{b}	12.5^{a}	0.0^{b}	0.0^{b}	0.0^{b}	80.35	<0.001	1.3	1.7	1.4	0.50	0.607	0.83	0.364	0.66	0.418
Group3	0.2^{a}	0.0^{b}	0.0^{b}	0.1^{a}	0.0^{b}	0.0^{b}	0.0^{b}	5.32	<0.001	0.0	0.0	0.0	0.94	0.395	0.26	0.612	1.84	0.179
Group4	1.5^{a}	0.5^{b}	0.2^{bc}	0.2^{bc}	0.1^{bc}	0.1^{c}	0.3^{bc}	7.08	<0.001	0.2	0.4	0.3	0.95	0.392	1.88	0.173	0.37	0.544
Groups12	17.5^{a}	0.2^{c}	0.0^{c}	13.3^{b}	0.0^{c}	0.0^{c}	0.0^{c}	88.83	<0.001	1.4	1.9	1.5	0.59	0.556	1.09	0.300	0.62	0.434
Groups123	17.9^{a}	0.2^{c}	0.0^{c}	13.6^{b}	0.0^{c}	0.0^{c}	0.0^{c}	90.83	<0.001	1.5	2.0	1.6	0.75	0.475	1.33	0.252	0.88	0.352
Groups1234	20.0^{a}	0.9^{c}	0.3^{c}	14.1^{b}	0.1^{c}	0.1^{c}	0.4^{c}	72.55	<0.001	2.3	3.1	2.4	0.87	0.423	1.39	0.241	1.20	0.276
Broadleaved spp.	2.8^{a}	0.4^{bc}	0.1^{d}	0.7^{b}	0.0^{d}	0.0^{d}	0.1^{cd}	23.10	<0.001	0.2	0.6	0.3	4.66	0.012	9.30	0.003	2.65	0.107
Grasses	16.6^{a}	0.3^{b}	0.2^{b}	13.1^{a}	0.1^{b}	0.1^{b}	0.1b	72.82	<0.001	1.8	2.2	1.6	0.50	0.608	0.41	0.524	0.97	0.327
Bare above	26.9^{a}	34.9^{b}	35.5^{b}	26.9^{a}	38.2^{b}	37.5^{b}	38.7^{b}	6.06	<0.001	22.1	39.6	41.2	62.83	<0.001	85.91	<0.001	0.68	0.411
Bare below	67.2^{a}	85.5^{b}	87.0^{b}	69.0^{a}	87.7^{b}	86.9^{b}	89.1^{b}	12.53	<0.001	82.8	79.4	85.0	3.01	0.054	2.07	0.153	5.95	0.017
Litter	4.0	7.5	6.8	6.8	7.9	7.3	5.6	1.72	0.126	6.1	8.2	5.4	4.26	0.017	4.31	0.041	7.92	0.006
Crop	52.3	58.0	58.2	58.0	55.9	57.3	55.8	1.71	0.127	71.1	49.1	48.7	153.01	<0.001	225.60	<0.001	0.07	0.798
Poa annua	15.2^{a}	0.1^{b}	0.0^{b}	12.3^{a}	0.0^{b}	0.0^{b}	0.0^{b}	77.75	<0.001	1.3	1.5	1.3	0.27	0.763	0.44	0.511	0.38	0.540
Species richness	5.5^{a}	2.3^{c}	1.3^{d}	3.8^{b}	0.7^{d}	1.1^{d}	1.2^{d}	29.14	<0.001	1.8	2.7	2.3	4.95	0.009	9.83	0.002	1.77	0.187

Table 5.A23 Effect of herbicide and row spacing/cultivation treatments on % cover of Group 2 species at Gleadthorpe in 2004 (back transformed means; interaction between main factors).

	Herbicide							**Herbicide**		**Spacing/Cultivation**			**Spacing*Herbicide**	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; Space*Herb df = 12; resid df = 80														
Group2														
Conv	0.8	0.0	0.0	0.4	0.0	0.0	0.0	45.46	<0.001	**Spacing**	2.36	0.101	2.01	0.034
WSR	1.9	0.0	0.0	1.1	0.0	0.0	0.0			**Conv vs WSR**	4.73	0.033		
WSR+Cult	1.4	0.1	0.0	0.2	0.0	0.0	0.0			**WSR vs WSR+Cult**	1.16	0.284		

Table 5.A24 Effect of herbicide and row spacing/cultivation treatments on vegetation cover at Gleadthorpe in 2005 (back transformed means; no interaction between main factors).

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Group1	35.5^{a}	0.9^{c}	0.1^{c}	24.8^{b}	0.0^{c}	0.1^{c}	0.1^{c}	63.03	<0.001	3.5	3.6	3.7	0.01	0.986	0.01	0.913	0.00	0.954
Group2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.34	0.246	0.0	0.0	0.0	0.53	0.593	1.03	0.313	0.14	0.709
Group3	2.0^{a}	0.0^{b}	0.0^{b}	2.8^{a}	0.0^{b}	0.0^{b}	0.0^{b}	25.09	<0.001	0.2	0.3	0.2	0.50	0.607	1.00	0.319	0.22	0.641
Group4	0.4^{a}	0.2^{abd}	0.0^{d}	0.1^{abcd}	0.0^{d}	0.0^{bcd}	0.0^{cd}	3.81	0.002	0.1	0.1	0.0	0.37	0.694	0.00	0.959	0.59	0.446
Groups12	35.5^{a}	0.9^{c}	0.1^{c}	26.7^{b}	0.0^{c}	0.1^{c}	0.1^{c}	72.13	<0.001	3.9	3.7	3.7	0.02	0.984	0.03	0.857	0.00	0.946
Groups123	39.1^{a}	0.9^{b}	0.1^{b}	31.0^{a}	0.0^{b}	0.1^{b}	0.1^{b}	85.86	<0.001	4.3	4.2	4.2	0.00	0.997	0.00	0.965	0.00	0.972
Groups1234	40.9^{a}	1.3^{c}	0.1^{c}	30.1^{b}	0.0^{c}	0.1^{c}	0.1^{c}	77.01	<0.001	4.3	4.5	4.3	0.02	0.984	0.03	0.869	0.02	0.886
Broadleaved spp.	20.8^{a}	0.7^{c}	0.1^{c}	11.3^{b}	0.0^{c}	0.0^{c}	0.0^{c}	37.82	<0.001	2.5	1.7	1.5	0.93	0.399	0.99	0.322	0.09	0.760
Grasses	14.9^{a}	0.4^{b}	0.0^{b}	17.3^{a}	0.0^{b}	0.0^{b}	0.0^{b}	65.26	<0.001	1.1	2.1	2.2	2.39	0.097	3.15	0.079	0.05	0.826
Bare above	24.5^{a}	48.9^{b}	48.7^{b}	32.1^{a}	50.8^{b}	51.7^{b}	55.9^{b}	16.00	<0.001	34.3	49.5	49.8	20.89	<0.001	30.55	<0.001	0.02	0.891
Bare below	24.5^{a}	48.9^{b}	48.7^{b}	28.2^{a}	50.8^{b}	51.7^{b}	55.9^{b}	16.29	<0.001	32.6	49.5	49.8	23.23	<0.001	34.08	<0.001	0.02	0.897
Litter	1.9	2.4	3.4	3.4	2.6	2.8	2.5	0.74	0.616	3.0	2.8	2.3	0.83	0.440	0.22	0.641	0.65	0.423
Crop	42.0	46.8	45.5	40.0	45.1	42.6	39.4	0.88	0.509	54.0	37.4	37.9	22.54	<0.001	34.70	<0.001	0.02	0.878
Poa annua	14.4^{a}	0.3^{b}	0.0^{b}	17.1^{a}	0.0^{b}	0.0^{b}	0.0^{b}	64.22	<0.001	1.1	2.0	2.2	2.42	0.094	3.21	0.076	0.04	0.833
Stellaria media	13.5^{a}	0.2^{c}	0.0^{c}	5.3^{b}	0.0^{c}	0.0^{c}	0.0^{c}	18.27	<0.001	1.4	0.5	0.8	1.00	0.372	1.94	0.167	0.24	0.627
Species richness	4.1^{a}	2.7^{b}	0.6^{c}	3.7^{a}	0.3^{c}	0.8^{c}	0.5^{c}	35.34	<0.001	1.7	1.8	1.9	0.52	0.598	0.32	0.574	0.20	0.653

Table 5.A25 Effect of herbicide and row spacing/cultivation treatments on vegetation cover at High Mowthorpe in 2003 (back transformed means; no interaction between main factors).

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 52																		
Group3	2.5^{a}	0.1^{b}	0.2^{b}	2.1^{a}	0.0^{b}	0.0^{b}	0.3^{b}	8.57	<0.001	0.8	0.5	0.2	3.26	0.047	1.49	0.227	1.77	0.189
Group4	4.2^{a}	3.1^{ab}	3.3^{ab}	1.3^{bc}	1.3^{bc}	0.5^{c}	0.3^{c}	5.01	<0.001	1.6	2.2	1.3	1.07	0.351	0.85	0.361	2.09	0.155
Broadleaved spp.	13.6^{a}	5.7^{b}	4.7^{b}	4.7^{b}	1.8^{c}	0.7^{c}	0.6^{c}	15.75	<0.001	3.7	4.9	2.7	2.98	0.060	1.63	0.207	5.95	0.018
Bare below	64.3^{a}	80.6^{b}	77.2^{b}	68.6^{a}	79.3^{b}	79.6^{b}	79.1^{b}	6.13	<0.001	72.3	76.0	78.8	3.95	0.025	2.39	0.128	1.59	0.214
Litter	1.2	1.1	0.7	1.0	0.9	0.9	0.8	1.44	0.219	1.3	0.8	0.7	10.64	<0.001	9.91	0.003	1.81	0.184
Crop	57.8	54.4	61.4	57.9	58.1	55.1	55.3	0.62	0.710	69.8	50.1	51.0	31.66	<0.001	49.53	<0.001	0.09	0.763
Galium aparine	1.0	0.3	0.1	0.0	0.0	0.0	0.0	2.19	0.059	0.0	0.3	0.0	2.25	0.116	3.58	0.064	3.15	0.082
Sinapis arvensis	1.2^{a}	0.9^{ab}	0.6^{ab}	0.2^{bc}	0.2^{bc}	0.0^{c}	0.0^{c}	3.93	0.003	0.2	0.3	0.3	0.21	0.808	0.41	0.526	0.04	0.845
Vol. OSR	1.0^{a}	1.2^{a}	0.8^{a}	0.2^{b}	0.2^{b}	0.0^{c}	0.0^{c}	22.23	<0.001	0.4	0.3	0.3	0.34	0.716	0.27	0.603	0.08	0.776
Vol. Potato	0.3	0.4	0.9	0.3	0.6	0.4	0.2	0.62	0.716	0.4	0.4	0.5	0.06	0.945	0.00	0.956	0.07	0.797
Species richness	9.8^{a}	5.8^{c}	5.0^{c}	7.9^{b}	4.1^{cd}	2.3^{e}	2.9^{de}	21.17	<0.001	5.6	6.0	4.7	3.00	0.058	0.50	0.483	5.69	0.021

Table 5.A26 Effect of herbicide and row spacing/cultivation treatments on vegetation cover at High Mowthorpe in 2003 (back transformed means; interaction between main factors).

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; Space*Herb df = 12; resid df = 40														
Group1														
Conv	13.4	0.8	3.6	21.4	1.3	0.2	1.6	14.36	<0.001	**Spacing**	4.69	0.015	3.00	0.004
WSR	20.2	2.7	2.9	5.4	1.8	0.6	2.4			**Conv vs WSR**	0.01	0.905		
WSR+Cult	3.0	1.2	2.7	5.0	1.7	1.4	0.0			**WSR vs WSR+Cult**	6.71	0.013		
Group2														
Conv	0.0	0.3	0.0	0.0	0.0	0.0	0.0	7.16	<0.001	**Spacing**	0.73	0.487	3.04	0.004
WSR	0.1	0.0	0.0	0.2	0.0	0.0	0.0			**Conv vs WSR**	0.38	0.543		
WSR+Cult	0.2	0.0	0.0	0.0	0.0	0.0	0.0			**WSR vs WSR+Cult**	1.47	0.233		
Groups12														
Conv	13.5	1.1	3.6	21.5	1.3	0.2	1.6	15.35	<0.001	**Spacing**	5.07	0.011	3.05	0.004
WSR	20.4	2.9	2.9	5.7	1.8	0.6	2.4			**Conv vs WSR**	0.02	0.886		
WSR+Cult	3.3	1.3	2.7	5.0	1.7	1.4	0.0			**WSR vs WSR+Cult**	7.20	0.011		
Groups123														
Conv	19.7	1.2	4.8	25.5	1.3	0.4	3.4	17.83	<0.001	**Spacing**	6.71	0.003	2.85	0.006
WSR	23.6	3.5	3.1	8.1	1.8	0.9	2.5			**Conv vs WSR**	0.54	0.468		
WSR+Cult	4.2	1.3	2.8	6.3	1.9	1.4	0.2			**WSR vs WSR+Cult**	7.52	0.009		
Groups1234														
Conv	24.8	5.4	8.9	26.5	2.6	2.2	3.5	17.01	<0.001	**Spacing**	6.03	0.005	2.76	0.008
WSR	32.7	7.7	6.7	10.8	6.3	1.4	3.2			**Conv vs WSR**	0.11	0.742		
WSR+Cult	7.5	4.4	6.6	7.2	2.9	3.3	1.9			**WSR vs WSR+Cult**	7.99	0.007		

Cont'd…….

Spacing/Cult	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
	a	b	c	d	e	f	g	***F***	***P***		***F***	***P***	***F***	***P***
Grasses														
Conv	9.7	0.0	3.1	20.0	1.4	0.4	3.2	13.64	<0.001	**Spacing**	7.43	0.002	2.90	0.006
WSR	11.9	0.0	1.7	3.5	1.2	0.9	2.2			**Conv vs WSR**	3.22	0.080		
WSR+Cult	1.0	0.0	0.6	4.6	1.5	1.3	0.3			**WSR vs WSR+Cult**	4.24	0.046		
Poa annua														
Conv	9.7	0.0	3.0	19.7	1.2	0.2	1.5	16.79	<0.001	**Spacing**	8.14	0.001	3.66	<0.001
WSR	11.8	0.0	1.4	3.5	1.0	0.5	2.1			**Conv vs WSR**	2.64	0.112		
WSR+Cult	0.9	0.0	0.6	4.2	1.5	1.3	0.0			**WSR vs WSR+Cult**	5.69	0.022		

Table 5.A27 Effect of herbicide and row spacing/cultivation treatments on vegetation cover at High Mowthorpe in 2004 (back transformed means; no interaction between main factors).

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Group2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.90	0.089	0.0	0.0	0.1	2.96	0.057	0.09	0.770	3.79	0.055
Group3	1.2[a]	0.1[b]	0.0[bc]	1.3[a]	0.0[c]	0.0[bc]	0.0[c]	46.34	<0.001	0.1	0.2	0.2	1.49	0.230	2.57	0.112	0.06	0.806
Group4	5.0[a]	1.7[b]	0.9[bc]	0.7[c]	0.2[c]	0.3[c]	0.3[c]	19.94	<0.001	1.0	1.1	0.8	0.81	0.449	0.10	0.748	1.50	0.224
Broadleaved spp.	9.6[a]	3.6[b]	2.2[c]	3.3[bc]	0.6[d]	0.6[d]	0.7[d]	40.89	<0.001	2.4	2.4	2.3	0.05	0.950	0.00	0.973	0.09	0.769
Bare above	35.6[a]	43.0[bc]	45.7[c]	40.3[b]	46.4[c]	43.8[bc]	47.5[c]	7.24	<0.001	33.1	47.3	49.4	79.86	<0.001	102.55	<0.001	2.20	0.141
Bare below	88.7[a]	94.4[b]	94.5[b]	89.5[a]	95.0[b]	94.1[b]	94.8[b]	12.36	<0.001	91.9	93.1	94.4	6.89	0.002	3.12	0.081	3.78	0.055
Litter	1.5[a]	1.1[abc]	1.2[abc]	1.4[a]	1.0[bc]	1.3[ab]	0.9[c]	3.44	0.004	1.5	1.0	1.1	9.25	<0.001	16.57	<0.001	0.69	0.408
Crop	47.1	46.7	44.7	47.1	45.4	46.6	44.8	0.78	0.592	55.9	41.5	40.9	114.69	<0.001	164.52	<0.001	0.32	0.576
Fallopia convolvulus	1.0[a]	0.3[b]	0.9[a]	0.7[a]	0.2[b]	0.2[b]	0.2[b]	12.44	<0.001	0.4	0.5	0.4	1.20	0.307	0.82	0.368	2.37	0.127
Galium aparine	4.5[a]	0.9[b]	0.8[bc]	0.3[cd]	0.1[d]	0.1[d]	0.2[d]	23.84	<0.001	0.8	0.7	0.5	1.61	0.205	0.49	0.485	1.17	0.282
Sinapis arvensis	1.5[a]	1.0[a]	0.0[b]	0.1[b]	0.0[b]	0.0[b]	0.0[b]	24.73	<0.001	0.2	0.1	0.3	2.04	0.136	0.48	0.489	3.95	0.050
Species richness	8.4[a]	5.8[b]	3.4[c]	6.6[b]	2.9[c]	3.3[c]	3.1[c]	33.77	<0.001	4.3	4.6	5.5	7.19	0.001	1.00	0.320	7.11	0.009

Table 5.A28 Effect of herbicide and row spacing/cultivation treatments on vegetation cover at High Mowthorpe in 2004 (back transformed means; interaction between main factors).

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; Space*Herb df = 12; resid df = 80														
Group1														
Conv	9.1	2.7	1.1	3.1	0.2	0.4	0.3	46.28	<0.001	**Spacing**	0.68	0.510	2.25	0.017
WSR	6.4	1.3	1.2	6.1	0.5	0.3	0.3			**Conv vs WSR**	0.00	0.990		
WSR+Cult	3.7	1.6	1.0	4.4	0.4	0.4	0.6			**WSR vs WSR+Cult**	1.01	0.319		
Group12														
Conv	9.1	2.8	1.1	3.1	0.3	0.5	0.3	41.32	<0.001	**Spacing**	0.13	0.882	2.09	0.026
WSR	7.1	1.3	1.2	6.1	0.5	0.3	0.4			**Conv vs WSR**	0.00	0.949		
WSR+Cult	3.9	1.8	1.3	4.7	0.5	0.7	0.7			**WSR vs WSR+Cult**	0.16	0.692		
Groups123														
Conv	10.1	3.0	1.2	4.5	0.3	0.5	0.3	63.32	<0.001	**Spacing**	0.13	0.877	2.42	0.010
WSR	9.1	1.4	1.3	8.4	0.5	0.3	0.5			**Conv vs WSR**	0.11	0.744		
WSR+Cult	5.1	2.2	1.4	5.6	0.6	0.8	0.7			**WSR vs WSR+Cult**	0.25	0.616		
Groups1234														
Conv	17.3	4.9	2.5	5.3	0.5	0.7	0.6	56.46	<0.001	**Spacing**	0.57	0.570	2.02	0.033
WSR	13.9	3.5	2.5	10.0	0.7	0.6	1.2			**Conv vs WSR**	0.31	0.577		
WSR+Cult	9.0	3.9	2.0	6.2	1.3	1.4	0.9			**WSR vs WSR+Cult**	1.13	0.291		
Grasses														
Conv	4.9	0.6	0.0	2.7	0.0	0.1	0.1	47.65	<0.001	**Spacing**	1.10	0.337	2.48	0.008
WSR	3.2	0.1	0.2	6.0	0.1	0.1	0.1			**Conv vs WSR**	0.94	0.334		
WSR+Cult	2.0	0.5	0.0	2.8	0.3	0.1	0.1			**WSR vs WSR+Cult**	2.13	0.149		
Poa annua														
Conv	4.9	0.3	0.0	2.6	0.0	0.0	0.0	39.11	<0.001	**Spacing**	1.72	0.186	1.89	0.048
WSR	2.6	0.1	0.2	5.1	0.1	0.0	0.1			**Conv vs WSR**	0.42	0.520		
WSR+Cult	1.2	0.2	0.0	2.8	0.0	0.1	0.1			**WSR vs WSR+Cult**	3.34	0.071		

Table 5.A29 Effect of herbicide and row spacing/cultivation treatments on vegetation cover at High Mowthorpe in 2005 (back transformed means; no interaction between main factors).

	Herbicide									**Spacing/Cultivation**					**Conv vs WSR**		**WSR vs WSR+Cult**	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 92																		
Group2	0.5^{ab}	0.2^{bcd}	0.3^{abc}	0.6^{a}	0.0^{de}	0.1^{cd}	0.0^{e}	8.87	<0.001	0.2	0.3	0.1	4.47	0.014	4.69	0.033	8.23	0.005
Group3	13.6^{a}	0.0^{c}	0.2^{bc}	1.5^{b}	0.0^{c}	0.0^{c}	0.0^{c}	28.04	<0.001	0.7	0.7	0.8	0.09	0.916	0.00	0.960	0.15	0.700
Groups1234	38.4^{a}	4.5^{c}	1.6^{d}	17.8^{b}	0.6^{d}	0.3^{d}	0.6^{d}	57.23	<0.001	5.9	7.2	3.8	3.74	0.027	0.91	0.343	7.27	0.008
Broadleaved spp.	26.2^{a}	4.0^{b}	1.2^{cd}	2.6^{bc}	0.2^{d}	0.3^{d}	0.2^{d}	40.78	<0.001	2.7	3.6	1.9	2.09	0.129	0.94	0.336	4.19	0.044
Bare above	12.0^{a}	34.4^{c}	45.7^{d}	21.8^{b}	45.3^{d}	45.6^{d}	45.0^{d}	25.57	<0.001	24.0	37.5	44.0	29.48	<0.001	26.89	<0.001	5.34	0.023
Bare below	63.8	74.2	61.4	68.9	58.9	52.3	54.2	1.29	0.271	73.0	52.1	60.4	5.49	0.006	10.79	0.001	1.59	0.211
Litter	1.2	0.8	0.9	1.0	0.9	0.9	0.9	1.28	0.276	1.3	0.7	0.9	17.68	<0.001	34.33	<0.001	4.22	0.043
Crop	35.9^{a}	48.3^{b}	45.3^{b}	45.8^{b}	48.4^{b}	48.1^{b}	47.0^{b}	4.91	<0.001	55.3	39.7	41.6	41.66	<0.001	70.31	<0.001	1.14	0.288
Papaver spp.	12.6^{a}	0.0^{c}	0.2^{bc}	1.0^{b}	0.0^{c}	0.0^{c}	0.0^{c}	23.88	<0.001	0.5	0.7	0.7	0.15	0.859	0.21	0.645	0.00	0.976
Species richness	5.5^{a}	3.1^{bc}	3.5^{b}	5.0^{a}	2.3^{cd}	1.9^{d}	2.2^{cd}	16.92	<0.001	3.4	3.3	3.3	0.02	0.984	0.01	0.929	0.01	0.929

Table 5.A30 Effect of herbicide and row spacing/cultivation treatments on vegetation cover at High Mowthorpe in 2005 (back transformed means; interaction between main factors).

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; Space*Herb df = 12; resid df = 80														
Group1														
Conv	12.3	0.1	0.0	15.6	0.0	0.0	0.0	51.57	<0.001	**Spacing**	1.20	0.306	3.18	<0.001
WSR	4.0	0.0	0.2	24.3	0.1	0.0	0.1			**Conv vs WSR**	0.00	0.949		
WSR+Cult	9.7	0.1	0.1	5.0	0.0	0.0	0.0			**WSR vs WSR+Cult**	1.89	0.173		
Group4														
Conv	11.3	3.3	0.7	0.6	0.2	0.1	0.2	20.29	<0.001	**Spacing**	4.90	0.010	2.35	0.012
WSR	15.7	7.5	0.3	0.3	0.7	0.1	0.3			**Conv vs WSR**	1.35	0.248		
WSR+Cult	1.9	1.5	0.6	0.5	0.2	0.1	0.4			**WSR vs WSR+Cult**	9.61	0.003		
Groups12														
Conv	13.6	0.3	0.4	16.6	0.1	0.1	0.0	53.99	<0.001	**Spacing**	2.42	0.095	3.08	0.001
WSR	4.9	0.3	0.8	25.2	0.4	0.3	0.1			**Conv vs WSR**	0.13	0.723		
WSR+Cult	10.7	0.3	0.2	6.0	0.1	0.1	0.1			**WSR vs WSR+Cult**	4.24	0.043		
Groups123														
Conv	35.3	0.4	0.5	17.6	0.1	0.2	0.1	65.68	<0.001	**Spacing**	0.97	0.384	2.25	0.017
WSR	17.1	0.3	1.3	27.6	0.5	0.3	0.2			**Conv vs WSR**	0.01	0.919		
WSR+Cult	27.8	0.4	0.7	8.3	0.1	0.1	0.2			**WSR vs WSR+Cult**	1.57	0.214		
Grasses														
Conv	12.7	0.2	0.2	15.9	0.1	0.0	0.3	43.27	<0.001	**Spacing**	2.07	0.133	2.67	0.005
WSR	4.3	0.2	0.2	24.3	0.6	0.1	0.4			**Conv vs WSR**	0.04	0.835		
WSR+Cult	9.8	0.0	0.1	5.2	0.1	0.0	0.4			**WSR vs WSR+Cult**	3.45	0.067		
Galium aparine														
Conv	11.2	2.8	0.2	0.3	0.1	0.1	0.0	23.06	<0.001	**Spacing**	3.74	0.028	2.35	0.012
WSR	15.4	6.5	0.2	0.2	0.1	0.1	0.0			**Conv vs WSR**	0.95	0.332		
WSR+Cult	1.8	1.5	0.5	0.3	0.0	0.1	0.1			**WSR vs WSR+Cult**	7.29	0.008		

Cont'd…..

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Poa annua														
Conv	12.1	0.1	0.0	15.6	0.0	0.0	0.0	59.07	<0.001	**Spacing**	2.38	0.099	3.24	<0.001
WSR	3.9	0.0	0.1	24.1	0.0	0.0	0.0			**Conv vs WSR**	0.07	0.795		
WSR+Cult	9.6	0.0	0.0	5.0	0.0	0.0	0.0			**WSR vs WSR+Cult**	3.05	0.085		

Table 5.A31 Effect of herbicide treatment on production of total (T) and viable (V) seeds at Boxworth in 2003 (conventional spacing only).

	Herbicide					
	a	**b**	**d**	**h**	***F***	***P***
Herbicide df = 3; resid df = 6						
Group1T	198.5	12.8	6.8	11.3	3.87	0.074
Group1V	116.5[a]	1.1[b]	0.3[b]	2.0[b]	5.16	0.042
Groups123T	999.0[a]	39.7[b]	21.9[b]	13.1[b]	5.91	0.032
Groups123V	615.6[a]	7.7[b]	5.2[b]	2.0[b]	6.67	0.024
Groups1234T	999.0[a]	40.7[b]	21.9[b]	13.1[b]	5.91	0.032
Groups1234V	615.6[a]	8.1[b]	5.2[b]	2.0[b]	6.61	0.025
Broadleaved spp.T	999.0[a]	40.7[b]	21.9[b]	13.1[b]	5.94	0.031
Broadleaved spp.V	615.6[a]	8.1[b]	5.2[b]	2.0[b]	6.61	0.025
*Fallopia convolvulus*T	84.1	0.3	0.0	1.2	3.01	0.116
*Fallopia convolvulus*V	52.7	0.0	0.0	0.0	3.07	0.112

Table 5.A32 Effect of herbicide treatment on production of total (T) and viable (V) seeds at Boxworth in 2004 (conventional spacing only).

	Herbicide					
	a	**b**	**d**	**h**	***F***	***P***
Herbicide df = 3; resid df = 6						
Group1T	35480.3	6917.3	25703.0	644.7	4.52	0.055
Group1V	33112.1	6605.9	24546.1	425.6	4.24	0.063
Group3T	168.8[ab]	0.5[c]	345.7[a]	7.5[bc]	8.00	0.016
Group3V	168.8[a]	0.5[b]	330.1[a]	2.5[b]	25.58	<0.001
Group4T	1287.2	2690.5	2883.0	294.1	1.32	0.351
Group4V	1201.3	2343.2	2629.3	207.9	1.43	0.324
Groups123T	35480.3	6917.3	25703.0	757.6	4.48	0.056
Groups123V	33112.1	6605.9	25117.9	445.7	4.30	0.061
Groups1234T	39809.7	11480.5	30198.5	1777.3	4.69	0.052
Groups1234V	36306.8	10714.2	28839.3	1411.5	4.52	0.055
Broadleaved spp.T	35480.3	7243.4	25703.0	757.6	4.52	0.055
Broadleaved spp.V	33112.1	6759.8	25117.9	445.7	4.32	0.060
GrassesT	1095.5	2569.4	2817.4	294.1	1.34	0.347
GrassesV	1022.3	2289.9	2569.4	207.9	1.45	0.319
*Stellaria media*T	31621.8	793.3	25703.0	630.0	4.05	0.069
*Stellaria media*V	28839.3	723.4	24546.1	415.9	3.68	0.082
*Anisantha sterilis*T	1095.5	2569.4	2817.4	294.1	1.34	0.347
*Anisantha sterilis*V	1022.3	2289.9	2569.4	207.9	1.45	0.319
*Sinapis arvensis*T	2817.4[a]	5494.4[a]	2.0[b]	3.1[b]	35.26	<0.001
*Sinapis arvensis*V	2817.4[a]	5010.9[a]	0.8[b]	1.5[b]	52.99	<0.001
*Veronica hederifolia*T	106.2[ab]	0.0[c]	212.8[a]	4.4[bc]	7.54	0.018
*Veronica hederifolia*V	105.2[a]	0.0[b]	199.4[a]	0.0[b]	172.35	<0.001

Table 5.A33 Effect of herbicide treatment on production of total (T) and viable (V) seeds at Boxworth in 2005 (conventional spacing only).

	Herbicide					
	a	b	d	h	*F*	*P*
Herbicide df = 3; resid df = 12						
Group1T	252.5^{a}	3.5^{b}	2.8^{b}	2.3^{b}	27.85	<0.001
Group1V	99.0^{a}	3.0^{b}	1.7^{b}	0.4^{b}	10.04	0.001
Group4T	274.4	262.0	133.9	23.0	2.33	0.126
Group4V	194.0	106.2	37.9	15.6	2.04	0.162
Groups123T	266.9^{a}	6.4^{b}	2.8^{b}	2.3^{b}	21.03	<0.001
Groups123V	101.3^{a}	3.0^{b}	1.7^{b}	0.4^{b}	10.16	0.001
Groups1234T	811.8	280.8	153.9	44.7	2.92	0.077
Groups1234V	488.8	140.3	46.9	19.4	2.88	0.080
Broadleaved spp.T	659.7^{a}	181.0^{a}	14.5^{b}	9.2^{b}	13.82	<0.001
Broadleaved spp.V	425.6^{a}	127.8^{a}	4.5^{b}	1.7^{b}	13.11	<0.001
GrassesT	12.8	16.0	76.6	17.6	1.00	0.426
GrassesV	6.4	6.6	37.9	12.8	1.74	0.212
*Alopecurus myosuroides*T	8.1	8.8	35.3	1.2	2.10	0.153
*Alopecurus myosuroides*V	2.5	2.3	9.5	0.6	2.51	0.108
*Galium aparine*T	90.2^{a}	74.9^{a}	1.2^{b}	2.8^{b}	8.67	0.002
*Galium aparine*V	74.9^{a}	52.7^{a}	1.1^{b}	1.2^{b}	9.27	0.002
*Bromus commutatus*T	2.5	5.8	4.9	13.5	0.62	0.616
*Bromus commutatus*V	2.2	5.2	4.9	12.8	0.68	0.579
*Sinapis arvensis*T	92.3^{a}	1.3^{b}	1.0^{b}	0.0^{b}	8.09	0.003
*Sinapis arvensis*V	37.9^{a}	1.3^{b}	0.5^{b}	0.0^{b}	7.07	0.005

Table 5.A34 Effect of herbicide treatment on production of total (T) and viable (V) seeds at Gleadthorpe in 2003 (conventional spacing only).

	Herbicide				
	a	d	g	*F*	*P*
Herbicide df = 2; resid df = 4					
Group1T	6605.9^{a}	322.6^{b}	2.0^{c}	45.32	0.002
Group1V	2237.7	976.2	22.4	6.65	0.053
Group3T	0.5	130.8	18.1	2.90	0.166
Group3V	0.3	40.7	5.8	3.04	0.157
Groups123T	6605.9^{a}	1201.3^{a}	24.1^{b}	15.86	0.013
Groups123V	2186.8^{a}	228.1^{b}	10.7^{c}	26.14	0.005
Groups1234T	6605.9^{a}	1201.3^{a}	24.1^{b}	15.89	0.013
Groups1234V	2186.8^{a}	228.1^{b}	10.7^{c}	26.14	0.005
Broadleaved spp.T	870.0^{a}	106.2^{a}	3.9^{b}	11.15	0.023
Broadleaved spp.V	315.2	34.5	2.0	5.56	0.070
GrassesT	4264.8^{a}	1022.3^{a}	9.7^{b}	10.51	0.026
GrassesV	1070.5^{a}	157.5^{a}	4.1^{b}	12.55	0.019
*Poa annua*T	4264.8^{a}	9.5^{b}	0.0^{b}	8.22	0.038
*Poa annua*V	1070.5^{a}	4.0^{b}	0.0^{b}	11.35	0.022
*Stellaria media*T	122.0	16.4	0.5	2.82	0.172
*Stellaria media*V	108.6	11.0	0.0	3.07	0.156
*Fallopia convolvulus*T	359.6^{a}	27.7^{b}	0.0^{c}	95.91	<0.001
*Fallopia convolvulus*V	82.9^{a}	6.7^{b}	0.0^{c}	35.82	0.003

Table 5.A35 Effect of herbicide treatment on production of total (T) and viable (V) seeds at Gleadthorpe in 2004 (conventional spacing only).

	Herbicide				
	a	**d**	**g**	***F***	***P***
Herbicide df = 2; resid df = 4					
Group1T	3889.5[a]	757.6[a]	3.9[b]	22.09	0.007
Group1V	1411.5[a]	228.1[a]	2.7[b]	21.59	0.007
Groups123T	3980.1[a]	757.6[b]	16.0[c]	46.74	0.002
Groups123V	1478.1[a]	233.4[a]	2.7[b]	22.06	0.007
Groups1234T	3980.1[a]	762.8[b]	20.6[c]	56.01	0.001
Groups1234V	1478.1[a]	233.4[a]	2.7[b]	22.06	0.007
Broadleaved spp.T	113.8	9.2	3.5	3.43	0.136
Broadleaved spp.V	52.7[a]	5.0[ab]	0.0[b]	10.51	0.026
GrassesT	3889.5[a]	740.3[a]	3.9[b]	22.03	0.007
GrassesV	1411.5[a]	222.9[a]	2.7[b]	21.57	0.007
*Poa annua*T	3889.5[a]	740.3[a]	3.9[b]	22.03	0.007
*Poa annua*V	1411.5[a]	222.9[a]	2.7[b]	21.57	0.007

Table 5.A36 Effect of herbicide treatment on production of total (T) and viable (V) seeds at Gleadthorpe in 2005 (conventional spacing only).

	Herbicide				
	a	**d**	**g**	***F***	***P***
Herbicide df = 2; resid df = 8					
Group1T	1904.5[a]	3466.4[a]	6.6[b]	56.31	<0.001
Group1V	449.8[a]	802.5[a]	0.4[b]	176.08	<0.001
Groups123T	2171.7[a]	3731.5[a]	15.4[b]	85.51	<0.001
Groups123V	614.2[a]	969.5[a]	1.4[b]	221.05	<0.001
Groups1234T	2181.7[a]	3731.5[a]	24.4[b]	52.46	<0.001
Groups1234V	615.6[a]	976.2[a]	4.8[b]	35.57	<0.001
Broadleaved spp.T	415.9[a]	69.8[b]	15.6[b]	12.59	0.003
Broadleaved spp.V	194.4[a]	54.8[b]	1.4[c]	38.30	<0.001
GrassesT	1658.6[a]	3466.4[a]	1.5[b]	46.48	<0.001
GrassesV	353.8[a]	793.3[a]	1.3[b]	31.89	<0.001
Poa spp.T	1651.0[a]	3474.4[a]	0.0[b]	228.31	<0.001
Poa spp.V	352.2[a]	793.3[b]	0.0[c]	249.12	<0.001

Table 5.A37 Effect of herbicide treatment on production of total (T) and viable (V) seeds at High Mowthorpe in 2003 (conventional spacing only).

	Herbicide				
	a	**d**	**g**	***F***	***P***
Herbicide df = 2; resid df = 4					
Group1T	5622.4[a]	6308.6[a]	11.9[b]	29.72	0.004
Group1V	3234.9[a]	2569.4[a]	6.6[b]	26.07	0.005
Group3T	46.9[a]	24.1[a]	4465.8[b]	13.63	0.016
Group3V	34.5[a]	23.5[a]	1046.1[b]	7.06	0.049
Groups123T	5887.4	6308.6	4465.8	0.06	0.946
Groups123V	3387.4	2569.4	1070.[b]	0.35	0.723
Groups1234T	6024.6	6308.6	4465.8	0.06	0.944
Groups1234V	3466.4	2569.4	1070.5	0.36	0.716
Broadleaved spp.T	723.4[a]	92.3[a]	5.0[b]	13.59	0.016
Broadleaved spp.V	615.6[a]	84.1[a]	1.3[b]	16.26	0.012
GrassesT	3889.5	6165.0	4465.8	0.08	0.926
GrassesV	1818.7	2453.7	1070.5	0.14	0.876
*Poa annua*T	3800.9[a]	6165.0[a]	7.3[b]	24.44	0.006
*Poa annua*V	1777.3[a]	2453.7[a]	4.6[b]	22.93	0.006
Agrostis sp.T	0.0[a]	0.0[a]	4465.8[b]	74.99	<0.001
Agrostis sp.V	0.0[a]	0.0[a]	1046.1[b]	24.70	0.006
*Sinapis arvensis*T	82.2	0.3	0.0	3.02	0.159
*Sinapis arvensis*V	1.89	0.12	0	2.97	0.162

Table 5.A38 Effect of herbicide treatment on production of total (T) and viable (V) seeds at High Mowthorpe in 2004 (conventional spacing only).

	Herbicide				
	a	**d**	**g**	***F***	***P***
Herbicide df = 2; resid df = 4					
Group1T	6759.8	6605.9	228.1	6.61	0.054
Group1V	3466.4[a]	2753.2[a]	12.5[b]	14.23	0.015
Group2T	10.7	0.3	0.3	0.80	0.509
Group2V	10.0	0.0	0.0	1.00	0.444
Group3T	80.3	15.2	0.0	4.42	0.097
Group3V	23.0	10.2	0.0	3.52	0.131
Group4T	1948.8	140.3	46.9	6.42	0.056
Group4V	1121.0[a]	19.0[b]	18.5[b]	8.86	0.034
Groups12T	6917.3	6605.9	228.1	6.64	0.054
Groups12V	3547.1[a]	2753.2[a]	12.5[b]	14.51	0.015
Groups123T	7078.5	6605.9	228.1	6.85	0.051
Groups123V	3629.8[a]	2817.4[a]	12.5[b]	14.87	0.014
Groups1234T	9771.4[a]	6759.8[a]	536.0[b]	7.78	0.042
Groups1234V	5247.1[a]	2817.4[a]	73.1[b]	25.07	0.005
Broadleaved spp.T	2950.2[a]	157.5[b]	322.6[b]	9.53	0.030
Broadleaved spp.V	1777.3[a]	41.7[b]	42.7[b]	14.65	0.014
GrassesT	6605.9[a]	6455.5[a]	6.4[b]	12.39	0.019
GrassesV	3234.9[a]	2753.2[a]	4.2[b]	22.43	0.007
*Poa annua*T	6605.9[a]	6308.6[a]	6.4[b]	12.44	0.019
*Poa annua*V	3234.9[a]	2753.2[a]	4.2[b]	22.43	0.007
*Galium aparine*T	1948.8	69.8	46.9	5.93	0.064
*Galium aparine*V	1121.0[a]	19.0[b]	18.5[b]	8.86	0.034
*Matricaria discoidea*T	9.2	0.0	0.0	1.00	0.444
*Matricaria discoidea*V	9.0	0.0	0.0	1.00	0.444
*Fallopia convolvulus*T	26.5	18.1	99.0	0.90	0.476

Table 5.A39 Effect of herbicide treatment on production of total (T) and viable (V) seeds at High Mowthorpe in 2005 (conventional spacing only).

	Herbicide				
	a	**d**	**g**	***F***	***P***
Herbicide df = 2; resid df = 8					
Group1T	51.5	2.7	0.2	3.90	0.066
Group1V	24.7	1.6	0.0	2.43	0.150
Group3T	31621.8[a]	13866.6[a]	0.4[b]	270.85	<0.001
Group3V	23877.1[a]	7797.3[b]	0.2[c]	276.34	<0.001
Group4T	1379.4[a]	7.5[b]	5.8[b]	14.94	0.002
Group4V	1046.1[a]	7.3[b]	4.8[b]	15.47	0.002
Groups123T	37152.5[a]	13866.6[b]	0.7[c]	394.63	<0.001
Groups123V	28905.8[a]	7815.3[b]	0.2[c]	448.84	<0.001
Groups1234T	39809.7[a]	13802.8[a]	6.9[b]	61.20	<0.001
Groups1234V	30902.0[a]	7761.5[a]	4.8[b]	66.57	<0.001
Broadleaved spp.T	14790.1[a]	124.9[b]	2.1[b]	13.61	0.003
Broadleaved spp.V	11480.5[a]	88.1[b]	1.6[b]	13.57	0.003
GrassesT	7761.5[a]	10714.2[a]	2.0[b]	62.95	<0.001
GrassesV	5247.1[a]	5753.4[a]	1.5[b]	61.09	<0.001
Papaver sp.T	3889.5[a]	38.8[ab]	0.2[b]	7.75	0.013
Papaver sp.V	3387.4[a]	37.9[ab]	0.2[b]	7.74	0.013
Poa spp.T	2137.0[a]	5010.9[a]	0.2[b]	36.60	<0.001
Poa spp.V	1478.1[a]	3387.4[a]	0.0[b]	36.83	<0.001
*Poa annua*T	28.5	0.0	0.0	2.67	0.130
*Poa annua*V	24.7	0.0	0.0	2.66	0.130
*Galium aparine*T	1379.4[a]	0.6[b]	1.6[b]	26.56	<0.001
*Galium aparine*V	1046.1[a]	0.6[b]	1.2[b]	29.31	<0.001
Agrostis sp.T	4.1	27.2	0.0	1.00	0.409
Agrostis sp.V	3.3	7.5	0.0	0.66	0.544

Reproductive status

Weighted mean calculated as: (vegetative x 1) + (flower shoots/buds x 2) + (flowering x 3) + (seeding/dehiscing x 4). Cover = mean of raw data (no transformation).

Table 5.A40 Effect of herbicide on reproductive status at Boxworth.

2004	Vegetative	Flower shoots/ buds	Flowering	Seeding/ dehiscing	Weighted	Rank	Cover
Anisantha sterilis							
a	19	6	17	58	315	8	6.4
b	12	0	27	61	337	4	4.9
c	12	0	16	72	347	2	7.0
d	17	0	21	62	329	6	9.5
e	16	0	14	70	338	3	7.2
f	12	4	20	64	336	5	2.4
g	13	0	13	74	347	1	15.3
h	19	0	23	59	321	7	3.4
Sinapis arvensis							
a	12	2	13	73	348	2	16.0
b	19	2	14	65	324	3	12.0
c	-	-	-	-	0	8	0
d	0	0	13	88	388	1	0
e	92	3	3	1	113	4	0.1
f	100	0	0	0	100	5	0
g	100	0	0	0	100	5	0
h	100	0	0	0	100	5	0
Stellaria media							
a	16	26	8	51	294	1	54.1
b	59	21	2	18	180	8	1.0
c	23	26	10	41	268	2	32.2
d	26	28	7	38	257	3	39.1
e	53	24	6	18	189	7	1.1
f	52	24	6	19	191	6	0.3
g	35	24	7	34	240	4	16.5
h	39	35	12	14	200	5	0.2
Volunteer bean							
a	32	10	2	57	283	2	18.6
b	27	7	4	62	301	1	21.0
c	78	2	0	20	161	6	1.4
d	49	5	4	41	238	3	25.2
e	92	1	0	7	123	8	1.0
f	73	3	4	20	171	5	1.8
g	56	1	0	43	230	4	0.4
h	82	2	4	11	144	7	1.2

Table 5.A40 cont'd…..

2005	Vegetative	Flower shoots/ buds	Flowering	Seeding/ dehiscing	Weighted	Rank	Cover
Sinapis arvensis							
a	0	3	3	94	391	2	4.1
b	0	11	7	83	372	3	0.2
c	20	20	5	55	295	4	0.1
d	0	68	0	33	265	5	0.1
e	100	0	0	0	100	6	0
f	-	-	-	-	0	7	0
g	0	0	0	100	400	1	0
h	-	-	-	-	0	7	0
Galium aparine							
a	4	18	15	64	338	1	4.8
b	5	22	17	56	324	2	2.2
c	40	13	7	40	247	5	0.3
d	22	9	2	68	315	3	0.3
e	50	33	0	17	183	7	0.1
f	75	16	9	0	134	8	0
g	50	0	0	50	250	4	0
h	43	16	13	29	227	6	0.1
Bromus commutatus							
a	0	0	1	99	399	5	0.2
b	0	0	0	100	400	1	0.2
c	0	0	1	99	399	4	0.3
d	0	0	0	100	400	1	0.3
e	0	0	3	97	397	8	0.2
f	0	0	2	98	398	7	0.2
g	0	0	0	100	400	1	0.1
h	0	0	1	99	399	6	0.3
Alopecurus myosuroides							
a	0	0	7	93	393	5	1.8
b	0	0	7	93	393	4	0.7
c	0	0	3	98	398	2	0.2
d	0	0	5	95	395	3	3.2
e	0	0	10	90	390	6	0.1
f	0	0	67	33	333	8	0
g	0	0	0	100	400	1	0
h	0	0	10	90	390	6	0.1

Table 5.A41 Effect of herbicide on reproductive status at Gleadthorpe.

2003	Vegetative	Flower shoots/ buds	Flowering	Seeding/ dehiscing	Weighted	Rank	Cover
Fallopia convolvulus							
a	90	9	1	0	111	6	1.2
b	60	40	0	0	140	3	0.3
c	68	22	4	6	149	2	1.0
d	90	10	0	0	110	7	0.4
e	73	27	0	0	127	4	0.3
f	47	53	0	0	153	1	0.2
g	81	19	0	0	119	5	0.3
Poa annua							
a	63	2	24	11	183	2	12.6
b	91	0	9	0	119	6	0.1
c	52	0	47	0	195	1	0.1
d	66	3	25	6	170	3	2.3
e	73	13	11	3	145	4	0.6
f	95	0	5	0	111	7	0.1
g	81	0	19	0	138	5	0
Polygonum aviculare							
a	76	15	9	0	133	1	1.0
b	89	10	1	0	112	4	0.2
c	83	13	4	0	121	3	0.2
d	80	11	9	0	130	2	0.9
e	99	1	0	0	101	6	0.1
f	99	1	0	0	101	5	0.2
g	100	0	0	0	100	7	0.1
Stellaria media							
a	69	2	6	22	182	2	4.4
b	100	0	0	0	100	3	0
c	-	-	-	-	0	4	0
d	54	3	1	42	231	1	1.5
e	-	-	-	-	0	4	0
f	-	-	-	-	0	4	0
g	-	-	-	-	0	4	0
2004							
Poa annua							
a	58	0	33	8	192	3	16.4
b	80	0	20	0	140	4	0.8
c	97	0	0	3	109	6	0.1
d	56	1	25	19	207	1	13.6
e	-	-	-	-	0	7	0
f	88	0	13	0	125	5	0
g	50	0	50	0	200	2	0

Table 5.A41 cont'd.….

2005	Vegetative	Flower shoots/ buds	Flowering	Seeding/ dehiscing	Weighted	Rank	Cover
Veronica arvensis							
a	0	1	0	98	397	1	2.7
b	44	25	0	31	219	3	0
c	-	-	-	-	0	4	0
d	5	6	1	88	371	2	3.5
e	-	-	-	-	0	4	0
f	-	-	-	-	0	4	0
g	-	-	-	-	0	4	0
Stellaria media							
a	0	2	1	97	395	2	20.7
b	0	0	0	100	400	1	0.5
c	-	-	-	-	0	5	0
d	0	3	0	96	393	3	8.8
e	-	-	-	-	0	5	0
f	100	0	0	0	100	4	0
g	-	-	-	-	0	5	0
Poa annua							
a	8	4	6	82	361	3	16.3
b	29	1	1	69	309	4	0.6
c	0	0	0	100	400	1	0
d	6	3	7	84	370	2	19.4
e	67	0	0	33	200	7	0.1
f	50	0	0	50	250	5	0.1
g	53	9	0	38	222	6	0.1

Table 5.A42 Effect of herbicide on reproductive status at High Mowthorpe.

2003	Vegetative	Flower shoots/ buds	Flowering	Seeding/ dehiscing	Weighted	Rank	Cover
Galium aparine							
a	60	14	14	12	178	1	3.4
b	72	15	10	3	145	2	0.7
c	79	11	6	3	134	3	0.3
d	87	6	6	0	119	4	0.1
e	-	-	-	-	0	6	0
f	100	0	0	0	100	5	0
g	-	-	-	-	0	6	0
Poa annua							
a	48	0	44	8	212	2	7.7
b	24	0	51	26	278	1	0.1
c	55	3	38	5	192	4	2.0
d	51	0	40	8	206	3	10.0
e	66	3	29	2	167	6	1.4
f	72	4	23	1	153	7	1.3
g	66	1	28	5	173	5	1.3
Sinapis arvensis							
a	47	2	6	44	249	1	2.2
b	53	4	17	26	217	2	2.0
c	87	1	4	8	133	4	0.9
d	77	12	0	12	146	3	0.3
e	97	3	0	0	103	5	0.2
f	100	0	0	0	100	6	0
g	-	-	-	-	0	7	0
Volunteer OSR							
a	70	9	7	14	165	3	1.1
b	58	16	12	12	177	2	1.4
c	62	9	10	18	184	1	0.9
d	85	10	4	1	121	5	0.2
e	75	9	9	7	148	4	0.2
f	100	0	0	0	100	6	0
g	100	0	0	0	100	6	0
Volunteer potato							
a	100	0	0	0	100	2	0.7
b	100	0	0	0	100	2	1.2
c	100	0	0	0	100	2	2.6
d	98	0	2	0	104	1	0.7
e	100	0	0	0	100	2	2.2
f	100	0	0	0	100	2	1.2
g	100	0	0	0	100	2	0.9
2004							
Fallopia convolvulus							
a	100	0	0	0	100	2	1.1
b	100	0	0	0	100	2	0.5
c	100	0	0	0	100	2	1.1
d	100	0	0	0	100	1	0.9
e	100	0	0	0	100	2	0.3
f	100	0	0	0	100	2	0.3
g	100	0	0	0	100	2	0.3

Table 5.A42 cont'd....

2004	Vegetative	Flower shoots/ buds	Flowering	Seeding/ dehiscing	Weighted	Rank	Cover
Galium aparine							
a	50	11	26	13	201	1	5.0
b	60	15	16	9	174	2	1.3
c	70	9	14	7	159	3	1.2
d	80	9	8	3	134	4	0.5
e	92	5	0	2	113	7	0.1
f	87	7	6	0	119	6	0.2
g	80	14	5	1	126	5	0.4
Poa annua							
a	67	0	26	8	174	2	3.4
b	100	0	0	0	100	4	0.3
c	100	0	0	0	100	4	0.1
d	67	0	23	10	176	1	3.8
e	100	0	0	0	100	4	0.1
f	100	0	0	0	100	4	0.1
g	96	0	4	0	108	3	0.1
Sinapis arvensis							
a	60	6	10	24	198	1	1.9
b	59	6	24	11	187	2	1.5
c	95	2	2	0	107	5	0.1
d	91	1	5	2	118	4	0.2
e	99	0	1	0	103	6	0.1
f	86	0	14	0	128	3	0
g	100	0	0	0	100	7	0.1
2005							
Fumaria officinale							
a	74	1	13	12	162	6	0.5
b	63	9	8	20	186	3	0.4
c	66	9	7	18	177	5	0.5
d	44	13	27	17	216	2	0.8
e	52	14	34	0	182	4	0.1
f	46	2	32	19	225	1	0.3
g	100	0	0	0	100	7	0
Galium aparine							
a	29	35	36	0	208	1	11.1
b	33	29	38	0	205	2	5.5
c	44	29	27	0	184	3	0.4
d	70	20	9	0	139	4	0.4
e	83	17	0	0	117	5	0.2
f	100	0	0	0	100	6	0.1
g	100	0	0	0	100	6	0.1
Papaver spp.							
a	12	85	3	0	191	1	17.3
b	100	0	0	0	100	6	0
c	24	76	0	0	176	4	0.4
d	24	75	1	0	176	3	1.6
e	88	13	0	0	113	5	0.1
f	100	0	0	0	100	6	0
g	32	57	11	0	179	2	0.1
Poa annua							
a	40	12	43	5	212	2	10.2
b	77	2	20	0	143	5	0.1
c	46	5	49	0	202	3	0.1
d	36	14	46	4	219	1	16.2
e	96	0	4	0	108	6	0.1
f	100	0	0	0	100	7	0
g	66	4	30	0	164	4	0.1

APPENDIX 4 – INVERTEBRATE ANALYSES

Table 5.A43 High Mowthorpe 2003 no interactions.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 6; resid df = 52																		
Acalyptera	27.1[a]	17.8[ab]	21.8[a]	11.2[b]	22.7[a]	16.8[ab]	19.5[a]	2.75	0.03	21.1	17.0	19.0	0.92	0.41	1.83	0.183	0.49	0.490
Aschiza	8.0[a]	4.1[ab]	7.2[a]	6.0[ac]	3.2[bc]	5.0[ac]	1.9[b]	4.13	0.003	4.6	4.3	5.3	0.55	0.58	0.11	0.740	1.06	0.308
Brachycera	4.4	5.2	3.1	3.9	3.5	4.1	3.2	0.50	0.81	3.6	4.0	4.0	0.11	0.90	0.15	0.696	0	0.986
Calyptera	0.6	0.6	1.1	1.0	1.4	0.8	1.8	1.10	0.38	1.2	1.1	0.7	1.50	0.24	0.13	0.720	0.65	0.206
Tipulidae	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.81	0.57	0.0	0.0	0.0	0.49	0.62	0.73	0.397	0	1
Nematocera (No Tipulidae)	7.1	11.7	16.4	11.6	12.3	13.9	13.6	1.26	0.30	11.7	14.3	10.5	1.07	0.35	0.88	0.355	2.08	0.157
Total Diptera	53.5	42.0	52.3	42.4	46.1	44.6	41.5	0.97	0.46	45.0	43.7	48.9	0.70	0.50	0.10	0.756	1.32	0.258
Cantharidae																		
Carabidae	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.00	0.44	0.0	0.0	0.0	1.00	0.38	0	1	1.50	0.228
Chrysomelidae	0.5	0.1	0.3	0.2	0.4	0.1	0.3	0.80	0.58	0.1	0.3	0.3	2.52	0.09	3.73	0.061	0	0.979
Curculionidae	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.83	0.55	0.0	0.0	0.1	0.54	0.59	0.42	0.522	1.05	0.312
Elateridae	0.1	0.2	0.3	0.2	0.2	0.3	0.1	0.42	0.86	0.1	0.3	0.1	0.87	0.43	1.45	0.235	1.12	0.296
Staphylinidae	0.8	0.3	0.0	0.4	0.4	0.6	0.1	2.58	0.03	0.4	0.5	0.1	3.89	0.03	1.07	0.308	7.62	0.009
Total Coleoptera	2.4	1.3	1.0	1.0	1.1	1.1	0.8	1.58	0.18	0.7	1.6	1.4	4.35	0.02	7.32	0.010	0.12	0.736
Heteroptera	0.8	0.1	0.7	0.6	0.6	0.5	0.6	0.71	0.65	0.6	0.6	0.4	0.51	0.61	0.02	0.897	0.87	0.358
Homoptera	0.8	0.4	0.8	0.6	0.9	1.3	1.1	1.14	0.36	0.8	0.5	1.1	2.09	0.14	1.48	0.231	4.12	0.049
Symphyta Adults																		
Lepidoptera Adults	0.2	0.0	0.1	0.2	0.1	0.2	0.0	1.07	0.40	0.1	0.0	0.2	3.51	0.04	0.06	0.802	5.81	0.021
Lepidoptera Larvae	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.88	0.52	0.0	0.1	0.0	2.11	0.14	3.16	0.083	3.16	0.083
Neuroptera Larvae	0.0	0.3	0.0	0.0	0.0	0.1	0.1	1.39	0.24	0.1	0.1	0.1	0.02	0.98	0.04	0.847	0	1
Orthoptera																		
Araneae	2.5	2.0	1.5	1.6	1.9	1.8	0.8	1.17	0.34	1.79	1.52	1.70	0.16	0.85	0.3	0.584	0.14	0.707
Opiliones																		
Nectar Feeders	8.4[a]	4.8[ab]	7.6[a]	6.4[ab]	3.6[bc]	5.8[ab]	2.1[c]	4.21	0.002	5.0	4.6	5.8	0.60	0.55	0.16	0.690	1.18	0.284

Cont'd……

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Herbivores	1.6	0.4	1.3	1.0	1.5	1.5	1.5	1.75	0.13	1.1	1.1	1.5	0.27	0.76	0	0.988	2.11	0.154
Omnivore / Mixed	50.5	38.0	49.8	39.7	43.1	41.8	39.5	1.15	0.35	42.3	40.9	45.7	0.80	0.46	0.14	0.712	1.32	0.257
Predators	8.3	7.6	5.0	6.0	6.3	6.2	4.3	1.30	0.28	6.0	6.3	6.1	0.03	0.97	0.05	0.832	0.04	0.846
Total Arthropods	62.4	46.8	57.5	47.9	52.2	50.8	46.4	1.25	0.30	50.4	49.8	55.0	0.69	0.51	0.01	0.915	1.13	0.294
Chick Food Index	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.13	0.99	0.1	0.2	0.2	1.05	0.36	2.09	0.156	0.47	0.497
Skylark Food Items	7.7	4.6	4.7	4.7	5.7	5.6	3.9	1.24	0.31	4.9	5.0	5.7	0.34	0.72	0	0.953	0.46	0.501

Table 5.A44 High Mowthorpe 2003 interactions.

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; Space*Herb df = 14; resid df = 42														
Diptera larvae														
Conv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.22	0.06	**Spacing**	4.62	0.02	2.22	0.03
WSR	0.0	0.0	0.0	0.0	0.0	0.0	0.0			**Conv vs WSR**	0	1		
WSR+Cult	0.0	0.0	0.3	0.0	0.0	0.0	0.6			**WSR vs WSR+Cult**	6.92	0.012		
Other Coleoptera														
Conv	0.3	0.0	0.0	0.0	0.0	0.0	0.0	3.21	0.01	**Spacing**	6.54	0.004	3.63	0.001
WSR	0.0	2.0	0.0	0.0	0.0	0.0	0.0			**Conv vs WSR**	1.59	0.214		
WSR+Cult	1.5	0.3	1.3	0.0	0.0	0.0	1.1			**WSR vs WSR+Cult**	5.3	0.027		
Symphyta larvae														
Conv	0.0	0.0	0.0	0.0	0.6	0.0	0.0	2.22	0.06	**Spacing**	1.54	0.23	2.74	0.01
WSR	0.3	0.0	0.0	0.0	0.0	0.0	0.0			**Conv vs WSR**	0.77	0.386		
WSR+Cult	0.0	0.0	0.0	0.0	0.0	0.0	0.0			**WSR vs WSR+Cult**	0.77	0.386		

Table 5.A45 High Mowthorpe2004 no interactions.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	b	c	d	e	f	g	*F*	*P*	Conv	WSR	WSR +Cult	*F*	*P*	*F*	*P*	*F*	*P*
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 3; resid df = 50																		
Acalyptera	6.5	5.5	5.4	7.0				0.87	0.462	6.5	5.4	6.3	0.69	0.51	1.23	0.274	0.78	0.383
Aschiza	2.5	1.8	1.5	1.8				0.95	0.426	2.1	2.0	1.6	0.59	0.56	0.09	0.76	0.56	0.457
Brachycera	14.9	14.6	14.8	14.2				0.08	0.973	14.0	14.4	15.4	0.50	0.61	0.08	0.785	0.49	0.489
Nematocera (No Tipulidae)	1.2	1.5	1.7	1.7				0.4	0.756	2.2	1.2	1.2	3.06	0.06	4.99	0.031	0.04	0.844
Cantharidae																		
Carabidae	0.1	0.2	0.5	0.3				1.67	0.188	0.1	0.2	0.4	2.47	0.10	0.5	0.484	2.17	0.148
Chrysomelidae	0.4	0.8	0.5	0.4				0.83	0.486	0.6	0.5	0.4	0.37	0.69	0.23	0.633	0.15	0.705
Curculionidae	0.2	0.3	0.1	0.0				1.43	0.247	0.1	0.2	0.1	0.97	0.39	1.45	0.235	1.45	0.235
Elateridae	2.4	2.2	2.5	1.8				0.5	0.684	1.7	2.1	3.0	2.11	0.13	0.58	0.451	1.62	0.209
Staphylinidae	2.1	2.5	1.7	1.2				1.61	0.202	1.8	2.3	1.5	1.25	0.30	0.96	0.333	2.44	0.126
Other Coleoptera	21.0	16.7	13.4	10.4				2.18	0.103	18.6	14.0	12.6	1.30	0.28	1.27	0.266	0.19	0.664
Total Coleoptera	27.9	25.2	21.7	17.4				2.68	0.059	25.1	22.3	21.0	0.69	0.51	0.59	0.445	0.15	0.7
Heteroptera	1.2	1.4	1.1	1.7				0.5	0.682	1.6	1.2	1.3	0.52	0.60	0.98	0.328	0.08	0.781
Homoptera	0.6	0.3	0.9	0.5				2.04	0.122	0.5	0.6	0.6	0.42	0.66	0.5	0.484	0.03	0.874
Symphyta Larvae	0.1	0.4	0.3	0.3				0.73	0.542	0.3	0.4	0.2	0.96	0.39	0.53	0.469	1.92	0.173
Symphyta Adults																		
Lepidoptera Adults	0.0	0.0	0.0	0.0				0.65	0.586	0.1	0.0	0.0	1.96	0.15	2.93	0.094	0	1
Lepidoptera Larvae	0.2	0.2	0.1	0.1				0.33	0.805	0.1	0.2	0.1	0.91	0.41	0.65	0.424	1.79	0.188
Neuroptera Larvae	0.1	0.2	0.3	0.1				0.29	0.832	0.2	0.3	0.1	1.64	0.21	0.41	0.526	3.19	0.081
Orthoptera																		
Opiliones																		
Nectar Feeders	5.7	4.7	4.4	3.8				1.08	0.367	4.4	4.4	5.0	0.30	0.74	0	0.997	0.45	0.504
Herbivores	3.1	4.1	3.4	3.8				0.7	0.559	4.0	3.6	3.2	0.96	0.39	0.46	0.501	0.5	0.483
Omnivore / Mixed	39.2	33.5	29.3	27.8				2.01	0.127	35.3	31.8	29.6	0.87	0.43	0.59	0.445	0.29	0.593
Predators	19.5	20.2	19.4	17.5				0.73	0.542	18.7	19.3	19.3	0.08	0.92	0.13	0.725	0	0.988
Total Arthropods	67.4	64.5	58.6	54.1				2.35	0.085	63.9	60.8	58.2	0.75	0.48	0.39	0.536	0.36	0.552
Chick Food Index	1.3	1.4	1.6	1.1				0.76	0.521	1.1	1.3	1.7	2.75	0.08	0.78	0.381	2.07	0.157
Skylark Food Items	36.4^{a}	35.2^{a}	30.6^{ab}	25.4^{b}				2.98	0.042	34.8	31.8	28.6	1.42	0.25	0.62	0.435	0.81	0.374

Table 5.A46 High Mowthorpe 2004 interactions.

	Herbicide							**Herbicide**		**Spacing/Cultivation**			**Spacing*Herbicide**	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; Space*Herb df = 14; resid df = 42														
Calyptera														
Conv	3.1	0.0	2.2	0.8				1.33	0.277	**Spacing**	4.96	0.01	4.14	0.002
WSR	1.8	4.2	3.1	2.2						**Conv vs WSR**	9.17	0.004		
WSR+Cult	2.0	1.1	0.8	2.5						**WSR vs WSR+Cult**	5.12	0.029		
Tipulidae														
Conv	0.9	0.1	0.9	1.5				0.45	0.718	**Spacing**	1.28	0.289	2.5	0.036
WSR	0.3	0.9	0.6	0.0						**Conv vs WSR**	2.55	0.117		
WSR+Cult	0.9	0.3	0.5	0.6						**WSR vs WSR+Cult**	0.56	0.459		
Diptera larvae														
Conv	0.0	2.1	0.0	0.1				21.09	<0.001	**Spacing**	19.39	<0.001	15.99	<0.001
WSR	0.0	0.1	0.0	0.1						**Conv vs WSR**	21.44	<0.001		
WSR+Cult	0.0	0.0	0.0	0.0						**WSR vs WSR+Cult**	1.67	0.203		
Total Diptera														
Conv	28.4	27.1	34.8	27.8				0.41	0.75	**Spacing**	0.1	0.907	2.29	0.052
WSR	30.3	34.9	22.3	27.3						**Conv vs WSR**	0.19	0.664		
WSR+Cult	33.4	24.9	27.3	31.1						**WSR vs WSR+Cult**	0.07	0.791		
Araneae														
Conv	2.8	5.9	3.6	3.9				0.79	0.461	**Spacing**	1.06	0.375	2.36	0.046
WSR	4.0	6.7	4.0	1.7						**Conv vs WSR**	0.05	0.832		
WSR+Cult	4.6	1.9	2.8	3.3						**WSR vs WSR+Cult**	0.93	0.34		

Table 5.A47 High Mowthorpe 2005 no interactions.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 3; resid df = 50																		
Acalyptera	39.6[a]	25.4[b]	31.4[ab]	31.8[ab]				3.93	0.01	31.2	31.4	32.6	0.09	0.92	0	0.948	0.11	0.747
Aschiza	16.4[a]	7.2[b]	6.4[b]	12.2[a]				7.36	<0.001	11.7	11.4	7.1	3.80	0.03	0.02	0.897	5.38	0.025
Brachycera	15.4	14.0	16.7	18.3				1.05	0.38	17.7	13.8	16.7	1.75	0.19	3.22	0.08	1.84	0.182
Calyptera	3.7	1.8	2.7	2.9				1.88	0.15	2.4	3.3	2.4	0.83	0.44	1.26	0.268	1.22	0.275
Tipulidae	1.5	1.0	0.7	1.3				1.22	0.31	1.0	1.5	0.9	1.12	0.34	1.47	0.232	1.87	0.179
Nematocera (No Tipulidae)	7.6[a]	4.6[bc]	3.6b[c]	5.5[ac]				3.81	0.02	6.7	5.1	4.0	3.38	0.04	2.02	0.163	1.38	0.246
Diptera Larvae	0.3	0.1	0.4	0.5				1.29	0.29	0.3	0.5	0.2	1.82	0.17	1.61	0.212	3.49	0.069
Total Diptera	91.9[a]	58.4[b]	65.5[bc]	75.6[ac]				5.14	0.004	77.3	70.6	67.7	0.84	0.44	0.76	0.387	0.15	0.697
Cantharidae	0.0	0.0	0.0	0.0				0.65	0.59	0.0	0.1	0.0	1.96	0.15	2.93	0.094	2.93	0.094
Carabidae	0.3	0.2	0.3	0.3				0.03	1.00	0.3	0.2	0.3	0.18	0.84	0.21	0.651	0.31	0.579
Chrysomelidae	0.3	1.1	0.9	0.8				2.42	0.08	0.6	0.6	1.0	1.46	0.24	0.03	0.869	1.94	0.171
Curculionidae	0.1	0.0	0.0	0.0				1.50	0.23	0.1	0.0	0.1	1.66	0.20	1.42	0.24	3.19	0.081
Elateridae	0.1	0.2	0.1	0.5				1.74	0.17	0.0	0.1	0.6	7.00	0.002	0.6	0.444	7.76	0.008
Other Coleoptera	3.1	0.1	0.5	0.7				8.00	<0.001	1.1	0.9	0.6	0.68	0.51	0.2	0.658	0.5	0.481
Total Coleoptera	8.2[a]	4.1[bc]	3.2[b]	6.6[ac]				5.39	0.00	5.4	4.9	5.4	0.13	0.87	0.21	0.648	0.19	0.663
Heteroptera	0.18[a]	0.1[a]	0.1[a]	1.2[b]				9.80	<0.001	0.3	0.5	0.3	0.47	0.63	0.7	0.408	0.7	0.408
Homoptera	0.4	0.1	0.2	0.2				0.62	0.61	0.3	0.1	0.3	1.46	0.24	1.76	0.191	2.53	0.119
Symphyta Larvae	0.2	0.0	0.0	0.3				2.23	0.10	0.2	0.1	0.2	1.18	0.32	1.23	0.274	2.18	0.147
Symphyta Adults																		
Lepidoptera Adults																		
Lepidoptera Larvae	0.0	0.0	0.1	0.1				2.18	0.10	0.1	0.0	0.1	1.69	0.20	1.45	0.235	3.26	0.078
Neuroptera Larvae	0.0	0.0	0.0	0.0				0.34	0.79	0.0	0.0	0.1	1.03	0.37	0.52	0.477	2.06	0.158
Orthoptera																		
Araneae	3.1	3.9	3.1	1.9				1.55	0.22	4.2	2.3	2.5	2.53	0.09	4.32	0.044	0.08	0.773
Opiliones																		

Cont'd……

	Herbicide									Spacing/Cultivation					Conv vs WSR			
	a	b	c	d	e	f	g	*F*	*P*	Conv	WSR	WSR +Cult	*F*	*P*	*F*	*P*	*F*	*P*
Nectar Feeders	16.7[a]	7.6[b]	6.6[b]	13.1[a]				7.17	<0.001	11.8	11.6	7.9	2.50	0.09	0.01	0.91	3.52	0.067
Herbivores	1.0	1.4	1.4	1.5				0.34	0.79	1.3	0.9	1.9	2.90	0.07	1.52	0.225	5.81	0.02
Omnivore / Mixed	85.5[a]	45.1[c]	49.9[bc]	61.1[b]				11.83	<0.001	63.9	59.5	52.8	1.80	0.18	0.5	0.483	1.37	0.248
Predators	19.2	18.1	20.5	21.5				0.47	0.71	22.9	16.8	20.0	2.65	0.08	5.27	0.026	1.71	0.197
Total Arthropods	111.2[a]	67.6[b]	74.3[bc]	88.9[ac]				7.42	<0.001	92.3	81.0	79.2	1.40	0.26	1.73	0.195	0.06	0.813
Chick Food Index	0.3	0.4	0.3	0.5				1.31	0.28	0.3	0.3	0.6	5.62	0.01	0	0.958	8.58	0.005
Skylark Food	16.5[a]	9.9[b]	8.7[bc]	13.9[ac]				6.03	0.002	13.9	10.6	11.3	1.91	0.16	3.5	0.068	0.2	0.661

Table 5.A48 High Mowthorpe 2005 Interactions.

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 3; Space*Herb df = 6; resid df = 44														
Staphylinidae														
Conv	2.1	3.2	1.0	3.5				4.88	0.005	**Spacing**	0.62	0.542	2.31	0.05
WSR	2.5	0.8	1.0	4.4						**Conv vs WSR**	0.64	0.428		
WSR+Cult	4.0	1.6	0.9	1.3						**WSR vs WSR+Cult**	0.07	0.786		

Table 5.A49 Gleadthorpe 2003 no interactions.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 3; resid df = 50																		
Acalyptera	0.8		0.3	0.9	0.9			1.83	0.172	0.8	0.6	0.6	0.24	0.79	0.41	0.527	0.01	0.933
Aschiza	0.1		0.0	0.2	0.1			0.77	0.524	0.0	0.2	0.1	0.93	0.41	1.69	0.208	0.09	0.772
Brachycera	1.2		1.7	2.0	1.7			0.43	0.734	1.5	2.4	1.2	1.99	0.16	1.85	0.187	3.78	0.065
Calyptera	0.3		0.1	0.3	0.0			1.12	0.363	0.2	0.1	0.2	0.55	0.58	0.91	0.351	0.73	0.401
Tipulidae																		
Nematocera (No Tipulidae)	2.6[a]		1.3[ac]	0.5[bc]	0.4[bc]			5.46	0.006	1.4	0.8	1.0	0.80	0.46	1.57	0.223	0.22	0.644
Diptera Larvae																		
Total Diptera	5.8		3.9	4.4	3.5			0.96	0.429	4.8	4.5	3.7	0.56	0.58	0.06	0.804	0.58	0.455
Cantharidae																		
Carabidae	0.2		0.0	0.1	0.1			0.52	0.673	0.1	0.1	0.1	0.13	0.88	0.09	0.769	0.04	0.835
Chrysomelidae	0.2		0.2	0.2	0.1			0.17	0.916	0.3	0.1	0.1	2.71	0.09	4.06	0.056	0	1
Curculionidae	0.0		0.0	0.1	0.0			1	0.411	0.1	0.0	0.0	1.00	0.38	1.5	0.234	0	1
Elateridae																		
Staphylinidae																		
Heteroptera	1.1		0.6	1.2	0.9			0.45	0.722	0.9	1.4	0.6	1.13	0.34	0.62	0.44	2.26	0.147
Homoptera	0.9		0.4	0.8	0.4			0.62	0.609	0.6	0.4	0.8	0.42	0.67	0.26	0.614	0.83	0.373
Symphyta Larvae	0.0		0.0	0.1	0.0			1	0.411	0.1	0.0	0.0	1.00	0.38	1.5	0.234	0	1
Symphyta Adults																		
Lepidoptera Adults	0.1		0.0	0.0	0.0			1	0.411	0.0	0.0	0.1	1.00	0.38	0	1	1.5	0.234
Lepidoptera Larvae																		
Neuroptera Larvae	0.0		0.0	0.1	0.0			1	0.411	0.0	0.0	0.1	1.00	0.38	0	1	1.5	0.234
Orthoptera	0.0		0.0	0.0	0.1			1	0.411	0.1	0.0	0.0	1.00	0.38	1.5	0.234	0	1
Opiliones																		
Nectar Feeders	0.1		0.0	0.2	0.1			0.63	0.606	0.0	0.2	0.2	0.89	0.42	1.34	0.26	0	1
Herbivores	1.0		0.6	1.1	0.5			0.93	0.409	1.1	0.4	0.9	0.56	0.65	1.73	0.202	0.96	0.338
Omnivore / Mixed	8.0		4.8	4.1	4.2			4.73	0.011	4.5	6.6	4.4	1.70	0.21	2.4	0.135	2.68	0.116
Predators	4.1		6.0	6.0	4.9			0.91	0.451	7.0	5.4	3.6	3.76	0.04	1.17	0.291	2.7	0.115

Cont'd…..

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	b	c	d	e	f	g	*F*	*P*	Conv	WSR	WSR +Cult	*F*	*P*	*F*	*P*	*F*	*P*
Total Arthropods	13.8		12.6	12.1	10.7			0.37	0.775	13.8	13.1	10.1	1.25	0.31	0.07	0.79	1.47	0.238
Chick Food Index	0.1		0.0	0.1	0.1			1.29	0.301	0.1	0.1	0.1	0.05	0.95	0.08	0.785	0.07	0.793
Skylark Food	7.4		8.6	6.9	5.8			0.38	0.771	8.5	7.9	5.3	1.19	0.32	0.06	0.814	1.44	0.243

Table 5.A50 Gleadthorpe 2003 interactions.

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 3; Space*Herb df = 6; resid df = 22														
Araneae														
Conv	3.9		10.9	3.7	4.8			0.36	0.78	**Spacing**	6.64	0.006	3.25	0.019
WSR	2.6		3.4	1.8	0.8					**Conv vs WSR**	6.92	0.015		
WSR+Cult	1.9		0.8	5.4	3.9					**WSR vs WSR+Cult**	0.76	0.394		
Other Coleoptera														
Conv	0.0		0.0	0.0	0.0			2.08	0.132	**Spacing**	7.51	0.003	6.83	<0.001
WSR	0.0		0.0	0.3	2.9					**Conv vs WSR**	15.01	<0.001		
WSR+Cult	2.6		7.1	0.0	0.0					**WSR vs WSR+Cult**	4.14	0.054		
Total Coleoptera														
Conv	1.3		0.3	0.6	0.8			0.63	0.604	**Spacing**	1.59	0.226	3.55	0.013
WSR	0.7		0.3	0.6	3.2					**Conv vs WSR**	2.99	0.098		
WSR+Cult	2.7		7.4	0.8	0.0					**WSR vs WSR+Cult**	1.55	0.227		

Table 5.A51 Gleadthorpe05 no interactions.

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	b	c	d	e	f	g	*F*	*P*	Conv	WSR	WSR +Cult	*F*	*P*	*F*	*P*	*F*	*P*
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 3; resid df = 50																		
Acalyptera	22.4	13.1	13.1	14.6				1.14	0.34	16.9	19.7	11.0	2.11	0.13	0.25	0.618	3.91	0.054
Aschiza	2.5	2.8	2.3	2.3				0.18	0.91	2.6	3.0	2.0	0.96	0.39	0.26	0.61	1.88	0.177
Brachycera	5.6	4.6	4.9	3.6				1.05	0.38	4.4	5.2	4.3	0.45	0.64	0.53	0.47	0.79	0.378
Tipulidae	0.0	0.1	0.0	0.0				2.29	0.09	0.0	0.0	0.1	0.29	0.75	0	1	0.43	0.516
Nematocera (No Tipulidae)	1.6	1.7	2.3	2.4				0.76	0.53	1.8	1.5	2.7	2.12	0.13	0.33	0.571	4	0.052
Diptera Larvae	0.0	0.0	0.1	0.1				0.62	0.61	0.0	0.2	0.0	2.69	0.08	4.03	0.051	4.03	0.051
Total Diptera	37.1	23.4	24.8	26.2				1.10	0.36	28.2	33.4	21.9	1.53	0.23	0.5	0.483	3.02	0.089
Cantharidae	0.0	0.0	0.0	0.0				1.00	0.40	0.0	0.0	0.0	1	0.38	1.5	0.227	0	1
Carabidae	0.1	0.4	0.0	0.1				2.52	0.07	0.1	0.2	0.1	0.32	0.73	0.3	0.586	0.6	0.442
Chrysomelidae	0.0	0.0	0.0	0.1				1.96	0.14	0.0	0.0	0.0	0.49	0.62	0.73	0.396	0	1
Curculionidae																		
Elateridae																		
Staphylinidae	0.6	0.5	0.5	0.7				0.35	0.79	0.4	0.8	0.5	1.37	0.27	2.36	0.132	1.7	0.199
Other Coleoptera	2.2	2.3	1.9	2.9				0.72	0.54	1.9	2.3	2.8	1.11	0.339	0.49	0.487	0.62	0.436
Total Coleoptera	3.0	3.4	2.7	4.4				1.75	0.17	2.9	3.6	3.7	0.93	0.40	1.16	0.287	0.03	0.853
Heteroptera	2.8^{a}	0.3^{b}	0.7^{b}	1.7^{a}				11.20	<0.001	0.8	1.6	1.1	2.14	0.13	4.2	0.046	1.62	0.21
Homoptera	0.7	0.5	0.5	0.9				0.84	0.48	0.4	0.6	0.9	1.74	0.19	1	0.322	0.74	0.394
Symphyta Larvae																		
Symphyta Adults	0.0	0.0	0.0	0.0				1.00	0.40	0.0	0.0	0.0	1	0.38	0	1	1.5	0.227
Lepidoptera Adults																		
Orthoptera																		
Araneae	1.9	2.8	1.7	1.6				1.66	0.19	2.0	2.0	1.9	0.03	0.97	0.02	0.888	0.01	0.905
Opiliones																		
Nectar Feeders	2.5	2.8	2.3	2.3				0.18	0.91	2.6	3.0	2.0	0.96	0.39	0.26	0.61	1.88	0.177
Herbivores	0.7	0.6	0.5	1.0				0.89	0.45	0.4	0.7	1.0	2.61	0.09	1.64	0.207	0.99	0.325
Omnivore / Mixed	39.8	24.1	23.8	30.5				1.82	0.16	28.3	35.3	24.1	1.51	0.23	0.99	0.325	3.01	0.090
Predators	7.9	8.5	7.3	6.4				0.65	0.59	7.0	8.9	6.7	1.38	0.26	1.79	0.187	2.31	0.136

Cont'd……

	Herbicide									Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	b	c	d	e	f	g	*F*	*P*	Conv	WSR	WSR +Cult	*F*	*P*	*F*	*P*	*F*	*P*
Total Arthropods	51.2	34.2	32.5	38.9				1.51	0.23	37.0	47.3	32.8	1.7	0.19	1.47	0.232	3.28	0.077
Chick Food Index	0.1	0.2	0.1	0.1				2.32	0.09	0.1	0.2	0.1	1.96	0.15	3.65	0.063	1.96	0.168
Skylark Food	9.6[a]	8.2[ac]	6.6[bc]	10.3[a]				3.13	0.04	7.1	9.9	9.0	3.34	0.05	6.19	0.017	0.41	0.524

Table 5.A52 Gleadthorpe 2005 interactions.

	Herbicide							Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 3; Space*Herb df = 6; resid df = 22														
Lepidoptera larvae														
Conv	0.0	0.0	0.0	0.0				3.03	0.039	**Spacing**	6.64	0.006	3.25	0.019
WSR	0.0	0.0	0.1	0.0						**Conv vs WSR**	0.57	0.455		
WSR+Cult	0.0	0.5	0.0	0.0						**WSR vs WSR+Cult**	2.28	0.139		
Neuroptera larvae														
Conv	0.3	0.0	0.1	0.0				0.45	0.717	**Spacing**	6.22	0.004	3.71	0.005
WSR	0.1	0.2	0.1	0.3						**Conv vs WSR**	4.88	0.005		
WSR+Cult	0.1	0.1	0.2	0.0						**WSR vs WSR+Cult**	5.12	0.004		

Table 5.A53 Boxworth 2003 no interactions (only herbicide a sampled; WSR not sampled).

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 60																			
Acalyptera											0.6		0.4	0.09	0.79			0	1
Aschiza											0.6		0.0	1.00	0.42			1	0.423
Brachycera																			
Calyptera																			
Tipulidae																			
Nematocera (No Tipulidae)											0.8		2.0	8.17	0.10				
Diptera Larvae																			
Total Diptera											2.3		2.8	0.32	0.63			0	1
Cantharidae																			
Carabidae																			
Chrysomelidae																			
Curculionidae											0.8		0.8	0.00	1.00			0	1
Elateridae																			
Staphylinidae																			
Other Coleoptera											5.0		7.5	0.43	0.58			0.51	0.551
Total Coleoptera											6.4		8.7	0.69	0.49			0.73	0.483
Heteroptera											0.3		0.3	0.00	1.00			0	1
Homoptera																			
Symphyta Larvae																			
Symphyta Adults																			
Lepidoptera Adults																			
Lepidoptera Larvae																			
Neuroptera Larvae											0.0		0.6	4.00	0.18			4	0.184
Orthoptera																			

Cont'd…..

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Araneae											0.6		2.6	4.04	0.18			4	0.184
Opiliones																			
Nectar Feeders											0.6		0.0	1.00	0.42			1	0.423
Herbivores											0.8		0.8	0.00	1.00			0	1
Omnivore / Mixed											7.4		11.6	0.78	0.47			0.45	0.572
Predators											0.6		3.2	5.20	0.15			4.92	0.157
Total Arthropods											9.6		16.0	1.55	0.34			1.92	0.30
Chick Food Index											0.1		0.2	1.44	0.35			1.46	0.35
Skylark Food											7.2		12.5	2.09	0.29			2.42	0.26

Table 5.A54 Boxworth 2004 No interactions.

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 60																			
Acalyptera	30.4	6.3	6.6	9.9	4.3	3.8	6.2	3.7	11.90	<0.001	7.4	8.0	5.8	1.77	0.18	0.16	0.687	3.22	0.077
Aschiza	1.3	0.9	0.6	1.7	0.6	0.6	1.0	0.5	1.78	0.11	1.0	1.0	0.6	1.38	0.26	0	0.988	2.09	0.152
Brachycera	5.9	3.7	3.3	3.9	4.9	3.7	4.2	5.5	1.28	0.27	4.2	4.0	4.8	0.68	0.51	0.17	0.681	1.32	0.255
Calyptera	0.3	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.56	0.79	0.1	0.3	0.0	3.86	0.03	2.88	0.094	7.59	0.008
Tipulidae	3.7	4.1	4.4	5.2	5.2	4.2	3.7	4.2	0.56	0.79	4.9	4.3	3.8	1.54	0.22	0.7	0.406	0.84	0.362
Nematocera (No Tipulidae)	4.5[ab]	5.4[abe]	1.6[cf]	3.4[cd]	1.4[ce]	0.9[ef]	1.6[c]	1.2[ad]	7.15	<0.001	2.1	2.4	2.1	0.24	0.79	0.37	0.544	0.34	0.564
Diptera Larvae	0.0	0.1	0.0	0.2	0.0	0.0	0.1	0.1	1.10	0.37	0.1	0.0	0.0	5.68	0.01	8.52	0.005	0	1
Total Diptera	49.6[a]	23.4[bc]	18.1[cd]	28.4[b]	17.7[d]	14.6[d]	18.6[cd]	16.5[cd]	11.27	<0.001	22.1	22.9	20.1	0.85	0.43	0.11	0.745	1.59	0.212
Cantharidae	0.8	1.7	1.4	2.4	0.9	1.9	1.3	1.6	1.78	0.11	1.4	0.9	2.1	5.76	0.01	2.04	0.157	11.43	0.001
Carabidae	0.2	0.5	0.2	0.2	0.2	0.2	0.1	0.1	0.96	0.47	0.2	0.3	0.2	0.64	0.53	0.68	0.414	1.17	0.283
Curculionidae	0.7[a]	0.6[ac]	0[b]	0.3[c]	0.06[b]	0[b]	0.06[b]	0.1[b]	5.14	<0.001	0.2	0.3	0.2	0.42	0.66	0.39	0.533	0.79	0.378
Elateridae																			
Staphylinidae	1.8	0.9	0.7	1.1	0.7	0.5	1.0	1.1	1.76	0.11	1.2	0.9	0.7	2.14	0.13	1.42	0.237	0.75	0.389
Other Coleoptera	5.5[a]	3.0[b]	1.3[c]	2.9[b]	1.1[c]	0.6[c]	0.5[c]	1.0[c]	10.61	<0.001	2.0	1.8	1.2	2.62	0.08	0.14	0.705	3.12	0.082
Total Coleoptera	10.0[a]	7.7[b]	4.2[c]	7.4[b]	4.1[c]	3.5[c]	3.2[c]	4.8[c]	7.60	<0.001	5.7	5.0	5.1	0.49	0.62	0.85	0.36	0.03	0.874
Heteroptera	0.8[a]	0.1[b]	0.1[b]	0.1[b]	0.1[b]	0[b]	0.1[b]	0.1[b]	6.76	<0.001	0.1	0.1	0.3	3.17	0.05	0	1	4.76	0.033
Homoptera	0.4	0.3	0.2	0.3	0.2	0.1	0.2	0.2	0.49	0.84	0.2	0.4	0.2	1.92	0.15	3.78	0.056	1.42	0.238
Symphyta Larvae																			
Symphyta Adults	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	1.00	0.44	0.0	0.0	0.0	1	0.37	0	1	1.5	0.225
Lepidoptera Adults	0.1[ac]	0.2[bc]	0.0[a]	0.1[ac]	0.0[a]	0.0[a]	0.0[ac]	0.0[ac]	2.12	0.05	0.0	0.1	0.0	1.65	0.20	0.35	0.554	3.18	0.079
Lepidoptera Larvae	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.00	0.44	0.0	0.0	0.0	1	0.37	0	1	1.5	0.225
Neuroptera Larvae	0.7	0.8	0.5	0.3	0.7	0.6	0.3	0.5	0.70	0.67	0.6	0.6	0.4	0.68	0.51	0.08	0.783	1.25	0.268
Orthoptera																			
Opiliones	0.1	0.3	0.0	0.1	0.1	0.0	0.0	0.0	2.37	0.03	0.0	0.1	0.1	0.64	0.53	0.97	0.329	0	1

Cont'd…..

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Nectar Feeders	1.3	1.2	0.6	1.8	0.6	0.6	1.0	0.5	2.06	0.06	1.1	1.1	0.6	1.85	0.17	0	0.987	2.75	0.102
Total Arthropods	64.0[a]	35.8[c]	23.7[b]	38.2[c]	24.0[b]	19.8[b]	23.5[b]	23.3[b]	13.19	<0.001	30.2	30.6	27.4	0.8	0.45	0.02	0.894	1.33	0.252
Herbivores	2.1[a]	1.0[b]	0.3[cd]	1.0[be]	0.7[bcd]	0.1[cd]	0.5[bcd]	0.3[bcd]	5.32	<0.001	0.5	0.8	0.7	1.94	0.15	3.68	0.059	0.33	0.569
Omnivore / Mixed	46.0[a]	19.3[c]	11.8[b]	21.6[c]	9.2[b]	7.9[b]	11.4[b]	8.1[b]	14.37	<0.001	15.3	16.1	11.7	2.99	0.06	0.13	0.717	5.18	0.026
Predators	9.0	9.4	5.6	7.7	7.5	6.5	6.7	8.5	1.32	0.25	7.1	7.1	8.5	1.25	0.29	0	0.958	1.95	0.167
Pollinators	1.3	1.2	0.6	1.8	0.6	0.6	1.0	0.5	2.06	0.06	1.1	1.1	0.6	1.85	0.17	0	0.987	2.75	0.102
Chick Food Index	0.3	0.4	0.2	0.2	0.3	0.2	0.1	0.1	1.54	0.17	0.2	0.3	0.2	1.16	0.32	0.96	0.33	2.25	0.138
Skylark Food	17.5[a]	15.8[ab]	9.9[c]	15.4[ab]	11.5[bc]	9.5[c]	8.8[c]	11.0[c]	5.41	<0.001	12.9	12.2	11.2	1.03	0.36	0.28	0.6	0.8	0.375

Table 5.A55 Boxworth 2004 interactions.

	Herbicide								Herbicide		Spacing/Cultivation			Spacing*Herbicide	
Spacing/Cult.	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***		***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; Space*Herb df = 14; resid df = 69															
Araneae															
Conv	0.3	1.5	0.4	0.4	0.2	1.0	0.9	0.0	1.86	0.09	**Spacing**	2.17	0.12	1.89	0.04
WSR	2.1	2.1	0.4	0.4	0.7	0.3	0.6	0.7			**Conv vs WSR**	2.16	0.15		
WSR+Cult	0.4	0.4	0.2	1.2	0.0	0.7	0.0	1.0			**WSR vs WSR+Cult**	4.05	0.05		
Chrysomelidae															
Conv	0	0	0	0.2	0	0	0	0	3.1	0.007	**Spacing**	1.66	0.198	4.19	<0.001
WSR	0	0	0	0	1.2	0	0	0			**Conv vs WSR**	2.56	<0.001		
WSR+Cult	0.2	0	0.2	0	0	0	0	0			**WSR vs WSR+Cult**	6.14	<0.001		

Table 5.A56 Boxworth 2005 No interactions (only herbicide treatments a – d sampled on the conventional spacing).

	Herbicide										**Spacing/Cultivation**					**Conv vs WSR**		**WSR vs WSR+Cult**	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Spacing/Cultivation df = 2; Contrast df = 1; Herbicide df = 7; resid df = 60																			
Acalyptera	11.9	10.7	12.6	11.6					0.11	0.95									
Aschiza	4.3	3.5	2.6	1.4					0.84	0.50									
Brachycera	6.3	7.6	7.5	7.3					0.16	0.92									
Calyptera	1.6	0.4	0.6	0.6					1.91	0.18									
Tipulidae	0.6	0.3	1.5	0.6					1.53	0.26									
Nematocera (No Tipulidae)	4.1[a]	2.2[ab]	0.4[b]	1.7[at]					3.38	0.05									
Diptera Larvae	0.0	0.1	0.0	0.0					1.00	0.43									
Total Diptera	30.0	26.4	26.7	24.9					0.14	0.93									
Cantharidae	0.0	0.6	0.6	0.8					1.95	0.18									
Carabidae	0.6	1.0	1.5	0.4					1.00	0.42									
Chrysomelidae																			
Curculionidae																			
Elateridae	0.0	0.0	0.1	0.0					1.00	0.43									
Staphylinidae	1.7	0.1	0.8	1.0					2.71	0.09									
Other Coleoptera	0.6	0.7	0.3	0.3					0.26	0.86									
Total Coleoptera	3.7	2.9	3.6	3.2					0.11	0.96									
Heteroptera	0.9[a]	0.0[b]	0.0[b]	0.0[b]					12.86	<0.001									
Homoptera	2.2	2.0	1.8	2.0					0.05	0.99									
Symphyta Larvae																			
Symphyta Adults																			
Lepidoptera Adults																			
Lepidoptera Larvae																			
Neuroptera Larvae	0.5	0.1	0.5	0.6					0.64	0.60									
Orthoptera																			

Cont'd…….

	Herbicide										Spacing/Cultivation					Conv vs WSR		WSR vs WSR+Cult	
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	***F***	***P***	**Conv**	**WSR**	**WSR +Cult**	***F***	***P***	***F***	***P***	***F***	***P***
Opiliones	0.0	0.1	0.0	0.0					1.00	0.43									
Nectar Feeders	4.3	3.5	2.6	1.4					0.82	0.51									
Total Arthropods	4.3	3.5	2.6	1.4					0.84	0.50									
Herbivores	2.2	2.0	1.8	2.0					0.05	0.99									
Omnivore / Mixed	28.3	19.9	20.5	19.2					0.71	0.57									
Predators	10.0	13.6	13.3	15.1					0.64	0.60									
Pollinators	41.9	37.4	38.2	37.9					0.07	0.97									
Chick Food Index	0.4	0.5	0.8	0.3					0.97	0.44									
Skylark Food	10.8	11.0	12.7	13.4					0.21	0.89									

APPENDIX 5 – COMMUNITY ANALYSIS

Gleadthorpe 2003 - Weeds

Herbicides A & B

Average dissimilarity = 70.98

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	8.64	0.03	33.56	33.56
Stellaria media	3.07	0.00	23.68	57.24
Polygonum aviculare	0.89	0.18	8.43	65.66
Fallopia convolvulus	0.95	0.82	7.74	73.40
Poa trivialis	0.44	0.00	6.70	80.10
Volunteer oilseed rape	0.08	0.04	5.17	85.27
Tripleurospermum inodorum	0.15	0.00	3.38	88.65
Chenopodium album	0.04	0.02	3.21	91.86

Herbicides B & C

Average dissimilarity = 64.57

Species	Herb B Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Poa annua	0.03	1.84	25.86	25.86
Stellaria media	0.00	0.78	16.45	42.31
Polygonum aviculare	0.18	0.77	14.75	57.06
Poa trivialis	0.00	0.36	11.65	68.71
Fallopia convolvulus	0.82	0.32	10.34	79.05
Volunteer oilseed rape	0.04	0.01	4.53	83.58
Chenopodium album	0.02	0.00	3.48	87.06
Galium aparine	0.01	0.00	2.26	89.32
Viola arvensis	0.00	0.01	2.06	91.38

Herbicides A & D

Average dissimilarity = 78.35

Species	Herb A Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Poa annua	8.64	0.14	31.93	31.93
Stellaria media	3.07	0.00	23.59	55.52
Polygonum aviculare	0.89	0.03	11.07	66.58
Fallopia convolvulus	0.95	0.25	9.44	76.02
Poa trivialis	0.44	0.00	5.60	81.62
Volunteer oilseed rape	0.08	0.00	4.28	85.90
Volunteer potato	0.04	0.00	3.60	89.49
Tripleurospermum inodorum	0.15	0.00	3.28	92.78

Herbicides C & D

Average dissimilarity = 73.87

Species	Herb C Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Poa annua	1.84	0.14	27.45	27.45
Polygonum aviculare	0.77	0.03	19.42	46.86
Stellaria media	0.78	0.00	16.13	62.99
Poa trivialis	0.36	0.00	11.08	74.07
Fallopia convolvulus	0.32	0.25	8.02	82.09
Volunteer oilseed rape	0.01	0.00	3.95	86.04
Alopecurus myosuroides	0.00	0.01	2.42	88.47
Chenopodium album	0.00	0.00	2.42	90.88

Gleadthorpe 2003: Arthropods

Herbicides A & B

Average dissimilarity = 48.03

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Oth.Nematocera	2.55	1.34	15.66	15.66
Heteroptera	1.14	0.62	13.71	29.37
Homoptera	0.86	0.38	13.27	42.64
Acalypterae	0.78	0.26	10.96	53.60
Araneae	2.72	3.57	10.84	64.45
Brachycera	1.24	1.69	10.43	74.88
Coleoptera others	0.51	1.00	6.55	81.43
Staphylinidae	0.35	0.07	6.00	87.43
Calyptera	0.29	0.07	3.93	91.35

Herbicides B & C

Average dissimilarity = 55.25

Species	Herb B Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Araneae	3.57	3.37	15.72	15.72
Oth.Nematocera	1.34	0.55	13.18	28.89
Coleoptera others	1.00	0.07	10.70	39.59
Homoptera	0.38	0.78	10.43	50.02
Brachycera	1.69	2.02	10.04	60.06
Heteroptera	0.62	1.19	9.99	70.05
Acalypterae	0.26	0.95	9.03	79.08
Calyptera	0.07	0.32	5.17	84.24
Chrysomelidae	0.17	0.17	4.48	88.73
Aschiza	0.00	0.23	3.19	91.92

Herbicides B & D

Average dissimilarity = 54.54

Species	Herb B Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Coleoptera others	1.00	0.58	21.44	21.44
Araneae	3.57	2.72	15.91	37.35
Brachycera	1.69	1.69	12.76	50.11
Oth.Nematocera	1.34	0.41	11.40	61.51
Heteroptera	0.62	0.91	10.82	72.33
Acalypterae	0.26	0.86	8.02	80.35
Homoptera	0.38	0.38	7.76	88.11
Chrysomelidae	0.17	0.07	3.44	91.55

Gleadthorpe 2005: Weeds

Herbicides A & C

Average dissimilarity = 97.41

Species	Herb A Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Poa annua	14.41	0.00	41.24	41.24
Stellaria media	13.50	0.00	31.45	72.69
Veronica arvensis	1.31	0.00	12.67	85.36
Polygonum aviculare	0.19	0.03	4.24	89.60
Galium aparine	0.23	0.00	2.99	92.60

Herbicides A & B

Average dissimilarity = 82.49

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	14.41	0.32	35.59	35.59
Stellaria media	13.50	0.18	32.39	67.97
Veronica arvensis	1.31	0.00	12.85	80.82
Galium aparine	0.23	0.07	4.89	85.71
Polygonum aviculare	0.19	0.09	4.31	90.02

Herbicides C & B

Average dissimilarity = 91.72

Species	Herb C Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	0.00	0.32	25.28	25.28
Polygonum aviculare	0.03	0.09	25.18	50.46
Stellaria media	0.00	0.18	13.99	64.45
Galium aparine	0.00	0.07	10.52	74.97
Volunteer potato	0.00	0.00	6.66	81.63
Fallopia convolvulus	0.00	0.00	4.67	86.30
Chenopodium album	0.00	0.00	4.25	90.55

Herbicides D & B

Average dissimilarity = 83.11

Species	Herb D Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	17.07	0.32	41.53	41.53
Stellaria media	5.30	0.18	20.35	61.87
Veronica arvensis	2.12	0.00	17.64	79.51
Polygonum aviculare	0.04	0.09	4.37	83.88
Fallopia convolvulus	0.04	0.00	3.51	87.39
Veronica persica	0.05	0.00	3.50	90.89

Gleadthorpe 2005: Weeds continued

Herbicides C & D

Average dissimilarity = 98.21

Species	Herb C Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Poa annua	0.00	17.07	48.25	48.25
Stellaria media	0.00	5.30	20.29	68.54
Veronica arvensis	0.00	2.12	17.84	86.38
Fallopia convolvulus	0.00	0.04	3.54	89.92
Veronica persica	0.00	0.05	3.52	93.44

Gleadthorpe 2005: Arthropods

Herbicides C & B

Average dissimilarity = 36.55

Species	Herb C Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Oth.Nematocera	2.31	1.69	13.53	13.53
Acalypterae	13.13	13.13	11.54	25.08
Aschiza	2.31	2.89	10.49	35.57
Brachycera	4.89	4.62	9.91	45.48
Coleoptera others	1.88	2.31	9.20	54.69
Araneae	1.69	2.80	7.08	61.77
Total Heteroptera	0.70	0.26	6.49	68.26
Calyptera	0.58	0.26	5.83	74.09
Homoptera	0.51	0.48	5.37	79.46
Staphylinidae	0.48	0.48	5.22	84.68
Carabidae	0.05	0.35	3.99	88.67
Neuroptera larvae	0.32	0.20	3.49	92.15

Boxworth 2004: Weeds

Herbicides A & B

Average dissimilarity = 80.88

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	3.38	0.01	21.74	21.74
Galium aparine	3.93	0.06	21.59	43.32
Sinapis arvensis	1.08	0.00	13.30	56.62
Veronica persica	0.64	0.00	10.10	66.72
Veronica hederifolia	0.38	0.00	7.34	74.07
Fallopia convolvulus	0.94	0.27	6.88	80.95
Matricaria discoidea	0.06	0.00	3.00	83.95
Volunteer oilseed rape	0.06	0.00	2.99	86.94
Elytrigia repens	0.01	0.03	2.63	89.57
Polygonum aviculare	0.03	0.00	1.92	91.49

Herbicides A & C

Average dissimilarity = 44.42

Species	Herb A Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Galium aparine	3.93	0.33	22.83	22.83
Sinapis arvensis	1.08	0.04	14.33	37.16
Poa annua	3.38	3.45	13.08	50.24
Fallopia convolvulus	0.94	0.63	8.44	58.68
Veronica hederifolia	0.38	0.46	7.91	66.60
Veronica persica	0.64	0.70	6.78	73.38
Volunteer oilseed rape	0.06	0.01	3.90	77.28
Stellaria media	0.01	0.03	3.78	81.06
Matricaria discoidea	0.06	0.00	3.61	84.67
Volunteer potato	0.00	0.03	3.39	88.06
Avena fatua	0.00	0.04	2.68	90.74

Herbicides B & C

Average dissimilarity = 77.42

Species	Herb B Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Poa annua	0.01	3.45	31.27	31.27
Veronica persica	0.00	0.70	15.84	47.11
Veronica hederifolia	0.00	0.46	11.32	58.43
Fallopia convolvulus	0.27	0.63	8.51	66.94
Galium aparine	0.06	0.33	7.45	74.40
Volunteer potato	0.01	0.03	4.15	78.55
Avena fatua	0.00	0.04	3.97	82.52
Elytrigia repens	0.03	0.00	3.88	86.40
Sonchus spp.	0.01	0.01	3.20	89.60
Sinapis arvensis	0.00	0.04	3.17	92.78

Herbicides A & D

Average dissimilarity = 79.93

	Herb A Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Galium aparine	3.93	0.08	21.26	21.26
Poa annua	3.38	0.03	21.25	42.51
Sinapis arvensis	1.08	0.00	13.53	56.04
Veronica persica	0.64	0.00	9.99	66.03
Veronica hederifolia	0.38	0.00	7.62	73.65
Fallopia convolvulus	0.94	0.16	7.54	81.19
Volunteer oilseed rape	0.06	0.01	3.12	84.32
Matricaria discoidea	0.06	0.00	3.10	87.42
Elytrigia repens	0.01	0.02	2.21	89.63
Polygonum aviculare	0.03	0.00	2.06	91.69

Boxworth 2004: Weeds continued

Herbicides C & D

Average dissimilarity = 77.78

Species	Herb C Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Poa annua	3.45	0.03	30.10	30.10
Veronica persica	0.70	0.00	15.50	45.60
Veronica hederifolia	0.46	0.00	11.77	57.37
Fallopia convolvulus	0.63	0.16	9.44	66.80
Galium aparine	0.33	0.08	9.06	75.86
Volunteer potato	0.03	0.01	3.93	79.80
Avena fatua	0.04	0.00	3.22	83.02
Sinapis arvensis	0.04	0.00	3.05	86.07
Elytrigia repens	0.00	0.02	3.03	89.10
Stellaria media	0.03	0.00	2.84	91.94

Herbicides A & E

Average dissimilarity = 76.68

Species	Herb A Av.Abund	Herb E Av.Abund	Contrib%	Cum.%
Galium aparine	3.93	0.13	22.01	22.01
Poa annua	3.38	0.05	21.77	43.78
Sinapis arvensis	1.08	0.00	14.01	57.79
Veronica persica	0.64	0.00	10.52	68.31
Veronica hederifolia	0.38	0.00	8.06	76.37
Fallopia convolvulus	0.94	0.20	7.67	84.05
Matricaria discoidea	0.06	0.00	3.20	87.25
Volunteer oilseed rape	0.06	0.01	3.13	90.37

Herbicides C & E

Average dissimilarity = 74.31

Species	Herb C Av.Abund	Herb E Av.Abund	Contrib%	Cum.%
Poa annua	3.45	0.05	31.01	31.01
Veronica persica	0.70	0.00	16.35	47.35
Veronica hederifolia	0.46	0.00	12.55	59.90
Fallopia convolvulus	0.63	0.20	9.51	69.41
Galium aparine	0.33	0.13	9.13	78.54
Volunteer potato	0.03	0.00	3.39	81.94
Avena fatua	0.04	0.00	3.15	85.08
Stellaria media	0.03	0.00	3.11	88.19
Sinapis arvensis	0.04	0.00	3.05	91.24

Herbicides A & F

Average dissimilarity = 54.71

	Herb A Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Poa annua	3.38	0.19	21.27	21.27
Galium aparine	3.93	0.81	17.92	39.19
Sinapis arvensis	1.08	0.52	10.05	49.24
Veronica persica	0.64	0.05	9.71	58.95
Fallopia convolvulus	0.94	0.32	8.54	67.49
Veronica hederifolia	0.38	0.03	8.04	75.54
Volunteer potato	0.00	0.09	4.44	79.98
Matricaria discoidea	0.06	0.01	3.59	83.57
Volunteer oilseed rape	0.06	0.05	3.43	87.00
Polygonum aviculare	0.03	0.01	2.65	89.66
Stellaria media	0.01	0.00	2.04	91.69

Boxworth 2004: weeds continued

Herbicides B & F

Average dissimilarity = 78.04

Species	Herb B Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Galium aparine	0.06	0.81	18.10	18.10
Sinapis arvensis	0.00	0.52	15.83	33.93
Fallopia convolvulus	0.27	0.32	14.64	48.57
Poa annua	0.01	0.19	10.20	58.77
Volunteer oilseed rape	0.00	0.05	8.23	67.00
Volunteer potato	0.01	0.09	7.04	74.04
Elytrigia repens	0.03	0.00	5.47	79.51
Veronica persica	0.00	0.05	4.24	83.75
Sonchus spp.	0.01	0.01	3.66	87.41
Veronica hederifolia	0.00	0.03	3.54	90.96

Herbicides D & F

Average dissimilarity = 74.40

Species	Herb D Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Sinapis arvensis	0.00	0.52	17.18	17.18
Galium aparine	0.08	0.81	16.77	33.95
Fallopia convolvulus	0.16	0.32	12.16	46.10
Volunteer oilseed rape	0.01	0.05	10.56	56.67
Poa annua	0.03	0.19	9.52	66.19
Volunteer potato	0.01	0.09	7.95	74.14
Elytrigia repens	0.02	0.00	5.50	79.65
Veronica persica	0.00	0.05	4.21	83.86
Sonchus spp.	0.01	0.01	3.64	87.50
Veronica hederifolia	0.00	0.03	3.56	91.06

Herbicides C & F

Average dissimilarity = 64.31

Species	Herb C Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Poa annua	3.45	0.19	24.04	24.04
Galium aparine	0.33	0.81	12.16	36.21
Veronica persica	0.70	0.05	11.66	47.87
Veronica hederifolia	0.46	0.03	9.75	57.62
Fallopia convolvulus	0.63	0.32	9.08	66.70
Sinapis arvensis	0.04	0.52	8.48	75.18
Volunteer potato	0.03	0.09	6.07	81.26
Avena fatua	0.04	0.01	4.50	85.76
Volunteer oilseed rape	0.01	0.05	3.89	89.65
Stellaria media	0.03	0.00	3.10	92.76

Herbicides E & F

Average dissimilarity = 73.88

	Herb E Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Galium aparine	0.13	0.81	21.48	21.48
Sinapis arvensis	0.00	0.52	16.36	37.84
Fallopia convolvulus	0.20	0.32	13.16	51.00
Poa annua	0.05	0.19	10.62	61.61
Volunteer oilseed rape	0.01	0.05	7.40	69.02
Volunteer potato	0.00	0.09	5.79	74.81
Veronica persica	0.00	0.05	5.52	80.33
Sonchus spp.	0.01	0.01	4.02	84.34
Veronica hederifolia	0.00	0.03	3.80	88.15
Elytrigia repens	0.00	0.00	2.67	90.82

Boxworth 2004: weeds continued

Herbicides A & H

Average dissimilarity = 64.30

Species	Herb A Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Poa annua	3.38	0.04	24.32	24.32
Galium aparine	3.93	0.73	16.93	41.25
Sinapis arvensis	1.08	0.01	14.50	55.75
Veronica persica	0.64	0.00	11.27	67.02
Veronica hederifolia	0.38	0.00	8.79	75.81
Fallopia convolvulus	0.94	0.98	6.63	82.44
Volunteer oilseed rape	0.06	0.00	3.66	86.10
Matricaria discoidea	0.06	0.00	3.50	89.60
Polygonum aviculare	0.03	0.00	2.27	91.87

Herbicides B & H

Average dissimilarity = 60.69

Species	Herb B Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Galium aparine	0.06	0.73	29.27	29.27
Fallopia convolvulus	0.27	0.98	27.15	56.41
Poa annua	0.01	0.04	7.79	64.20
Elytrigia repens	0.03	0.00	6.75	70.95
Sinapis arvensis	0.00	0.01	5.52	76.47
Volunteer potato	0.01	0.00	5.41	81.88
Sonchus spp.	0.01	0.00	5.26	87.14
Volunteer oilseed rape	0.00	0.00	2.89	90.03

Herbicides C & H

Average dissimilarity = 67.37

Species	Herb C Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Poa annua	3.45	0.04	30.68	30.68
Veronica persica	0.70	0.00	15.41	46.08
Veronica hederifolia	0.46	0.00	12.22	58.30
Galium aparine	0.33	0.73	10.48	68.78
Fallopia convolvulus	0.63	0.98	9.71	78.49
Volunteer potato	0.03	0.00	4.39	82.88
Stellaria media	0.03	0.00	3.23	86.11
Sinapis arvensis	0.04	0.01	3.20	89.31
Avena fatua	0.04	0.00	2.95	92.26

Herbicides F & H

Average dissimilarity = 63.97

	Herb F Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Galium aparine	0.81	0.73	21.01	21.01
Fallopia convolvulus	0.32	0.98	15.92	36.93
Sinapis arvensis	0.52	0.01	14.86	51.79
Poa annua	0.19	0.04	13.26	65.05
Volunteer oilseed rape	0.05	0.00	6.82	71.86
Volunteer potato	0.09	0.00	6.80	78.66
Veronica persica	0.05	0.00	4.57	83.23
Veronica hederifolia	0.03	0.00	3.91	87.14
Polygonum aviculare	0.01	0.00	2.42	89.56
Sonchus spp.	0.01	0.00	2.24	91.80

Boxworth 2004: Arthropods

Herbicides A & B

Average dissimilarity = 35.85

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Acalypterae	30.62	6.24	14.16	14.16
Tipulidae	3.79	4.13	8.55	22.70
Cantharidae	0.78	1.69	7.61	30.31
Coleoptera others	5.61	2.98	7.00	37.31
Aschiza	1.29	0.95	6.70	44.01
Araneae	0.82	1.24	6.55	50.56
Oth.Nematocera	4.50	5.46	6.13	56.69
Heteroptera	0.86	0.07	6.05	62.74
Brachycera	5.92	3.68	6.02	68.76
Staphylinidae	1.82	0.86	5.96	74.72
Neuroptera larvae	0.70	0.74	5.22	79.94
Curculionidae	0.74	0.58	4.26	84.20
Carabidae	0.15	0.48	3.91	88.11
Homoptera	0.38	0.35	3.50	91.61

Herbicides A & C

Average dissimilarity = 42.98

Species	Herb A Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Acalypterae	30.62	6.59	14.62	14.62
Coleoptera others	5.61	1.24	10.88	25.50
Oth.Nematocera	4.50	1.63	8.63	34.13
Tipulidae	3.79	4.37	7.44	41.57
Aschiza	1.29	0.62	7.17	48.74
Brachycera	5.92	3.37	7.12	55.87
Cantharidae	0.78	1.45	7.05	62.91
Staphylinidae	1.82	0.70	6.48	69.39
Heteroptera	0.86	0.07	5.83	75.22
Curculionidae	0.74	0.00	5.17	80.39
Araneae	0.82	0.35	5.09	85.49
Neuroptera larvae	0.70	0.51	4.37	89.86
Homoptera	0.38	0.15	3.25	93.11

Boxworth 2004: Arthropods continued

Herbicides A & D

Average dissimilarity = 36.28

Species	Herb A Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Acalypterae	30.62	9.96	11.31	11.31
Cantharidae	0.78	2.47	8.68	19.99
Aschiza	1.29	1.69	8.00	27.98
Coleoptera others	5.61	2.89	7.76	35.75
Oth.Nematocera	4.50	3.37	7.62	43.37
Tipulidae	3.79	5.17	7.47	50.84
Brachycera	5.92	3.90	7.30	58.14
Araneae	0.82	0.66	6.37	64.51
Staphylinidae	1.82	1.09	5.98	70.49
Neuroptera*	0.70	0.32	5.49	75.99
Heteroptera	0.86	0.12	5.19	81.17
Curculionidae	0.74	0.32	4.90	86.08
Homoptera	0.38	0.35	3.89	89.97
Calyptera	0.32	0.12	3.02	92.99

Herbicides A & E

Average dissimilarity = 41.20

Species	Av.Abund	Av.Abund	Contrib%	Cum.%
Acalypterae	30.62	4.37	16.79	16.79
Coleoptera others	5.61	1.14	10.29	27.08
Oth.Nematocera	4.50	1.34	7.94	35.02
Tipulidae	3.79	5.17	7.84	42.86
Cantharidae	0.78	0.86	7.22	50.08
Staphylinidae	1.82	0.66	6.84	56.92
Aschiza	1.29	0.58	6.03	62.94
Neuroptera*	0.70	0.74	5.35	68.29
Curculionidae	0.74	0.07	5.01	73.30
Heteroptera	0.86	0.07	4.96	78.25
Araneae	0.82	0.26	4.85	83.10
Homoptera	0.38	0.23	3.66	86.76
Brachycera	5.92	4.89	3.65	90.42

Boxworth 2004: Arthropods continued

Herbicides B & E

Average dissimilarity = 39.68

Species	Herb B Av.Abund	Herb E Av.Abund	Contrib%	Cum.%
Oth.Nematocera	5.46	1.34	10.85	10.85
Acalypterae	6.24	4.37	9.12	19.97
Cantharidae	1.69	0.86	8.51	28.48
Coleoptera others	2.98	1.14	8.41	36.88
Staphylinidae	0.86	0.66	6.75	43.64
Brachycera	3.68	4.89	6.75	50.39
Tipulidae	4.13	5.17	6.50	56.89
Neuroptera*	0.74	0.74	6.36	63.25
Araneae	1.24	0.26	6.05	69.30
Aschiza	0.95	0.58	5.92	75.21
Curculionidae	0.58	0.07	4.52	79.73
Carabidae	0.48	0.20	4.07	83.80
Homoptera	0.35	0.23	3.83	87.63
Calyptera	0.20	0.12	3.02	90.66

Herbicides D & E

Average dissimilarity = 40.26

Species	Herb D Av.Abund	Herb E Av.Abund	Contrib%	Cum.%
Acalypterae	9.96	4.37	11.04	11.04
Cantharidae	2.47	0.86	10.58	21.62
Coleoptera others	2.89	1.14	9.19	30.80
Oth.Nematocera	3.37	1.34	8.68	39.48
Aschiza	1.69	0.58	8.11	47.59
Staphylinidae	1.09	0.66	7.74	55.33
Brachycera	3.90	4.89	7.42	62.75
Neuroptera*	0.32	0.74	5.95	68.70
Araneae	0.66	0.26	5.67	74.37
Tipulidae	5.17	5.17	5.24	79.61
Homoptera	0.35	0.23	4.68	84.28
Chrysomelidae	0.07	0.32	3.72	88.01
Curculionidae	0.32	0.07	2.90	90.91

Boxworth 2004: Arthropods continued

Herbicides A & F

Average dissimilarity = 46.49

Species	Herb A Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Acalypterae	30.62	3.79	16.63	16.63
Coleoptera others	5.61	0.55	12.03	28.66
Oth.Nematocera	4.50	0.86	9.42	38.08
Cantharidae	0.78	1.88	7.17	45.25
Tipulidae	3.79	4.13	6.87	52.11
Staphylinidae	1.82	0.51	6.06	58.18
Aschiza	1.29	0.55	5.94	64.11
Brachycera	5.92	3.68	5.86	69.98
Araneae	0.82	0.66	5.56	75.54
Heteroptera	0.86	0.00	5.03	80.57
Curculionidae	0.74	0.00	4.88	85.45
Neuroptera larvae	0.70	0.58	4.64	90.09

Herbicides B & F

Average dissimilarity = 42.41

Species	Herb B Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Oth.Nematocera	5.46	0.86	13.26	13.26
Coleoptera others	2.98	0.55	10.29	23.55
Acalypterae	6.24	3.79	9.11	32.67
Brachycera	3.68	3.68	8.48	41.15
Araneae	1.24	0.66	7.07	48.22
Tipulidae	4.13	4.13	6.86	55.08
Aschiza	0.95	0.55	6.03	61.11
Cantharidae	1.69	1.88	5.65	66.75
Neuroptera*	0.74	0.58	5.55	72.30
Staphylinidae	0.86	0.51	5.31	77.61
Curculionidae	0.58	0.00	4.73	82.34
Carabidae	0.48	0.23	4.31	86.65
Calyptera	0.20	0.23	3.90	90.55

Boxworth 2004: Arthropods continued

Herbicides D & F

Average dissimilarity = 41.69

Species	Herb D Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Coleoptera others	2.89	0.55	11.29	11.29
Acalypterae	9.96	3.79	11.17	22.46
Oth.Nematocera	3.37	0.86	10.67	33.13
Brachycera	3.90	3.68	9.57	42.70
Aschiza	1.69	0.55	8.39	51.09
Staphylinidae	1.09	0.51	7.11	58.20
Cantharidae	2.47	1.88	6.86	65.06
Tipulidae	5.17	4.13	6.26	71.32
Araneae	0.66	0.66	5.76	77.08
Neuroptera larvae	0.32	0.58	4.94	82.02
Homoptera	0.35	0.12	4.16	86.19
Carabidae	0.15	0.23	3.06	89.24
Curculionidae	0.32	0.00	2.63	91.87

Herbicides E & F

Average dissimilarity = 37.68

Species	Herb E Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Acalypterae	4.37	3.79	10.86	10.86
Cantharidae	0.86	1.88	10.08	20.95
Coleoptera others	1.14	0.55	9.91	30.86
Brachycera	4.89	3.68	9.17	40.03
Neuroptera larvae	0.74	0.58	7.71	47.74
Araneae	0.26	0.66	7.49	55.23
Tipulidae	5.17	4.13	6.97	62.20
Aschiza	0.58	0.55	6.68	68.88
Oth.Nematocera	1.34	0.86	6.66	75.54
Staphylinidae	0.66	0.51	6.50	82.04
Carabidae	0.20	0.23	4.66	86.70
Chrysomelidae	0.32	0.00	4.07	90.77

Boxworth 2004: Arthropods continued

Herbicides A & H

Average dissimilarity = 41.58

Species	Herb A Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Acalypterae	30.62	3.79	17.76	17.76
Coleoptera others	5.61	1.00	11.14	28.90
Oth.Nematocera	4.50	1.24	9.72	38.62
Cantharidae	0.78	1.57	8.06	46.68
Tipulidae	3.79	4.25	7.06	53.74
Aschiza	1.29	0.51	6.27	60.01
Heteroptera	0.86	0.07	5.81	65.82
Staphylinidae	1.82	1.14	5.49	71.30
Neuroptera*	0.70	0.51	5.39	76.69
Curculionidae	0.74	0.10	5.35	82.04
Araneae	0.82	0.51	4.49	86.53
Brachycera	5.92	5.46	4.23	90.76

Herbicides B & H

Average dissimilarity = 38.74

Species	Herb B Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Oth.Nematocera	5.46	1.24	14.05	14.05
Coleoptera others	2.98	1.00	10.32	24.38
Acalypterae	6.24	3.79	8.08	32.45
Brachycera	3.68	5.46	7.28	39.74
Staphylinidae	0.86	1.14	6.80	46.53
Tipulidae	4.13	4.25	6.72	53.26
Araneae	1.24	0.51	6.72	59.97
Cantharidae	1.69	1.57	6.48	66.46
Aschiza	0.95	0.51	5.99	72.44
Neuroptera*	0.74	0.51	5.85	78.30
Curculionidae	0.58	0.10	4.98	83.27
Carabidae	0.48	0.07	4.14	87.41
Homoptera	0.35	0.23	3.44	90.85

Boxworth 2004: Arthropods continued

Herbicides D & H

Average dissimilarity = 36.50

Species	Herb D Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Oth.Nematocera	3.37	1.24	12.19	12.19
Acalypterae	9.96	3.79	11.80	23.99
Aschiza	1.69	0.51	10.52	34.51
Coleoptera others	2.89	1.00	10.30	44.81
Cantharidae	2.47	1.57	8.88	53.69
Brachycera	3.90	5.46	8.86	62.55
Staphylinidae	1.09	1.14	7.21	69.75
Tipulidae	5.17	4.25	6.44	76.19
Araneae	0.66	0.51	4.39	80.58
Neuroptera*	0.32	0.51	4.20	84.78
Curculionidae	0.32	0.10	3.50	88.28
Homoptera	0.35	0.23	2.56	90.84

Herbicides E & H

Average dissimilarity = 34.69

Species	Herb E Av.Abund	Herb H Av.Abund	Contrib%	Cum.%
Coleoptera others	1.14	1.00	10.42	10.42
Cantharidae	0.86	1.57	9.81	20.23
Acalypterae	4.37	3.79	9.42	29.65
Oth.Nematocera	1.34	1.24	9.13	38.78
Staphylinidae	0.66	1.14	8.49	47.27
Neuroptera*	0.74	0.51	8.24	55.51
Aschiza	0.58	0.51	7.95	63.46
Tipulidae	5.17	4.25	6.40	69.86
Homoptera	0.23	0.23	6.01	75.87
Araneae	0.26	0.51	5.67	81.54
Brachycera	4.89	5.46	5.53	87.07
Chrysomelidae	0.32	0.00	3.58	90.65

High Mowthorpe 2003: Weeds

Herbicides A & C

Average dissimilarity = 66.43

Species	Herb A Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Papaver spp.	8.30	6.08	32.89	32.89
Poa annua	7.03	0.96	22.50	55.39
Galium aparine	10.29	2.94	21.41	76.80
Fumaria officinalis	0.44	0.30	6.15	82.95
Volunteer barley	0.04	0.05	2.92	85.87
Poa trivialis	0.07	0.00	2.37	88.25
Stellaria media	0.03	0.01	2.14	90.39

Herbicides A & D

Average dissimilarity = 75.58

Species	Herb A Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Galium aparine	10.29	0.17	28.88	28.88
Poa annua	7.03	0.09	25.13	54.01
Papaver spp.	8.30	0.22	23.55	77.56
Fumaria officinalis	0.44	0.13	4.78	82.33
Poa trivialis	0.07	0.01	4.47	86.80
Fallopia convolvulus	0.01	0.04	3.21	90.02

Herbicides A & E

Average dissimilarity = 55.71

Species	Herb A Av.Abund	Herb E Av.Abund	Contrib%	Cum.%
Galium aparine	10.29	0.21	27.21	27.21
Poa annua	7.03	12.44	24.49	51.70
Papaver spp.	8.30	0.82	21.60	73.30
Fumaria officinalis	0.44	0.44	5.90	79.19
Volunteer barley	0.04	0.08	3.91	83.11
Poa trivialis	0.07	0.03	3.84	86.95
Veronica persica	0.01	0.08	3.05	90.00

Herbicides C & E

Average dissimilarity = 74.65

	Herb C Av.Abund	Herb E Av.Abund	Contrib%	Cum.%
Poa annua	0.96	12.44	37.33	37.33
Papaver spp.	6.08	0.82	21.91	59.24
Galium aparine	2.94	0.21	12.23	71.47
Fumaria officinalis	0.30	0.44	7.41	78.88
Volunteer barley	0.05	0.08	4.29	83.17
Veronica persica	0.00	0.08	2.77	85.93
Poa trivialis	0.00	0.03	2.40	88.34
Volunteer potato	0.00	0.02	2.28	90.62

Herbicides D & E

Average dissimilarity = 73.95

Species	Herb D Av.Abund	Herb E Av.Abund	Contrib%	Cum.%
Poa annua	0.09	12.44	48.35	48.35
Papaver spp.	0.22	0.82	10.82	59.18
Fumaria officinalis	0.13	0.44	9.28	68.46
Galium aparine	0.17	0.21	6.92	75.38
Volunteer barley	0.00	0.08	4.82	80.20
Poa trivialis	0.01	0.03	3.57	83.77
Veronica persica	0.00	0.08	3.39	87.16
Fallopia convolvulus	0.04	0.00	3.01	90.17

Herbicides C & F

Average dissimilarity = 78.40

Species	Herb C Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Poa annua	0.96	6.60	22.62	22.62
Papaver spp.	6.08	0.68	21.52	44.15
Galium aparine	2.94	0.30	19.40	63.54
Fumaria officinalis	0.30	0.68	13.05	76.59
Volunteer barley	0.05	0.01	4.02	80.62
Elytrigia repens	0.00	0.02	3.40	84.02
Fallopia convolvulus	0.01	0.02	3.18	87.20
Stellaria media	0.01	0.02	2.85	90.04

Herbicides A & F

Average dissimilarity = 61.55

Species	Herb A Av.Abund	Herb F Av.Abund	Contrib%	Cum.%
Galium aparine	10.29	0.30	28.04	28.04
Papaver spp.	8.30	0.68	26.55	54.59
Poa annua	7.03	6.60	22.24	76.83
Fumaria officinalis	0.44	0.68	5.78	82.60
Poa trivialis	0.07	0.00	2.63	85.23
Stellaria media	0.03	0.02	2.54	87.78
Volunteer barley	0.04	0.01	2.26	90.04

Herbicides A & G

Average dissimilarity = 69.39

	Herb A Av.Abund	Herb G Av.Abund	Contrib%	Cum.%
Papaver spp.	8.30	0.00	29.41	29.41
Poa annua	7.03	0.02	27.93	57.34
Galium aparine	10.29	3.87	20.67	78.01
Fumaria officinalis	0.44	0.13	6.42	84.43
Poa trivialis	0.07	0.00	4.17	88.60
Fallopia convolvulus	0.01	0.01	2.28	90.88

Herbicides E & G

Average dissimilarity = 81.73

Species	Herb E Av.Abund	Herb G Av.Abund	Contrib%	Cum.%
Poa annua	12.44	0.02	41.48	41.48
Galium aparine	0.21	3.87	18.81	60.29
Papaver spp.	0.82	0.00	11.98	72.27
Fumaria officinalis	0.44	0.13	8.89	81.16
Volunteer barley	0.08	0.01	4.24	85.40
Veronica persica	0.08	0.00	2.93	88.33
Poa trivialis	0.03	0.00	2.83	91.16

Herbicides F & G

Average dissimilarity = 78.11

Species	Herb F Av.Abund	Herb G Av.Abund	Contrib%	Cum.%
Galium aparine	0.30	3.87	28.84	28.84
Poa annua	6.60	0.02	28.67	57.51
Fumaria officinalis	0.68	0.13	13.29	70.81
Papaver spp.	0.68	0.00	9.21	80.01
Elytrigia repens	0.02	0.00	3.26	83.27
Fallopia convolvulus	0.02	0.01	2.95	86.22
Avena fatua	0.00	0.00	2.55	88.77
Stellaria media	0.02	0.00	2.39	91.16

Herbicides A & B

Average dissimilarity = 58.07

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	7.03	3.81	28.56	28.56
Galium aparine	10.29	3.65	26.51	55.08
Papaver spp.	8.30	1.62	20.30	75.38
Fumaria officinalis	0.44	0.25	5.96	81.34
Poa trivialis	0.07	0.01	5.39	86.74
Volunteer barley	0.04	0.05	3.68	90.41

Herbicides G & B

Average dissimilarity = 66.14

	Herb G Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Galium aparine	3.87	3.65	29.92	29.92
Poa annua	0.02	3.81	25.16	55.07
Papaver spp.	0.00	1.62	16.88	71.95
Fumaria officinalis	0.13	0.25	8.54	80.49
Volunteer barley	0.01	0.05	6.00	86.49
Senecio vulgare	0.00	0.05	3.64	90.13

High Mowthorpe: Arthropods

Herbicides A & C

Average dissimilarity = 27.33

Species	Herb A Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Oth.Nematocera	2.09	2.85	16.12	16.12
Calyptera	0.46	0.72	10.71	26.82
Brachycera	1.69	1.42	10.23	37.06
Araneae	1.25	0.91	9.84	46.89
Staphylinidae	0.58	0.00	7.65	54.55
Heteroptera	0.60	0.54	7.28	61.82
Chrysomelidae	0.39	0.23	6.77	68.59
Aschiza	2.20	2.11	6.35	74.94
Homoptera	0.60	0.58	5.81	80.75
Acalypterae	3.34	3.12	5.01	85.75
Coleoptera others	0.39	0.28	4.39	90.15

Herbicides A & G

Average dissimilarity = 32.27

Species	Av.Abund	Av.Abund	Contrib%	Cum.%
Araneae	1.25	0.56	14.01	14.01
Aschiza	2.20	1.07	13.93	27.95
Oth.Nematocera	2.09	2.68	13.21	41.16
Brachycera	1.69	1.42	8.66	49.81
Calyptera	0.46	1.01	8.63	58.45
Heteroptera	0.60	0.48	6.63	65.08
Staphylinidae	0.58	0.12	6.24	71.31
Homoptera	0.60	0.72	5.87	77.18
Chrysomelidae	0.39	0.26	4.97	82.16
Acalypterae	3.34	3.02	4.97	87.13
Coleoptera others	0.39	0.24	3.22	90.35

Herbicides A & B

Average dissimilarity = 30.25

	Group A	Group B	Contrib%	Cum.%
Oth.Nematocera	2.09	2.54	13.87	13.87
Araneae	1.25	1.08	10.88	24.76
Aschiza	2.20	1.63	10.37	35.13
Brachycera	1.69	1.83	8.38	43.51
Coleoptera others	0.39	0.45	8.36	51.87
Acalypterae	3.34	2.93	7.65	59.51
Calyptera	0.46	0.50	7.52	67.03
Heteroptera	0.60	0.08	6.89	73.92
Homoptera	0.60	0.31	6.13	80.06
Chrysomelidae	0.39	0.08	4.43	84.49
Staphylinidae	0.58	0.23	4.41	88.89
Elateridae	0.08	0.20	3.62	92.51

Herbicides G & B

Average dissimilarity = 27.96

	Group G	Group B	Contrib%	Cum.%
Calyptera	1.01	0.50	11.58	11.58
Aschiza	1.07	1.63	10.87	22.44
Araneae	0.56	1.08	10.85	33.29
Coleoptera others	0.24	0.45	8.24	41.53
Brachycera	1.42	1.83	8.07	49.60
Homoptera	0.72	0.31	7.83	57.43
Heteroptera	0.48	0.08	7.78	65.21
Acalypterae	3.02	2.93	7.02	72.23
Oth.Nematocera	2.68	2.54	6.03	78.26
Neuroptera larvae	0.08	0.24	4.81	83.07
Chrysomelidae	0.26	0.08	4.67	87.74
Staphylinidae	0.12	0.23	4.57	92.31

High Mowthorpe 2004: Weeds

Herbicides A & B

Average dissimilarity = 70.59

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	1.49	0.02	24.89	24.89
Fallopia convolvulus	0.51	0.00	15.71	40.60
Sinapis arvensis	0.28	0.00	12.05	52.65
Galium aparine	0.96	0.92	10.67	63.32
Elytrigia repens	0.07	0.00	5.64	68.96
Stellaria media	0.05	0.00	4.77	73.73
Volunteer potato	0.05	0.00	4.45	78.18
Volunteer oilseed rape	0.04	0.00	4.45	82.64
Veronica hederifolia	0.03	0.01	4.34	86.97
Polygonum aviculare	0.02	0.00	3.13	90.11

Herbicides A & C

Average dissimilarity = 54.61

Species	Herb A Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Poa annua	1.49	0.07	22.25	22.25
Sinapis arvensis	0.28	0.43	11.42	33.67
Galium aparine	0.96	0.70	11.06	44.73
Fallopia convolvulus	0.51	0.58	10.74	55.47
Volunteer potato	0.05	0.01	5.72	61.19
Elytrigia repens	0.07	0.02	5.54	66.73
Avena fatua	0.01	0.03	4.84	71.57
Stellaria media	0.05	0.00	4.69	76.26
Veronica hederifolia	0.03	0.01	4.58	80.84
Volunteer oilseed rape	0.04	0.00	4.41	85.25
Sonchus spp.	0.00	0.02	3.95	89.20
Veronica persica	0.00	0.02	3.71	92.91

Herbicides B & C

Average dissimilarity = 68.75

Species	Herb B Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Fallopia convolvulus	0.00	0.58	24.03	24.03
Sinapis arvensis	0.00	0.43	19.70	43.73
Galium aparine	0.92	0.70	15.21	58.94
Poa annua	0.02	0.07	8.17	67.11
Veronica hederifolia	0.01	0.01	4.93	72.04
Veronica persica	0.00	0.02	4.85	76.88
Avena fatua	0.00	0.03	4.83	81.71
Elytrigia repens	0.00	0.02	4.32	86.04
Sonchus spp.	0.00	0.02	4.00	90.03

Herbicides B & D

Average dissimilarity = 70.70

Species	Herb B Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Poa annua	0.02	0.96	26.51	26.51
Galium aparine	0.92	0.31	22.88	49.38
Elytrigia repens	0.00	0.05	8.95	58.34
Veronica persica	0.00	0.06	7.29	65.63
Veronica hederifolia	0.01	0.02	6.60	72.23
Sinapis arvensis	0.00	0.04	6.21	78.44
Fallopia convolvulus	0.00	0.03	5.22	83.66
Volunteer potato	0.00	0.02	3.28	86.94
Volunteer oilseed rape	0.00	0.01	2.76	89.70
Polygonum aviculare	0.00	0.00	2.48	92.18

High Mowthorpe 2004: Weeds continued

Herbicides C & D

Average dissimilarity = 67.45

Species	Herb C Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Poa annua	0.07	0.96	18.27	18.27
Fallopia convolvulus	0.58	0.03	16.81	35.08
Sinapis arvensis	0.43	0.04	14.20	49.27
Galium aparine	0.70	0.31	13.57	62.84
Veronica persica	0.02	0.06	7.12	69.96
Elytrigia repens	0.02	0.05	5.46	75.43
Veronica hederifolia	0.01	0.02	4.78	80.20
Sonchus spp.	0.02	0.01	4.77	84.98
Volunteer potato	0.01	0.02	4.30	89.28
Avena fatua	0.03	0.00	4.21	93.49

High Mowthorpe 2004: Arthropods

Herbicides A & B

Average dissimilarity = 28.16

	Herb A	Herb B		
Species	Av.Abund	Av.Abund	Contrib%	Cum.%
Calyptera	2.31	1.24	9.77	9.77
Araneae	3.79	4.37	7.64	17.41
Heteroptera	1.19	1.45	7.02	24.43
Elateridae	2.39	2.24	6.69	31.11
Oth.Nematocera	1.19	1.45	6.67	37.78
Staphylinidae	2.09	2.55	6.55	44.34
Aschiza	2.55	1.82	6.55	50.89
Acalypterae	6.59	5.46	6.10	57.00
Tipulidae	0.70	0.45	5.83	62.82
Chrysomelidae	0.38	0.74	5.52	68.34
Homoptera	0.62	0.32	4.80	73.15
Coleoptera others	20.88	16.78	4.69	77.84
Diptera*	0.00	0.51	4.12	81.96
Curculionidae	0.20	0.26	3.13	85.09
Lepidoptera*	0.20	0.17	3.07	88.16
Brachycera	14.85	14.49	3.01	91.16

Herbicides B & D

Average dissimilarity = 29.85

	Herb B	Herb D		
Species	Av.Abund	Av.Abund	Contrib%	Cum.%
Coleoptera others	16.78	10.48	9.41	9.41
Elateridae	2.24	1.75	7.99	17.40
Staphylinidae	2.55	1.24	7.90	25.30
Araneae	4.37	2.89	7.70	33.00
Aschiza	1.82	1.82	7.24	40.24
Heteroptera	1.45	1.69	6.85	47.08
Calyptera	1.24	1.75	6.48	53.56
Oth.Nematocera	1.45	1.69	6.01	59.57
Tipulidae	0.45	0.58	5.99	65.56
Chrysomelidae	0.74	0.45	5.01	70.57
Acalypterae	5.46	6.94	4.93	75.50
Homoptera	0.32	0.51	3.92	79.42
Diptera*	0.51	0.10	3.76	83.17
Symphyta*	0.38	0.32	3.58	86.76
Brachycera	14.49	14.14	3.11	89.87
Carabidae	0.20	0.26	2.92	92.79

High Mowthorpe 2005: Weeds

Herbicides A & C

Average dissimilarity = 78.63

Species	Herb A Av.Abund	Herb C Av.Abund	Contrib%	Cum.%
Papaver spp.	12.55	0.19	28.35	28.35
Poa annua	8.16	0.02	27.51	55.86
Galium aparine	8.32	0.29	22.16	78.02
Fumaria officinalis	0.35	0.24	4.71	82.73
Poa trivialis	0.04	0.00	2.86	85.58
Volunteer barley	0.05	0.02	2.75	88.34
Fallopia convolvulus	0.01	0.02	2.27	90.61

Herbicides A & D

Average dissimilarity = 55.38

Species	Herb A Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Papaver spp.	12.55	1.00	27.75	27.75
Poa annua	8.16	13.85	24.93	52.68
Galium aparine	8.32	0.25	23.29	75.97
Fumaria officinalis	0.35	0.52	5.37	81.34
Volunteer barley	0.05	0.04	3.20	84.54
Poa trivialis	0.04	0.02	2.95	87.50
Veronica persica	0.01	0.04	2.27	89.77
Stellaria media	0.03	0.01	1.94	91.70

Herbicides C & D

Average dissimilarity = 75.88

Species	Herb C Av.Abund	Herb D Av.Abund	Contrib%	Cum.%
Poa annua	0.02	13.85	50.39	50.39
Papaver spp.	0.19	1.00	11.94	62.33
Fumaria officinalis	0.24	0.52	8.33	70.66
Galium aparine	0.29	0.25	7.17	77.83
Volunteer barley	0.02	0.04	3.56	81.40
Poa trivialis	0.00	0.02	2.79	84.18
Volunteer potato	0.02	0.00	2.51	86.69
Fallopia convolvulus	0.02	0.00	2.48	89.17
Veronica persica	0.00	0.04	2.25	91.42

Herbicides A & B

Average dissimilarity = 75.03

	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Papaver spp.	12.55	0.00	31.39	31.39
Poa annua	8.16	0.01	28.30	59.69
Galium aparine	8.32	3.30	19.23	78.92
Fumaria officinalis	0.35	0.20	5.07	83.99
Volunteer barley	0.05	0.01	2.73	86.72
Poa trivialis	0.04	0.00	2.62	89.34
Fallopia convolvulus	0.01	0.02	1.94	91.28

Herbicides C & B

Average dissimilarity = 72.43

Species	Herb C Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Galium aparine	0.29	3.30	38.43	38.43
Fumaria officinalis	0.24	0.20	13.78	52.21
Papaver spp.	0.19	0.00	11.02	63.23
Volunteer barley	0.02	0.01	5.74	68.97
Poa annua	0.02	0.01	5.60	74.57
Fallopia convolvulus	0.02	0.02	5.16	79.73
Volunteer potato	0.02	0.00	4.49	84.22
Avena fatua	0.00	0.01	4.04	88.25
Elytrigia repens	0.00	0.01	2.96	91.21

Herbicides D & B

Average dissimilarity = 82.27

Species	Herb D Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Poa annua	13.85	0.01	43.67	43.67
Galium aparine	0.25	3.30	18.50	62.18
Papaver spp.	1.00	0.00	12.64	74.82
Fumaria officinalis	0.52	0.20	7.60	82.42
Volunteer barley	0.04	0.01	2.87	85.30
Poa trivialis	0.02	0.00	2.23	87.53
Fallopia convolvulus	0.00	0.02	2.06	89.59
Veronica persica	0.04	0.00	1.99	91.58

Herbicides A & C

Average dissimilarity = 26.61

Species	Group A Av.Abund	Group C Av.Abund	Contrib%	Cum.%
Coleoptera others	3.07	0.51	13.26	13.26
Aschiza	16.38	6.41	11.51	24.78
Staphylinidae	2.80	0.95	9.86	34.64
Oth.Nematocera	7.71	3.57	8.37	43.01
Araneae	3.07	3.07	7.85	50.86
Calyptera	3.68	2.63	7.69	58.54
Tipulidae	1.51	0.74	6.54	65.08
Chrysomelidae	0.32	0.91	5.67	70.75
Diptera larvae	0.29	0.41	4.65	75.39
Acalypterae	39.74	31.36	4.47	79.87
Carabidae	0.29	0.26	3.65	83.52
Brachycera	15.60	16.78	3.61	87.13
Homoptera	0.35	0.20	3.53	90.66

Herbicides A & D

Average dissimilarity = 25.15

Species	Group A Av.Abund	Group D Av.Abund	Contrib%	Cum.%
Coleoptera others	3.07	0.70	13.52	13.52
Araneae	3.07	1.88	9.31	22.84
Aschiza	16.38	12.18	8.02	30.86
Staphylinidae	2.80	2.80	7.98	38.84
Total Heteroptera	0.17	1.24	7.41	46.25
Calyptera	3.68	2.89	6.70	52.95
Tipulidae	1.51	1.34	6.27	59.22
Chrysomelidae	0.32	0.82	5.28	64.50
Oth.Nematocera	7.71	5.46	4.81	69.31
Acalypterae	39.74	32.11	4.59	73.89
Diptera larvae	0.29	0.45	4.35	78.25
Symphyta larvae	0.17	0.32	3.85	82.10
Brachycera	15.60	18.50	3.77	85.88
Carabidae	0.29	0.26	3.60	89.48
Elateridae	0.15	0.45	3.43	92.91

Herbicides A & B

Average dissimilarity = 26.16

Species	Herb A Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Coleoptera others	3.07	0.10	14.45	14.45
Aschiza	16.38	7.71	11.90	26.35
Calyptera	3.68	1.82	9.64	35.99
Staphylinidae	2.80	1.88	8.62	44.61
Araneae	3.07	4.50	7.45	52.05
Chrysomelidae	0.32	1.24	6.57	58.63
Tipulidae	1.51	1.04	6.39	65.02
Acalypterae	39.74	28.51	4.76	69.78
Oth.Nematocera	7.71	5.46	4.72	74.50
Homoptera	0.35	0.15	3.94	78.44
Carabidae	0.29	0.20	3.87	82.30
Brachycera	15.60	16.38	3.57	85.88
Elateridae	0.15	0.23	2.92	88.80
Diptera*	0.29	0.15	2.92	91.72

Herbicides D & B

Average dissimilarity = 24.16

Species	Herb D Av.Abund	Herb B Av.Abund	Contrib%	Cum.%
Araneae	1.88	4.50	9.47	9.47
Aschiza	12.18	7.71	8.96	18.42
Staphylinidae	2.80	1.88	8.68	27.11
Calyptera	2.89	1.82	8.63	35.73
Total Heteroptera	1.24	0.15	8.31	44.04
Tipulidae	1.34	1.04	6.97	51.02
Chrysomelidae	0.82	1.24	6.41	57.43
Coleoptera others	0.70	0.10	6.22	63.65
Oth.Nematocera	5.46	5.46	4.80	68.45
Elateridae	0.45	0.23	4.75	73.20
Diptera*	0.45	0.15	4.66	77.86
Homoptera	0.23	0.15	4.00	81.86
Brachycera	18.50	16.38	3.92	85.78
Acalypterae	32.11	28.51	3.79	89.57
Carabidae	0.26	0.20	3.71	93.27

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The SAFFIE Project Report

Chapter 6 – Experiment 2 – Management of the non-cropped margin structure to maximise biodiversity

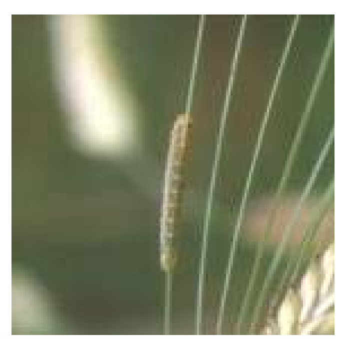
(Pages 268 - 523)

Sustainable Arable Farming For an Improved Environment

SAFFIE

Enhancing Biodiversity




6 EXPERIMENT 2 - MANAGEMENT OF THE NON-CROPPED MARGIN STRUCTURE TO MAXIMISE BIODIVERSITY

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Chapter 6 contents

6.1 SUMMARY

Three grass seed mixtures comprising a grass mix (CS, typical of countryside stewardship), a mixture of tussock grasses and flowers (TG, to increase ground-dwelling invertebrates), and a mixture of fine-leafed grasses and flowers (FG, to increase insect diversity, including pollen and nectar feeders), were sown as 5 m wide margins, at three sites in during October 2001–March 2002. Three different spring management treatments (cutting, scarification and a low rate of a selective graminicide) started in 2003, and were applied annually to each margin type, to manipulate the architecture of the vegetation. The resulting vegetation, invertebrates and birds were monitored until 2006.

6.1.1 Weeds and agronomy

- Plants sown in the margin did not become weeds in the adjacent crop.
- Crop pest incidence did not increase adjacent to the margins.

6.1.2 Vegetation

- Distinct plant communities developed in the establishment year in relation to seed mix, but no effects on bare ground, litter cover and coarse grain vegetation structure were determined.
- A greater species number and diversity resulted from sowing diverse seed mixes. In plots sown with the CS mix, mean species number was 7.0 compared with 9.9 for the TG mix and 9.3 for the FG mix. Mean values of Simpson's unbiased diversity were 0.82, 0.89 and 0.87 for the CS, TG and FG mixes respectively.
- Species number and diversity decreased with time regardless of seed mix and treatment. In 2003 the mean number of species was 9.7 compared with 7.1 in 2006, while values of Simpson's unbiased diversity decreased from 0.89 to 0.83.
- Sward scarification helped to maintain sown species in the sward and enhance plant species diversity, but the effect was site specific.
- Sward scarification instigated a convergence in plant community composition between the different seed mixes. The extent of this was site specific.
- Graminicide application produced plant communities depicted by sown forb species.
- Seed mix type had a minimal impact on values of bare ground cover.
- Sward scarification was associated with the greatest values of bare ground area (% of total area) in both June and September. In June, mean values were 21.1%, compared with 3.1% with cutting and 3.5% with graminicide, whilst in September values were 0.5%, 3.0% and 0.4% for cutting, scarification and graminicide respectively.
- Values of coarse grain vegetation structure were highly variable with respect to treatment, site and year. Treatments of scarification, graminicide and the FG mix were generally associated with the lowest values.

- Scarification was associated with reduced values of reproductive resources, but tended to promote the resource abundance of the unsown components.

- Cutting was generally associated with greater values of reproductive resources, although in plots sown with the TG mix values were greater with graminicide.

- Plots sown with the CS mix generally had a greater resource abundance of the unsown components, but a lower abundance of reproductive resources overall.

- Plots sown with the FG mix generally had greater values of reproductive resources.

6.1.3 Invertebrates (except bees and butterflies)

- Tere is evidence that the abundance and species richness of a variety of invertebrate taxa will either peak or plateau 2–3 years after their establishment.

- The countryside stewardship seed mix provides a good resource for those invertebrate species that are dependent on sward architectural complexity. However, it can be a poor resource for phytophagous species, particularly where their host plants are forbs.

- The tussock grass and forbs seed mix provided an architecturally complex sward and forb and grass host plants vital for many invertebrate species. When considered across a variety of non-pollinator invertebrates this was superior to both the countryside stewardship (grass) and fine grass and forbs seed mix.

- Responses to margin management often showed strong contrasts between taxa. Species that required either an architecturally complex sward or dense grass vegetations responded poorly to scarification, e.g. planthoppers, spiders and Symphyta/ Lepidoptera larvae. In contrast, improved establishment of some key floral species in response to scarification benefited some phytophagous invertebrates, e.g. the weevils and leaf beetles.

- The abundance and species richness of all the non-pollinator, invertebrate taxa did not respond to the interaction between seed mix and management, although they did respond individually to these factors. However, it was shown that the species composition did respond to the interaction of seed mix and management at all three sites.

- There was no significant effect of seed mix on the diversity of soil macrofauna.

- Isopod abundance and species density responded significantly to management with fewer species and lower abundances in the scarified plots.

- Species assemblages in the scarified plots consisted of species commonly associated with cropped or exposed habitats.

- Litter-dwelling species, with their requirement for surface residue to provide cover and food, had low densities in the scarified plots.

- The abundance and diversity of soil- and litter-feeders did not respond to seed mix but were significantly influenced by management treatment. Lower abundances and species densities were found in the scarified plots in the spring, but these then increased to levels equal to, or greater than, the other management treatments in autumn.

6.1.4 Bumblebees and Butterflies

- Inclusion of forbs in the seed mixture resulted in the largest increases in abundance and diversity of pollen and nectar resources, bumblebees and butterflies.

- The rare bumblebee species, *Bombus ruderatus*, utilised the margins sown with forbs in all five years at the Boxworth site.

- Margin management effects were secondary: soil disturbance by scarification increased diversity of flowering plants; graminicide application reduced competition from grasses, and increased flower abundance and species richness of bees.

- Sowing a diverse seed mixture of perennial forbs is the most effective means of creating foraging habitat for bees and butterflies on arable field margins.

- Graminicide application is a practical option for enhancing the value of the large area of species-poor grass margins for pollinators.

6.1.5 Birds

- Birds responded positively to treatments with higher prey densities (of ground beetles in particular) and greater vegetation density.

- Birds responded positively to margin scarification or graminicide-treatment, compared with cutting.

- Compared with margin management, the response by birds to seed-mix was weak but significant after five years, birds being more strongly associated with the tussock and fine grass mixes with wildflowers, than the grass mix.

6.2 MATERIALS AND METHODS

6.2.1 Objective

The overall objective of the project was to enhance farmland biodiversity by integrating novel habitat management approaches, in the crop and non-cropped margins, to develop more sustainable farming.

The hypothesis was that an improved understanding of interactions would lead to increased invertebrate and weed seed abundance, the availability of which will be of particular benefit to farmland birds.

6.2.2 Site Details

Experimentation commenced in October 2001. There were 3 sites as detailed in Table 6.1. All sites were cropped in a rotation typical of the area and soil type. Details of cropping are in Appendix 1.

Table 6.1. Location of sites.

Site Name	Location	Soil type
ADAS Boxworth	Cambridgeshire	Calcareous Clay
ADAS Gleadthorpe	Nottinghamshire	Sand
ADAS High Mowthorpe	North Yorkshire	Shallow silt loam over chalk

6.2.3 Experimental design

The margins were located around the boundary of the fields selected for the experiment, placement was agreed by Alison Riding (ADAS), Tim Sparks (CEH) and Nick Aebischer (GCT). Each of the three sites each had nine treatments and five replicates, these were located within two fields at Boxworth and three fields at Gleadthorpe and High Mowthorpe. Plot size was 25 m x 5 m, with the long edge running parallel to the field boundary. A 2.5 m buffer zone was included at the end of each plot (equivalent to 5 m between plots) to both prevent cross contamination between treatments and to allow entry of machinery to the plots (Figure 6.1). An example of plot layout in relation to field boundaries can be seen in Figure 6.2.

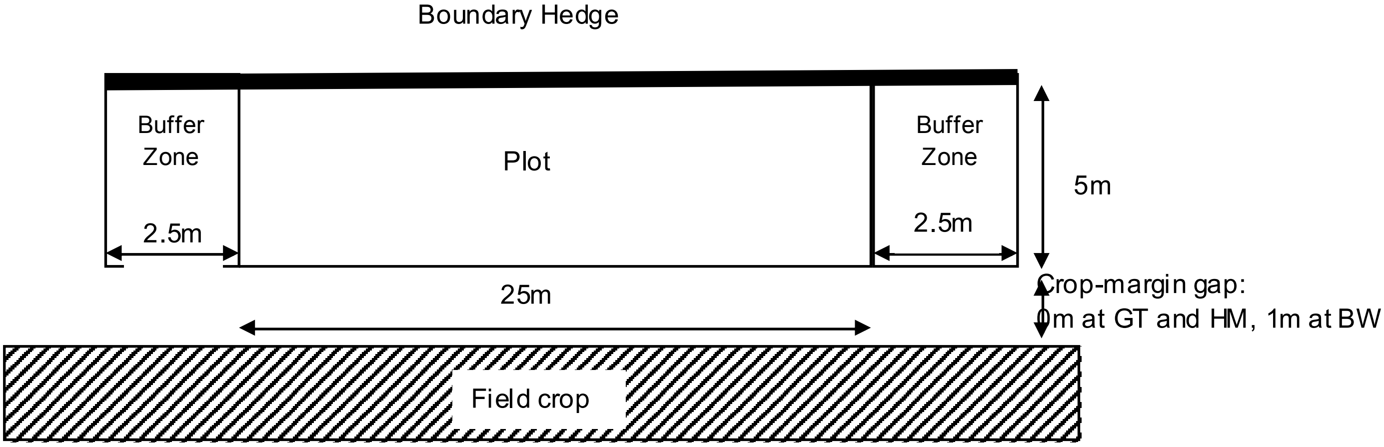

Figure 6.1. Plot layout.

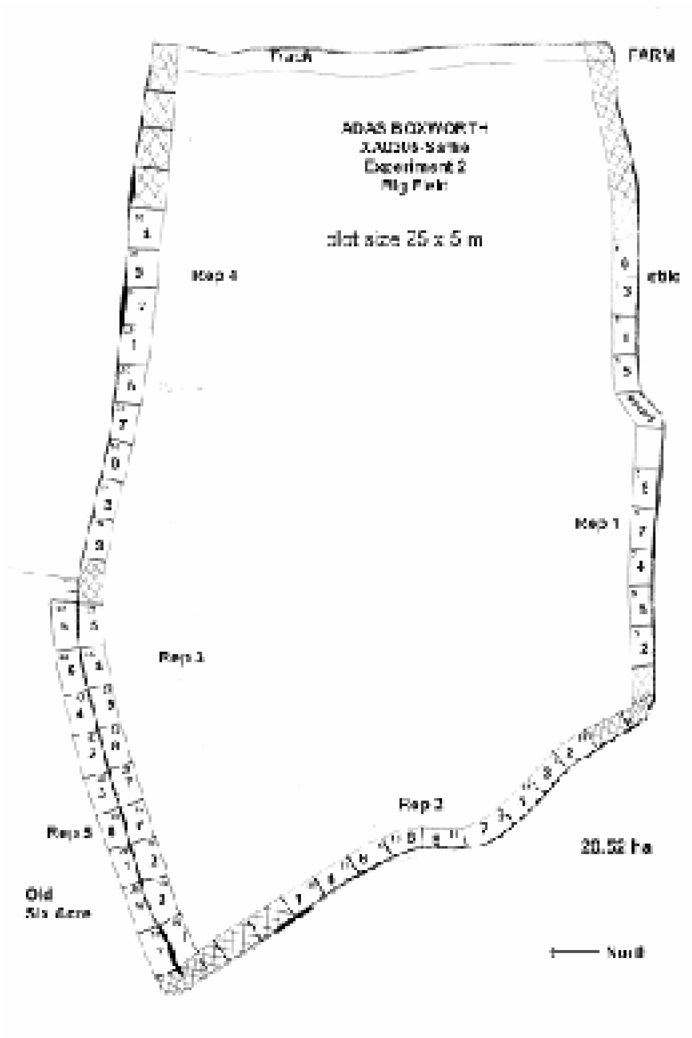

Figure 6.2. An example of plot arrangement in relation to the field boundary at ADAS Boxworth. The numbers in plots indicate treatment and plot identifiers.

6.2.4 Treatments

Treatments were comprised of three seed mixtures applied in factorial combination with three management treatments as detailed in Table 6.2.

Table 6.2. Seed mixture and management treatments.

Treatment number	Seed mixture	Management
1	Countryside stewardship mix (CS)	Cutting (Cut)
2	"	Scarification (Scar)
3	"	Selective graminicide (Gram)
4	Tussock grass and forbs (TG)	Cut
5	"	Scar
6	"	Gram
7	Fine-leaved grass and forbs (FG)	Cut
8	"	Scar
9	"	Gram

Seed mixtures

The tussock and countryside stewardship seed mixtures were identical at all sites. The fine grass and forbs mixture was tailored to suit soil type and site. Species are detailed in Table 6.3. Seed was purchased from a single supplier. Countryside stewardship mixture was drilled at 20 kg/ha, and the tussock and fine grass mixtures were drilled at 35 kg/ha.

Drilling date

The margins at Boxworth and High Mowthorpe were sown on 3 October 2001 and 12 October 2001 respectively. At Gleadthorpe drilling was delayed by wet weather until 13 March 2002.

Table 6.3. Details of seed mixtures

a) Countryside Stewardship Mix.

Species	Common Name	% (by wt.)
Agrostis capillaris	Common Bent	5.0
Cynosurus cristatus	Crested Dogstail	15.0
Dactylis glomerata	Cocksfoot	10.0
Festuca pratensis	Meadow Fescue	10.0
Festuca ovina	Sheep Fescue	20.0
Festuca rubra ssp. *juncea*	Slender Red Fescue	20.0
Poa pratensis	Smooth Meadow Grass	20.0

b) Tussock grass and broad-leaved forbs.

Species	Common Name	% (by wt.)
Grasses		
Alopecurus pratensis	Meadow Foxtail	4.0
Dactylis glomerata	Cocksfoot	16.0
Deschampsia cespitosa (w)	Wavy Hair-Grass	8.0
Festuca pratensis	Meadow Fescue	20.0
Festuca rubra spp. *rubra*	Red Fescue	20.0
Holcus lanatus	Yorkshire Fog	4.0
Phleum pratense	Timothy	8.0
Forbs		
Achillea millefolium	Yarrow	1.2
Centaurea nigra	Common Knapweed	2.4
Centaurea scabiosa	Greater Knapweed	1.6
Daucus carota	Wild Carrot	2.4
Dipsacus fullonum	Wild Teasel	1.6
Galium mollugo	Hedge Bedstraw	2.0
Geranium pratense	Meadow Cranesbill	1.6
Lathyrus pratensis	Meadow Vetchling	1.0
Leucanthemum vulgare	Oxeye Daisy	2.0
Silene dioica	Red Campion	3.0
Vicia cracca	Tufted Vetch	1.2

c) Fine leaved grass and broad-leaved forbs.

Species	Common name	% by weight		
		Boxworth	High Mowthorpe	Gleadthorpe
Grasses				
Agrostis capillaris	Common Bent	5.0		
Cynosurus cristatus	Crested Dogstail	35.0		
Festuca rubra ssp. *commutata*	Red Fescue	15.0		
Festuca rubra ssp. *juncea*	Slender Red Fescue	25.0		
Forbs				
Achillea millefolium	Yarrow	0.5	0.5	0.5
Centaurea nigra	Common Knapweed	1.0	0.5	1.0
Daucus carota	Wild Carrot	1.0	1.0	1.5
Galium verum	Lady's Bedstraw	1.5	1.0	2.0
Leucanthemum vulgare	Oxeye Daisy	1.0	1.0	1.0
Lotus corniculatus	Birdsfoot Trefoil	0.5	1.0	0.5
Plantago lanceolata	Ribwort Plantain	1.0	1.0	1.0
Primula veris	Cowslip	1.2	1.0	1.0
Prunella vulgaris	Selfheal	1.0	1.0	1.0
Ranunculus acris	Meadow Buttercup	3.5	1.5	1.5
Rhinanthus minor	Yellow Rattle	1.0	0.5	1.0
Knautia arvensis	Field Scabious	1.3	1.5	-
Leontodon hispidus	Rough Hawkbit	1.0	1.0	-
Plantago media	Hoary Plantain	-	1.0	0.6
Malva moschata	Musk Mallow	1.5	-	2.0
Rumex acetosa	Common Sorrel	1.0	-	1.0
Anthyllis vulneraria	Kidney Vetch	-	1.5	-
Centaurea scabiosa	Greater Knapweed	-	1.0	-
Origanum vulgare	Wild Marjoram	-	1.0	-
Pimpinella saxifraga	Burnet-saxifrage	-	1.0	-
Reseda lutea	Wild Mignonette	-	0.5	-
Sanguisorba minor ssp. *minor*	Salad Burnet	-	2.5	-
Echium vulgare	Viper's Bugloss	-	-	1.5
Linaria vulgaris	Common Toadflax	-	-	0.5
Ranunculus bulbosus	Bulbous Buttercup	-	-	1.4
Silene vulgaris	Bladder Campion	-	-	2.0
Vicia cracca	Tufted Vetch	1.5	-	-

6.2.4.1 Management

Management treatments began in 2003, following establishment of the seed mixtures. All treatments were mown to 30 cm height in the spring to facilitate treatment application. Dates of treatments are detailed in (Table 6.4).

1. **Cutting**. The sward was mown to a height of 15 cm using a flail mower, target date was early March, at the start of spring growth, cuttings were left *in situ*.

2. **Scarification**: A power harrow was used to scarify the sward. The power harrow was set at a suitable depth to cultivate the top 2.5 cm of the soil, with the aim of creating 60% soil disturbance. Scarification was done in early spring when the ground was fit to travel.

3. **Graminicide**: Fluazifop-P-butyl (as Fusilade Max, Syngenta Crop Protection Ltd) was applied at half label rate (0.8 l/ha) in 200 litres of water/ha, at 2 bar pressure with a farm sprayer. The aim was to suppress susceptible grass species.

Table 6.4. Actual dates of treatments.

	2003	**2004**	**2005**	**2006**
Boxworth				
Cut	19 March	10 March	21 March	20 March
Scar	13 March	10 March	21 March	21 March
Gram	14 March except plot 4, 24 March	14 April (delay due to weather)	1 April	18 April (delay due to cold conditions and slow growth
Gleadthorpe				
Cut	13 March	30 March	23 March	7 April
Scar	13 March	30 March	23 March	7 April
Gram	18 March	2 April	23 March	14 April
High Mowthorpe				
Cut	13 March	31 March	23 March	18 April
Scar	13 March	31 March	23 March	28 April
Gram	13 March	8 April	19 April	4 May (delayed due to cold conditions)

<u>Mown strip</u>

The management method for the 1 m strip between margin and crop was different at all 3 sites. At Boxworth this area was mown with a 1 m mower during the spring. At High

Mowthorpe and Gleadthorpe the crop was sown close to the margin negating the need for management of this area.

Hedges and basal vegetation

Hedges were cut annually in spring, with the cut as near vertical as possible at the base of the hedge. This was intended to prevent encroachment into the margin (especially of brambles and thistles). This was necessary to minimise the impact of the hedge and basal vegetation on the plant and invertebrate communities within the margin. Basal vegetation was cut back horizontally at a similar time to the hedges (Table 6.5).

Table 6.5. Dates of hedge and basal vegetation cutting.

Site	**Area cut**	**2003**	**2004**	**2005**	**2006**
Boxworth	Hedge and base	28 February	9 March	Not cut	20 March
Gleadthorpe	Hedge	26 March	Not cut	16 February	Not cut
	Base	3 March	Not cut	23 March	Not cut
High Mowthorpe	Hedge	28 February	18 March	28 February	Not cut
	Base	Not cut	Not cut	Not cut	28 April

6.2.5 Assessments

6.2.5.1 Weeds and Agronomy

The sites were visited every 2 weeks from drilling to monitor for any pest, disease and other problems, which may have originated from the margin treatments.

Weed counts (June/July)

Weed numbers were assessed in late June or early July each year. Counts were made in the crop adjacent to the margin, in five, 0.1 m^2 quadrats per plot. The quadrats were placed at right angles to the margin at 0.5 m and 6 m from the sown margin edge (Figure 6.3), and the number of plants was recorded by species. Notes were also made of any field-scale weed problems that were patchy in nature.

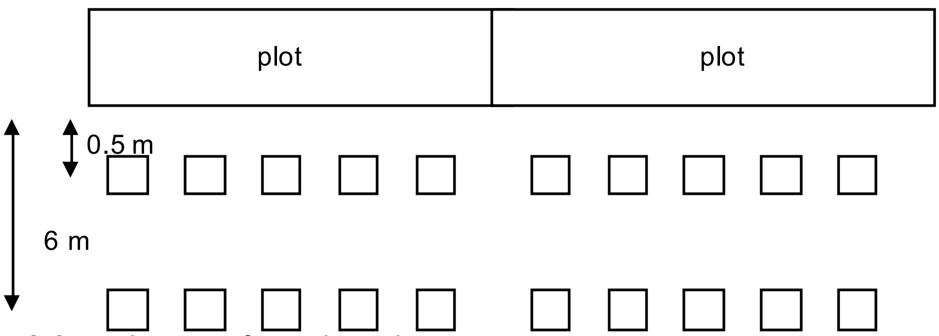

Figure 6.3. Layout of weed quadrats.

Statistical analysis

The data were analysed for each site and year separately, using analysis of variance (ANOVA) in GenStat® Release 8.1 (2005). The design was a randomised block, with five blocks and one plot of each of nine treatments in each block. Data were not transformed.

6.2.5.2 Field margin vegetation

Timing

Assessments were conducted in June and September during 2002, 2003, 2004 and 2006.

Species cover

Botanical assessments were performed in each plot using ten 0.5 x 0.5 m (0.25 m^2) quadrats per plot. The ten quadrats were divided along the margin:crop interface and the margin: hedge interface leaving a buffer of approximately one metre to avoid edge effects. In June, all species were identified and assigned a percentage cover value according to an eight-point scale (1 = < 1%, 2 = 1-5%, 3 = 6-10%, 4 = 11-20%, 5 = 21-40%, 6 = 41-60%, 7 = 61-80% & 8 = 81-100%). Values of Simpson's unbiased diversity (D) (Pielou, 1969) were calculated. This index (on a scale of 0 to 1.0) represents the probability that two randomly selected individuals in a sample belong to the same species. In September the vegetation was assessed by assigning species to functional groups: grasses, leguminous forbs and non-leguminous forbs. Values of Shannon evenness were then calculated. This index takes into account the number of groups and their relative abundances. The index (on a scale of 0 to 1.0) is increased either by having more unique groups, or by having a greater evenness in abundance values.

Values of percentage bare ground and unattached litter cover within the quadrats were determined in June and September using the same quadrats.

Reproductive Status

At the same time as performing the botanical assessments in June, the reproductive status of each plant species was recorded to enable values of relative resource abundance to be calculated. The status of each species was categorised according to the proportion of individuals that were i) vegetative only, ii) possessed flowering shoots/buds, iii) had flowers open, or iv) possessed seed/fruit that was forming, ripe or dehiscent. The proportion of each was assigned a value according to a four-point scale: 1 = 1-25%, 2 = 26-50 %, 3 = 51-75 % & 4 = 76-100%. Values of resource abundance were determined for individual species for each quadrat by multiplying the proportion of each reproductive status represented, by a species percentage cover value. As such, the units of resource abundance are based on values of cover abundance.

Coarse grain vegetation structure

The 'drop disc method' (Stewart et al. 2001) was used to provide an indication of height, and leaf and stem densities, within the sward canopy during June and September. A standard disc weighing 200 g with a diameter of 300 mm was dropped from a height of one metre down a vertically held ruler. In total, 24 measurements were taken, located in a diagonal line across each plot at one metre intervals. Height readings were taken as the distance from the ground where the drop disc comes to rest.

Fine grain vegetation structure

The point quadrat method was used to obtain detailed assessments of vegetation architecture in June. A linear frame consisting of ten 3 mm diameter pins separated by 100 mm gaps was used. Individual pins were divided into 50 mm height class intervals from the ground. Vegetation was categorised into six functional groups: i) fine grasses, ii) tussock grasses, iii) other grasses, iv) leguminous forbs, v) non-leguminous forbs, & vi) unattached dead litter. The number of contacts made by each functional group at each height interval was recorded. Four frames were randomly positioned in each plot, leaving a buffer of at least 1 m from the edge. For each functional group, Shannon-Wiener diversity values (H') (Shannon & Weaver, 1963) were calculated individually for pins and means were obtained for each plot. Values were used as an index of architectural complexity (Moffatt et al. 2005).

Statistical analysis

Values of species diversity and principal component analyses (PCA) were performed using Multi Variate Statistical Package Version 3.1 (MVSP, 1999). Data for species number ($\log_e n$+1), species diversity, bare ground (angular transformed), litter cover ($\log_e$), coarse grain structure ($\log_e$), architectural complexity, and resource abundance ($\log_e n$+1) were analysed using linear mixed models in SPSS Version 11.5 (SPSS, 2002). Four different models were used. The first model was used to analyse response variables assessed in the establishment year (2002), using seed mix as a fixed effect. Site and margin replicate block nested within site were used as random effects to account for random variation between and within sites. The second model was similar to the first, but as sites were analysed individually, and margin replicate block was the only random effect. The third model was used to analyse responses across years (2003, 2004 & 2006). Seed mix, sward treatment and year were set as fixed effects and interactions between these parameters were also included. Year was also set as a repeated measure with an autoregressive covariance structure to account for covariance between sample years. Site and margin replicate block nested within site were used as random effects. The fourth model was used to analyse responses across years but individually at each site. Seed mix, sward treatment and year were set as fixed effects. Year was also set as a repeated measure with an autoregressive covariance structure. Margin replicate block was used as the only random effect.

In all instances, model simplification was by deletion of non-significant factors, except where a factor was part of a significant interaction. Degrees of freedom were calculated using the iterative Satterthwaite's method (Schabenberger & Pierce 2002). When a factor was significant and not part of an interaction, *post-hoc* pairwise comparisons (P = 0.05) were made to investigate within treatment differences.

6.2.5.3 Invertebrates (except bees and butterflies)

Six collection methods were employed to sample key invertebrate groups within the field margins. These were vacuum sampling; sweep netting; pitfall traps; pan traps; octet method; and soil sampling. These methods were largely complementary in terms of target groups collected and were applied at times of high abundance of these specific taxonomic / functional groups. Invertebrate sampling within the experimental plots occurred for the years 2002, 2003, 2004 and 2006. Below-ground invertebrates were sampled in 2005 only.

Vacuum sampling

A Vortis suction sampler (manufactured by Burkard, UK) was used to collect twice-yearly samples, in June and September, to coincide with both early and late emergences of adult invertebrates, and to account for the relationship between the phenological development of sward and the invertebrate communities. For each sample 75 suctions over separate areas of the sward were made, each for 10 seconds duration. Samples for a particular date and plot were then amalgamated and returned to the lab for subsequent sorting and identification. The 75 suction samples within an individual plot were taken in an approximate evenly spaced grid of 5 x 15 sampling points covering the length of the plot. Vortis sample area (nine sucks) was 0.174 m^2. All invertebrates were retained and stored in 70 % industiral methylated spirits (IMS) Beetles (Carabidae, Curculionidae, Apionidae, Chrysomelidae and Coccinellidae), True Bugs (Heteroptera) and Planthoppers (Auchenorrhyncha: Cercopidae, Cicadellidae, Cixiidae, Delphacidae) were identified to species level. Spider total abundance was counted. All results presented are based on total abundances and species richnesses as recorded for each sample year. These have been presented in their raw values and have not been adjusted for the sample area which was the same for each experimental plot.

Sweep netting

To assess the occurrence and biomass of key bird food taxa, two 10 m transects comprising 20 sweeps were made on each side of the plot (Figure 6.4). Sweep net samples were made twice a year coinciding with the Vortis samples in June and September. Butterfly / Moth (Lepidoptera) and Sawfly (Symphyta) larvae were immediately separated and stored in air tight containers in a cool place before being and counted and weighed to give a measure of wet larval biomass. Larvae were weighed with an Acculab portable field balance readable to ± 0.01g.The Orthoptera were identified in situ or retained in 70% alcohol. Total abundance of the St Mark's Flies (Bibionidae) and Craneflies (Tipulidae) within sweep net samples were also counted. Nets were standard sweep net (Watkins and Doncaster) and were identical to those used for sampling in the the crop, as reported in other chapters.

Pitfall trapping

5 pitfalls were placed evenly along the centre of the plot (Figure 6.4) and left open for 5 days. Pitfall traps comprise 60 mm diameter tubs and lids (A W Gregory & Co Ltd) and were filled with 100 ml 50 % ethylene glycol and unscented detergent mix. All pitfall trap samples were made in May for a period of 2 weeks. From these samples the total abundance and species richness of the ground beetles (Carabidae) were calculated. Pitfall traps do not provide a true measure of ground active invertebrate density, but are highly dependent on the relationship between the activity and abundance of individual species. The pitfall traps do, however, have the advantage that they trap continuously over an extended period of time. Data derived from the pitfall traps was therefore intended to provide an indication of the overall availability of a key food resource for birds.

Pan traps

Pan traps were used to assess the abundance of agriculturally important slugs. To do this five pan traps were placed evenly along the centre of the plot (Figure 6.4) and collected after 2 days. Traps were 150 mm inverted flowerpot saucers baited with bran. Total abundance of slugs was then recorded. Pan traps were placed out in September of 2002, 2003 and 2006 only.

Octet method

The Octet method was evaluated as a potential method for sampling earthworms during year 1, and calibrated against other methods. This method was dropped in favour of a combination of other methods, which were more effective, rapid and reliable for sampling below ground invertebrates, including earthworms.

Below ground invertebrates

Five soil cores measuring 25 cm^2 and 10 cm deep were taken from each plot in the four replicated blocks, in April and October 2005. Soil cores were located 3 m apart on a transect running parallel to the hedge, halfway between the hedge and crop edge. Soil cores were handsorted for 40 minutes and all macrofauna were extracted into 80% alcohol. The Lumbricidae, Diplopoda, Chilopoda, and Isopoda were identified to species and assigned to feeding groups as follows: adult and juvenile earthworms were identified as either litter-feeders (epigeics and anecics) or soil-feeders (endogeics) and woodlice and millipedes were categorised as litter-feeding detritivores.

Statistical Approach

Above Ground Invertebrates

The analysis of abundance and species richness used a temporal split-plot ANOVA approach to account for the repeated measurements taken within the same plots in 2003, 2004 and 2006. The establishment year 2002 was ignored in all these analyses as management was not implemented within the margins until 2003. Analyses were carried out using SAS Version 9.1 (SAS, 2002). For each site a single average value of invertebrate abundance and species richness was calculated for each of the nine treatment levels of the 3 × 3 factorial design. This was calculated by taking an average value across all five replicate blocks for a particular treatment, treating each site separately. For this reason replicate block was not included in the repeated measures ANOVA model. The whole-plot explanatory variables of the split-plot ANOVA model were: site (3 levels), seed mix (3 levels), management (3 levels), and seed-mix*management. These whole plot factors were tested against the error term of site*seed-mix*management. The temporal split-plot explanatory variables were: year (3 levels), year*seed-mix, year*management and year*seed-mix*management. All abundance and species richness data were $\log_e n+1$ transformed to normalise the data. Post hoc Tukey's tests where performed with an appropriate error terms for the whole plot factors.

The beetles were used as a model system with which to investigate assemblage level responses to seed mix, management and the continuous measures of between plot variation in plant community structure and sward architecture. Changes in the structure of the beetle assemblages were assessed using the linear ordination method redundancy analysis (RDA). This was chosen on the basis of the short gradient lengths determined from preliminary detrended correspondence analysis (DCA). Only beetles represented by more than one individual were included in these analyses. In all cases, abundances of individual species were summed within a particular year and $\log_{10}$ transformed. Following ter Braak & Smilauer (2003), the temporal change in beetle assemblage structure was tested based on interactions of environmental variables with year. Sample year (2003, 2004 and 2006) and replicate block were also included as covariables within each individual RDA analysis, with the latter of these being used as a blocking factor. Separate analyses were performed for individual sites, a factor necessitated by large, between-site variation in species composition caused principally by site, soil type and geographical location. Repeated measurements taken each year of the study were treated as a temporal split-plot within the analysis, and samples were permuted freely between whole plots only. In all cases significance was tested for each interaction using Monte Carlo permutation tests of both canonical axes under a reduced model (1000 permutations). The RDA analysis was divided into two sections, the first focusing on the effects of the treatments, seed mix and management, by considering in separate analysis: 1) overall effect of seed mix; 2) overall effect of management; 3) overall effect of seed-mix × management interactions; 4) individual effects of seed-mix × management interactions. The treatments effects were coded individually by nominal environmental variables, and were tested individually. The second part of the RDA analysis considered the effect of continuous environmental measures of between margin plot variation in plant community structure and sward architecture. These were: 1) Overall Shannon diversity measure of sward architecture (Architecture H_{all}); 2) Shannon iversity measure of tussock grass architecture (Architecture $H_{tussock}$); 3) Shannon diversity measure of legume architecture (Architecture H_{legume}); 4) Percentage area of bare ground (%Bare); 5) Shannon diversity of grasses (Grass H'); 6) Shannon diversity of forbs (Forb H'); 7) Shannon diversity of legumes (Legume H'); 8) Shannon diversity of thistles (Thistle H'). A final overall analysis including all significant treatment and continuous environmental parameter interactions with year was performed to assess the overall level of explained variation in the model. The analysis was carried out in CANOCO 4.53 (ter Braak & Šmilauer, 1997). The establishment year (2002) data have been included as a supplementary data for the purpose of the biplots only. Such data from 2002 have no direct effect on the RDA analysis, but they have been included to provide a reference point for beetle assemblage structure in response to seed mix in this establishment year.

Below ground invertebrates

To identify the effects of the seed mix and management on soil macrofaunal biodiversity, overall abundance and species densities of the Lumbricidae, Isopoda, Chilopoda, and Diplopoda were assessed with general linear mixed models using SAS Version 9.1 (SAS, 2002). The treatments (seed mix and management) were included as fixed factors and replicate block as random effect. Abundances were $\log_{10}(n+1)$ transformed, and deletion of non-significant parameters performed to achieve model simplification. When a significant effect of the treatment was found, pairwise comparisons of least square mean values were performed using SAS. Repeated measures analyses with general linear mixed models were carried out to identify the effect of the treatments, and any interactions with season, on the responses of individual feeding group abundances and species densities.

Differences in soil invertebrate assemblages between the treatments were assessed using direct ordination methods in CANOCO 4.53 (ter Braak & Šmilauer, 1997). Abundances of each species were combined from the two seasons and log-transformed, and species represented by a single individual were excluded from the analyses. Soil cores taken from the crop were included as supplementary samples to allow a comparison between species assemblages in the margins and crop. To identify the main effects of seed mix and management on species assemblages, two pRDAs were carried out on the species data; the first with the three seed mixes as environmental variables and the managements and replicate blocks as covariables; and the second with the three managements as environmental variables and the seed mix and replicate blocks as covariables.

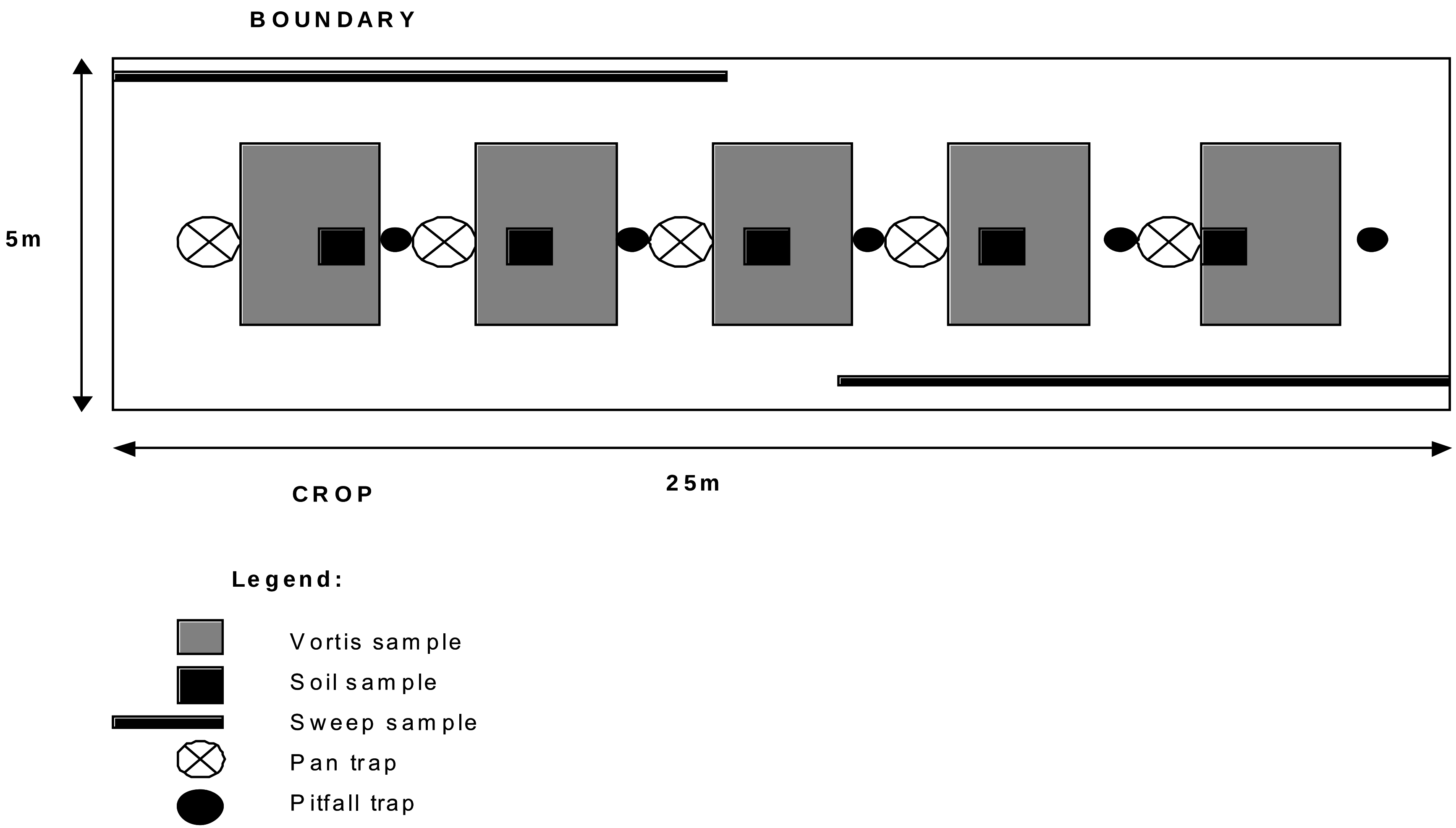

Figure 6.4 Spatial layout for invertebrate sampling methods.

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Sampling Times

Sampling times selected were based on the availability of invertebrates as potential food sources for birds and also reflected the key periods of abundance for each group (Table 6.6.).

Table 6.6. Rationale for selecting sample times for each method.

Method	Timing	Rationale
Vacuum	July	Encompasses nesting period of skylark and collects widest range of groups fed to nestlings.
	Sept	Key period of insect abundance.
Sweep	June	Primarily collects larvae, which are most abundant during this period.
	Sept	Key period of insect abundance.
Pitfall	May	Estimates activity/density of ground active invertebrates, which are abundant at these times
Pan traps	Sept	Collects mollusca, which are common during these periods

Taxonomic approach

Groups were identified to the appropriate taxonomic level for the project's objectives (Table 6.8).

Table 6.7. Five-year timetable for invertebrate sampling in the margin, showing temporal matches with vegetation sampling

Method	**2002**				**2003**				**2004**				**2005**				**2006**			
	M	Jn	Jl	S	M	Jn	Jl	S	M	Jn	Jl	S	M	Jn	Jl	S	M	Jn	Jl	S
Vacuum		■		■		■		■		■		■						■		■
Sweep		■		■		■		■		■		■						■		■
Pitfall	■				■				■								■			
Pan trap		■		■		■		■												■
Soil													■			■				
Plants		■		■		■		■		■		■						■		■

Management treatments: herbicide application, cutting and soil scarification in early spring (prior to all sampling).

Table 6.8. Invertebrate groups, sampling method and taxonomic approach

Group	Common name	Sampling method	Taxonomic level
Coleoptera:	Beetles	Vacuum + pitfall	
Chrysomelidae	Leaf beetles		Species
Curculionidae	Weevils		Species
Apionidae	Weevils		Species
Carabidae	Ground beetles		Species
Coccinellidae	Ladybirds		Species
Hemiptera:	Bugs	Vacuum	
Heteroptera	True bugs		Species
Auchenorrhyncha	Planthoppers		Species
Araneae	Spiders	Vacuum	Count
Diptera	Flies	Sweep	Key groups to Family
Orthoptera	Grasshoppers	Sweep	Species
Symphyta larvae	Sawflies	Sweep	Biomass and count
Lepidoptera larvae	Butterflies & Moths	Sweep	Biomass and count
Mollusca	Slugs and snails	Pan traps	Biomass and count
Lumbricidae	Earthworms	Soil sampling (hand sorting, Winkler bags and Tullgren funnels) and Octet method	Species, biomass and count
Diplopoda	Millipedes		
Chilopoda	Centipedes		
Isopoda	Woodlice		

6.2.5.4 Bumblebees and Butterflies

Timing and frequency of visits

Monitoring was done in years 1-5 of the experiment. Bumblebees and butterflies were monitored approximately once every two to three weeks between April and September each year. The frequency of visits was highly weather dependant.

Sampling method

Standard transect walks were carried out to measure the abundance and diversity of bumblebees and butterflies on each treatment plot following the methods described by Banaszak (1980); Teräs (1983); Pollard et al. (1975); Pollard & Yates (1993). A permanent transect route running along the centre line of treatment each plot (25 m) was marked and walked once on each sampling date to count bumblebees, then repeated to count butterflies. The direction in which a transect was walked, and whether bumblebees or butterflies were recorded first, was alternated for each visit.

Walks were carried out between 10.00 and 17.00 h BST, when weather conformed to Butterfly Monitoring Scheme (BMS) standards (Pollard & Yates 1993). The temperature was above 13°C with at least 60% clear sky, or 17°C in any sky conditions, it was not raining, and there was not a wind speed in excess of 5 on the Beaufort scale. Air temperature, percentage cloud cover and wind speed (using the Beaufort scale) were recorded at the end of each transect walk.

Bumblebee sampling

The margin was walked at a steady pace of around 15 – 20 m per minute, recording bumblebees within 2.5 m to either side of the transect. All foraging bumblebees of each species and cuckoo bumblebees (now subgenus *Psithyrus*, brood parasites of the social *Bombus* species) were recorded. *B. terrestris/lucorum* were recorded together as workers of these species cannot be reliably distinguished in the field (Prŷs-Jones & Corbet 1991). The different castes (queen, worker, male) were recorded separately for *Bombus lapidarius* only, as sex separation of other species in the field can be unreliable. The plant species on which each bumblebee was first seen foraging was also recorded.

Butterfly sampling

All individual butterflies occurring (either in flight or on a flower) within 2.5 metres to either side of the transect were recorded, as for the standard BMS methodology (Pollard & Yates, 1993).

Flower abundance counts

Following each transect walk the diversity and abundance of flowering forbs in each plot was recorded to give a measure of the forage resource availability. All flowering forbs were identified in the field (164 species, nomenclature follows Stace 1997) and the approximate abundance of single flowers and multi-flowered stems (racemes, corymbs, e.g. *Trifolium repens*; capitulums, e.g. *Centaurea nigra*; umbels, e.g. *Daucus carota*) were scored using a simple floristic index (Carvell et al., 2004; Pywell et al., 2005):

1. approx. 1 – 25 flowers per 125 m^2
2. 26 - 100 flowers per 125 m^2
3. 101 - 200 flowers per 125 m^2
4. 201 - 500 flowers per 125 m^2
5. >500 flowers per 125 m^2.

For each species the median of the flower abundance range class was calculated and summed over all visits in a year.

Statistical analysis

All counts of individual bumblebee and butterfly species were summed for each treatment plot in each year. The summary groupings of total abundance and species richness were also calculated. In addition, the functional groups of short-tongued (*B. terrestris/lucorum, B. pratorum* and *B. lapidarius*) and long-tongued bumblebee species (*B. pascuorum, B. hortorum* and *B. ruderatus*) were calculated (Prŷs-Jones & Corbet 1991). Similarly, the functional classification of 'mobile' or 'immobile' was applied to each butterfly species according to Warren (1992). The flower abundance scores from each visit were summed, and the total abundance and richness of all forb flowers, annuals and perennials, and sown and unsown species was calculated.

Logarithmic transformation of all count data was undertaken prior to analysis to meet assumptions of normality of residuals. An oversites analysis of variance (ANOVA) with site and treatment in the model was used to investigate the effects of seed mixture and management on the abundance and richness of bumblebees, butterflies and flower resources in individual years. An identical ANOVA model with repeated measures using Greenhouse-Geisser corrections (Maxwell and Delaney, 2003) was used to investigate treatment effects over the four years. Pairwise comparisons of the seed mix and management treatments were made using Tukeys tests. All analyses were undertaken using GenStat® Release 7.0 (2003).

6.2.5.5 Birds

Bird data were gathered over the period 2002 to 2006 inclusive. In 2002 and 2003, bird data were collected from all three sites, at Boxworth, Gleadthorpe and High Mowthorpe, with each site being visited from five to eight times, from April and July. Initially, this entailed bird surveys, nest finding and nest forage watches. In 2004, 2005 and 2006, Gleadthorpe was no longer visited, as bird counts on margins were too heavily influenced by adjacent woodland. Bird survey work, which had not initially been scheduled for years 2004 to 2006, was therefore able to continue on the remaining two sites.

Bird surveys

Birds were recorded along approximate 30 min survey transects that ran through the adjacent crop, parallel to each margin replicate. These data provided counts that could be used to assess relative differences in bird densities between margin treatments, and assess relative temporal changes in the use of margins by birds. Thus, all birds seen or heard were recorded onto site maps using a consistent, standard notation as for a Common Birds Census (Marchant et al., 1990). Birds were accurately recorded as being on the margin plots, on the immediately adjacent boundary or at distances of 5 m, 25 m or 50 m either side of the margin or boundary, into the adjacent fields, regardless of crop type. All counts were completed before 1030 h BST. No counts were carried out in persistent heavy rain or wind speeds above Beaufort force 4 (i.e., “Moderate Breeze: Raises dust and loose paper; small branches are moved”).

Vegetation surveys

Although some vegetation data was initially collected by bird surveyors in 2002 and 2003, only the data collected by CAER (see this report 6.3.2) were used in conjunction with the bird data for a combined analysis. This was because the CAER data were collected consistently across all survey years, from 2002 to 2006.

Nest data

Nest finding was carried out on an *ad hoc* basis, focusing mainly on three species, whitethroat (*Sylvia communis)*, blackbird (*Turdus merula)* and yellowhammer (*Emberiza citrinella)*, but including other buntings (*Emberiza* species). The purpose was to determine whether provisioning activities of parent birds (and perhaps reproductive output) was influenced by foraging destination, especially margin treatment effects (data from 2003 only). The success of this exercise was largely dependent on the proportion of time that parent birds spent using SAFFIE margins, relative to nearby habitats or crops (data from 2002 and 2003) to procure food. The species above were chosen for being relatively common (for sample size), and to represent insectivorous and seed-eating functional groups; or groups including the government-monitored Farmland Bird Index or species of high conservation concern that are subject to Biodiversity Action Plans (Table 6.9). They are also known to use margins to nest in and/or find food. A target was set for a minimum of 10 nests for yellowhammer and five each for blackbird and whitethroat in each year, located in treatment margins, adjacent boundaries or nearby scrub/hedgerow habitats. At some nests faecal samples were collected from chicks in case a large enough sample was generated for a diet analysis. Nestling biometrics were taken as body mass (g) and tarsus length (mm) to examine relationships between body development, adult source of provisioning and margin treatments.

For nest forage watches, each nest location was observed for 1.5 h per watch with repeated visits (at least two) after chicks reached four days old. The following data was gathered for provisioning adults where it could be determined: (1) foraging destination to nearby field, crops or margin treatments (the latter, 2003 only), (2) forage distance and (3) provisioning rate by both adults combined.

Statistical analysis

The bird survey data (where the unit of measure was a count per bird species or per bird functional group for combined species, per margin treatment/plot) were analysed using General Linear Models with Poisson error terms. Scale adjustments for over dispersion used “√Pearson chi-square value/degrees of freedom”. Model factors included temporal variables (‘year’ and repeated measures for visit date), spatial and habitat variables (‘farm site’, ‘margin seed-mix’, ‘margin management’ and vegetation data) and invertebrate daa. Vegetation data was a summary at the margin treatment/plot level for variables such as, vegetation height, cover, variance in height. Invertebrate data was a summary data set at the margin treatment/plot level for the relative abundance of taxa (Coleoptera, Heteroptera, Auchenorrhyncha and Arachnidae, and a sub-group ‘diurnal carabids’ (Carabidae) see 6.3.3 this report). Margin plot areas and adjacent hedge conditions were treated as constants. Type-III probabilities were calculated for explanatory variables and selected interactions between them. For nest watches, only low sample sizes were generated and no statistical tests were carried out on these data for the treatment year 2003.

Table 6.9. Bird species and species groups that contributed to the analysis of margin treatments.

Species		Analytical species groups: Insecti-vores	Grani-vores	Wood-land	FBI[1]	BAP[2]
Kestrel	*Falco tinnunculus*				*	
Grey partridge	*Perdix perdix*				*	*
Lapwing	*Vanellus vanellus*				*	*
Woodpigeon	*Columba palumbus*				*	
Stock dove	*Columba oenas*				*	
Turtle dove	*Steptopelia turtur*				*	*
Green woodpecker	*Picus viridus*	*				
Skylark	*Alauda arvensis*		*		*	*
Pied wagtail	*Motacilla alba*	*				
Yellow wagtail	*Motacilla flava*	*			*	*
Dunnock	*Prunella modularis*	*				
Wren	*Trogolodytes trogolodytes*	*		*		
Robin	*Erithacus rubecula*	*				
Blackbird	*Turdus merula*	*				
Song thrush	*Turdus philomelos*	*				*
Lesser whitethroat	*Sylvia curruca*			*		
Whitethroat	*Sylvia communis*	*			*	
Jackdaw	*Corvus monedula*				*	
Rook	*Corvus frugilegus*				*	
Starling	*Sturna vulgaris*	*				
House sparrow	*Passer domesticus*		*			
Tree sparrow	*Passer montanus*		*		*	*
Bullfinch	*Pyrrhula pyrrhula*		*		*	*
Goldfinch	*Caruelis carduelis*		*		*	
Greenfinch	*Carduelis chloris*		*		*	
Linnet	*Carduelis cannabina*		*		*	*
Chaffinch	*Fringilla coelebs*		*			
Reed bunting	*Emberiza schoeniclus*		*		*	*
Yellowhammer	*Emberiza citrinella*		*		*	*

[1]**FBI =** Species on the national Farmland Bird Index; [2]**BAP=**Species subject to national Biodiversity Action Plans.

6.3 RESULTS

6.3.1 Weeds and agronomy

Regular observations were made of the crop adjacent to the margin edge. At High Mowthorpe increased slug activity was seen in crops adjacent to the crop margin in 2004/05 and 2005/06. Damage was limited to small areas of approximately 5 m x 2 m, but was not consistent with any seed mixture or margin management treatment.

Rats were active in the tussock grass mixture margins at High Mowthorpe in 2005/06 but there was not evidence that this was linked to treatment.

Crop damage from Fusilade was noted at High Mowthorpe in 2005/06 and at Boxworth in 2003/04 up to 2 m into the crop adjacent to the margin. This was linked to wind speed and direction on the day of spraying.

The crop adjacent to the margin was monitored regularly for significant ingress of margin species into the crop. Creeping Thistle (*Cirsium arvense*) did move into the crop at Boxworth during the growing season but was controlled by routine cultivations during the autumn and there was some effect of crop herbicides. No specific herbicide applications were made to the crop for its control.

The formal weed assessment done in June or July indicated that at all three sites, weed species found at 0.5 m and 6 m from the margin edge were typical for the farm location and soil type. Generally there were no differences between treatments and sown margin species had not spread into the field (Table 6.10 to Table 6.20).

At Gleadthorpe in 2003 there were significantly ($p<0.05$) more weeds adjacent to the fine and tussock grass mixes at 0.5 m and fine grass at 6 m than adjacent to the CS mix, but this result was not seen at other sites and in other years (Table 6.13).

At High Mowthorpe in 2004 *Anchusa arvensis* populations were significantly ($p<0.05$) higher adjacent to the tussock mix than the other two mixes. This species had not been sown in the margin.

Table 6.10. Within crop weed counts (weeds per m^2) at 0.5 m from the margin edge, Boxworth 2003. There were less than 5 weeds per m^2 at the 6 m distance.

Margin type	**Management**	***Poa annua***	**Total weed number**
CS Mix	Cut	2	22
CS Mix	Scar	1	6
CS Mix	Gram	5	15
TG mix	Cut	1	7
TG mix	Scar	0	3
TG mix	Gram	4	12
FG mix	Cut	4	18
FG mix	Scar	3	9
FG mix	Gram	4	22
S.E.D. (32 df)		2.60^{ns}	8.23^{ns}

Table 6.11. Within crop weed counts at 0.5m and 6m from margin edge, Boxworth2005.

0.5 m from margin

Margin type	Management	*Atriplex patula*	*Cirsium* spp	Total weed number
CS Mix	Cut	6	3	22
CS Mix	Scar	3	3	8
CS Mix	Gram	11	3	22
TG mix	Cut	4	1	12
TG mix	Scar	6	1	14
TG mix	Gram	2	0	6
FG mix	Cut	4	2	15
FG mix	Scar	0	2	10
FG mix	Gram	0	1	6
S.E.D. (32 df)		5.18^{ns}	0.64^{ns}	7.60^{ns}

6 m from margin

Margin type	Management	*Atriplex patula*	*Cirsium* spp.	Total weed number
CS Mix	Cut	13	0	17
CS Mix	Scar	2	1	4
CS Mix	Gram	4	1	7
TG mix	Cut	0	0	0
TG mix	Scar	0	0	0
TG mix	Gram	1	2	4
FG mix	Cut	0	1	1
FG mix	Scar	0	1	4
FG mix	Gram	0	0	1
S.E.D. (32 df)		4.39^{ns}	0.16^{ns}	5.75^{ns}

Table 6.12. Within crop weed counts at 0.5 m and 6 m from margin edge, Boxworth 2006.

0.5 m from margin

Margin type	Management	*Anisantha sterilis*	*Cirsium* spp.	Total weed number
CS Mix	Cut	34	14	22
CS Mix	Scar	0	7	8
CS Mix	Gram	8	8	22
TG mix	Cut	78	1	12
TG mix	Scar	52	6	14
TG mix	Gram	19	6	6
FG mix	Cut	72	2	15
FG mix	Scar	12	4	10
FG mix	Gram	13	2	6
S.E.D. (32 df)		28.85^{ns}	4.29^{ns}	7.60^{ns}

6 m from margin

Margin type	Management	*Atriplex patula*	*Cirsium* spp.	Total weed number
CS Mix	Cut	13	0	17
CS Mix	Scar	2	1	4
CS Mix	Gram	4	1	7
TG mix	Cut	0	0	0
TG mix	Scar	0	0	0
TG mix	Gram	1	2	4
FG mix	Cut	0	1	1
FG mix	Scar	0	1	4
FG mix	Gram	0	0	1
S.E.D. (32 df)		4.39^{ns}	0.16^{ns}	5.75^{ns}

Table 6.13. Within crop weed counts at 0.5 m and 6 m from margin edge, Gleadthorpe 2003.

0.5 m from margin

Margin type	**Management**	***Poa annua***	***Chenopodium album***	***Capsella bursa pastoris***	***Urtica* spp.**	**Total weed number**
CS Mix	Cut	20	14	5	1	8
CS Mix	Scar	22	7	4	10	7
CS Mix	Gram	34	5	10	5	6
TG mix	Cut	16	9	7	4	18
TG mix	Scar	21	5	12	6	15
TG mix	Gram	26	11	5	9	12
FG mix	Cut	13	6	4	3	17
FG mix	Scar	30	3	3	1	14
FG mix	Gram	19	5	5	7	19
S.E.D. (32 df)		10.20^{ns}	3.89^{ns}	5.70^{ns}	4.34^{ns}	3.01***

6 m from margin

Margin type	**Management**	***Triplospermum inodorum***	***Poa annua***	***Capsella bursa pastoris***	**Total weed number**
CS Mix	Cut	1	27	3	8
CS Mix	Scar	2	23	6	7
CS Mix	Gram	2	30	5	4
TG mix	Cut	4	30	7	8
TG mix	Scar	2	27	5	8
TG mix	Gram	8	31	7	14
FG mix	Cut	13	19	4	23
FG mix	Scar	10	18	3	11
FG mix	Gram	3	20	9	13
S.E.D. (32 df)		5.83^{ns}	10.33^{ns}	3.51^{ns}	2.72***

Table 6.14. Within crop weed counts at 0.5 m and 6 m from margin edge, Gleadthorpe 2004.

0.5 m from margin

Margin type	Management	*Poa annua*	Total weed number
CS Mix	Cut	40	53
CS Mix	Scar	28	42
CS Mix	Gram	27	33
TG mix	Cut	37	52
TG mix	Scar	43	58
TG mix	Gram	38	48
FG mix	Cut	31	39
FG mix	Scar	20	30
FG mix	Gram	38	54
S.E.D. (32 df)		9.33^{ns}	10.56^{ns}

6 m from margin

Margin type	Management	*Poa annua*	Total weed number
CS Mix	Cut	21	23
CS Mix	Scar	21	26
CS Mix	Gram	20	23
TG mix	Cut	19	24
TG mix	Scar	30	33
TG mix	Gram	27	42
FG mix	Cut	16	18
FG mix	Scar	30	32
FG mix	Gram	21	27
S.E.D. (32 df)		8.02^{ns}	9.55^{ns}

Table 6.15. Within crop weed counts at 0.5 m and 6 m from margin edge, Gleadthorpe 2005.

0.5 m from margin

Margin type	Management	*Poa annua*	*Cirsium arvensis*	Total weed number
CS Mix	Cut	5	0	3
CS Mix	Scar	8	0	3
CS Mix	Gram	11	0	4
TG mix	Cut	15	0	2
TG mix	Scar	13	1	5
TG mix	Gram	6	1	6
FG mix	Cut	9	0	1
FG mix	Scar	11	1	5
FG mix	Gram	4	1	7
S.E.D. (32 df)		1.45^{ns}	0.90^{ns}	2.04^{ns}

6 m from margin

Margin type	Management	*Poa annua*	Total weed number
CS Mix	Cut	0	0
CS Mix	Scar	0	0
CS Mix	Gram	0	0
TG mix	Cut	0	0
TG mix	Scar	0	1
TG mix	Gram	0	0
FG mix	Cut	0	0
FG mix	Scar	0	1
FG mix	Gram	0	0
S.E.D. (32 df)		0.29^{ns}	0.40^{ns}

Table 6.16. Within crop weed counts at 0.5 m and 6 m from margin edge, Gleadthorpe 2006.

0.5 m from margin

Margin type	Management	*Fallopia convolvulus*	*Capsella bursa pastoris*	Total weed number
CS Mix	Cut	5	5	38
CS Mix	Scar	3	6	54
CS Mix	Gram	10	7	47
TG mix	Cut	15	9	56
TG mix	Scar	3	12	46
TG mix	Gram	10	4	41
FG mix	Cut	4	3	31
FG mix	Scar	3	9	49
FG mix	Gram	6	5	41
S.E.D. (32 df)		6.55^{ns}	4.74^{ns}	12.31^{ns}

6 m from margin

Margin type	Management	*Poa annua*	*Capsella bursa pastoris*	Total weed number
CS Mix	Cut	4	3	18
CS Mix	Scar	8	9	27
CS Mix	Gram	6	14	24
TG mix	Cut	7	10	27
TG mix	Scar	11	8	24
TG mix	Gram	12	10	32
FG mix	Cut	5	2	18
FG mix	Scar	2	11	18
FG mix	Gram	11	6	19
S.E.D. (32 df)		4.02^{ns}	5.10^{ns}	10.4^{ns}

Table 6.17. Within crop weed counts at 0.5 m and 6 m from margin edge, High Mowthorpe 2003.

0.5 m from margin

Margin type	Management	*Poa Annua*	Vol. potatoes	Total weed number
CS Mix	Cut	5	1	12
CS Mix	Scar	4	3	14
CS Mix	Gram	3	5	15
TG mix	Cut	4	6	16
TG mix	Scar	4	6	16
TG mix	Gram	4	3	8
FG mix	Cut	3	2	10
FG mix	Scar	3	1	14
FG mix	Gram	6	6	22
S.E.D. (32 df)		2.67^{ns}	3.31^{ns}	2.94^{ns}

6 m from margin

Margin type	Management	Vol. potatoes	Total weed number
CS Mix	Cut	6	8
CS Mix	Scar	3	4
CS Mix	Gram	2	7
TG mix	Cut	7	10
TG mix	Scar	6	10
TG mix	Gram	5	8
FG mix	Cut	10	14
FG mix	Scar	4	7
FG mix	Gram	4	7
S.E.D. (32 df)		3.68^{ns}	4.04^{ns}

Table 6.18. Within crop weed counts at 0.5 m and 6 m from margin edge, High Mowthorpe 2004.

0.5 m from margin

Margin type	Management	*Anchusa arvensis*	*Dactylis glomerata*	*Poa annua*	Vol. Cereal	Total weed number
CS Mix	Cut	0	13	18	26	10
CS Mix	Scar	0	8	13	40	12
CS Mix	Gram	0	10	10	11	6
TG mix	Cut	12	14	8	22	10
TG mix	Scar	23	9	8	26	11
TG mix	Gram	15	8	4	4	5
FG mix	Cut	0	1	3	7	4
FG mix	Scar	0	1	11	12	6
FG mix	Gram	0	1	7	6	6
S.E.D. (32 df)		6.86**	5.50^{ns}	5.19^{ns}	15.07^{ns}	3.22^{ns}

6 m from margin

Margin type	Management	Vol. Cereals	Total weed number
CS Mix	Cut	30	6
CS Mix	Scar	30	6
CS Mix	Gram	0	0
TG mix	Cut	1	1
TG mix	Scar	0	0
TG mix	Gram	43	9
FG mix	Cut	0	0
FG mix	Scar	1	1
FG mix	Gram	3	1
S.E.D. (32 df)		24.15^{ns}	4.78^{ns}

Table 6.19. Within crop weed counts at 0.5 m and 6 m from margin edge, High Mowthorpe 2005.

0.5 m from margin

Margin type	Management	*Dactylis glomeratus*	*Anistantha sterilis*	*Phleum pratense*	Total weed number
CS Mix	Cut	2	0	0	36
CS Mix	Scar	3	12	0	21
CS Mix	Gram	6	0	0	29
TG mix	Cut	24	20	5	55
TG mix	Scar	33	4	34	82
TG mix	Gram	5	0	0	33
FG mix	Cut	0	99	0	201
FG mix	Scar	3	0	0	151
FG mix	Gram	0	0	0	176
S.E.D. (32 df)		16.52^{ns}	45.7^{ns}	15.91^{ns}	102.1^{ns}

6 m from margin

Margin type	Management	Vol. potato	*Avena* sp.	Total weed number
CS Mix	Cut	3	0	3
CS Mix	Scar	1	0	1
CS Mix	Gram	4	0	4
TG mix	Cut	3	2	5
TG mix	Scar	2	1	4
TG mix	Gram	2	0	2
FG mix	Cut	1	0	1
FG mix	Scar	1	3	4
FG mix	Gram	0	0	0
S.E.D. (32 df)		1.80^{ns}	1.58^{ns}	2.45^{ns}

Table 6.20. Within crop weed counts at 0.5 m and 6 m from margin edge, High Mowthorpe 2006.

0.5 m from margin

Margin type	Management	*Poa annua*	*Poa trivialis*	*Veronica* sp.	Total weed number
CS Mix	Cut	3	2	0	11
CS Mix	Scar	3	7	1	11
CS Mix	Gram	8	0	1	19
TG mix	Cut	8	1	0	18
TG mix	Scar	16	0	2	32
TG mix	Gram	6	0	2	25
FG mix	Cut	4	0	0	8
FG mix	Scar	1	1	1	8
FG mix	Gram	3	0	1	12
S.E.D. (32 df)		4.32^{ns}	3.13^{ns}	1.06^{ns}	10.60^{ns}

6 m from margin

Margin type	Management	*Poa annua*	Total weed number
CS Mix	Cut	0	0
CS Mix	Scar	1	1
CS Mix	Gram	0	0
TG mix	Cut	0	0
TG mix	Scar	1	2
TG mix	Gram	0	0
FG mix	Cut	1	2
FG mix	Scar	0	0
FG mix	Gram	0	0
S.E.D. (32 df)		0.79^{ns}	1.15^{ns}

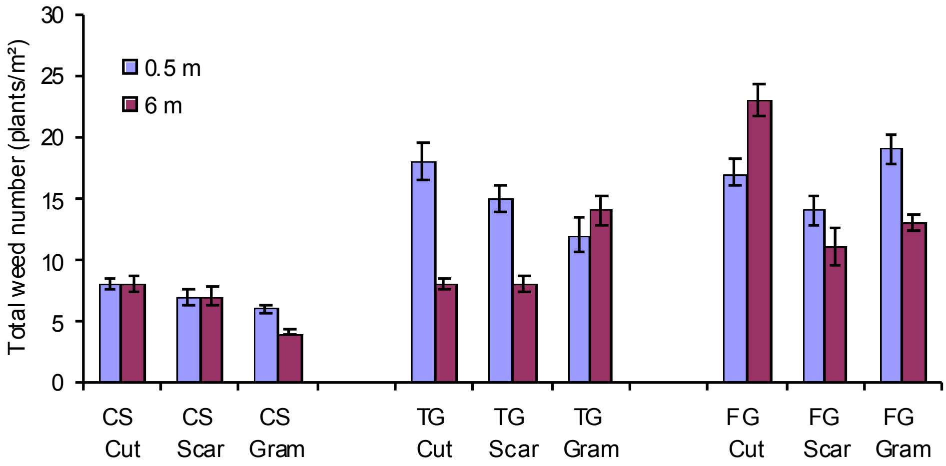


Figure 6.5. Total weed numbers (/m²) within the crop at 0.5 m and 6 m from the margin edge, Gleadthorpe 2003 (± SE).

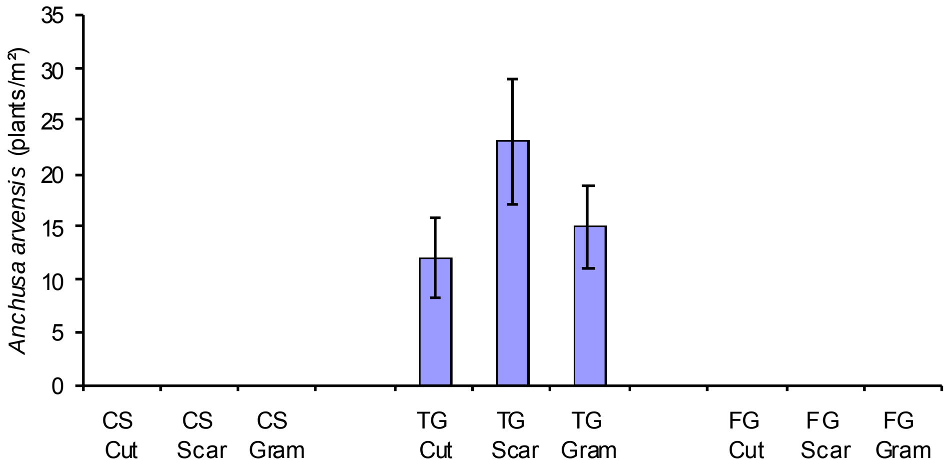


Figure 6.6. *Anchusa arvensis* populations (/m²) within the crop at 0.5 m and 6 m from the margin edge, High Mowthorpe 2004 (± SE).

6.3.2 Vegetation

6.3.2.1 Species number (total, sown & unsown)

Establishment Year June 2002

Overall responses

Seed mix type had a significant influence on values of total species number ($F_{2, 117.7}$ = 111.1, *P* < 0.001) and on the number of sown ($F_{2, 117.9}$ = 159.1, *P* < 0.001) and unsown species ($F_{2, 118.4}$ = 8.1, *P* < 0.01). Pairwise comparisons (*P* < 0.05) revealed that the CS mix was associated with the least number of sown species, which was also reflected by values of total species number (Figure 6.7). The TG mix was associated with the greatest total number of species, owing to the greater number of sown species recorded. However, the TG mix was also associated with the least number of unsown species, while no difference was found between the CS and FG mixes.

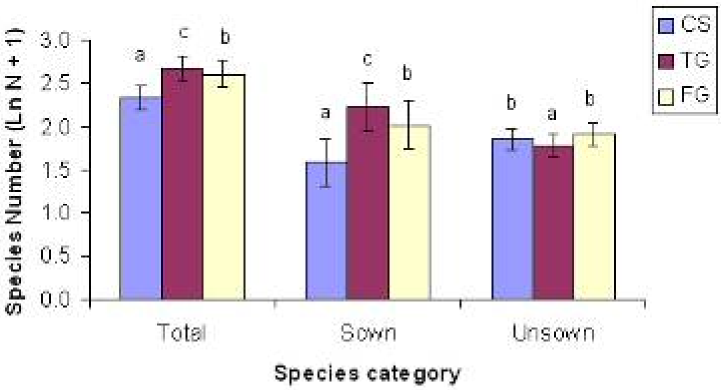


Figure 6.7. Total species number (species/0.25m^2) (± SE) depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter within each category do not differ significantly (*P* > 0.05).

Individual site responses

Boxworth

All categories (total, sown and unsown) of species number were found to be significantly influenced by seed mix type. The responses of total species number ($F_{2,42}$ = 21.0, *P* < 0.001) and the number of sown species ($F_{2,42}$ = 31.0, *P* < 0.001) were similar, with greater values in association with the TG and FG seed mixes compared with the CS mix (Figure 6.8). The significant effect on the number of unsown species ($F_{2,42}$ = 3.8, *P* < 0.05) resulted from a greater number in association with the FG mix compared with plots sown with the TG mix (Pairwise comparison, *P* < 0.05).

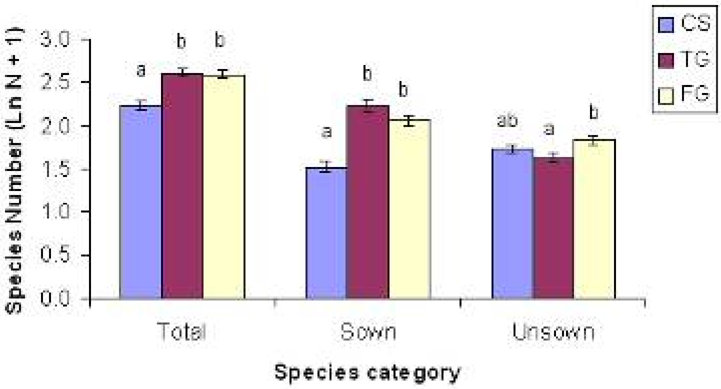


Figure 6.8. Total species number (species/0.25m^2) (± SE) at Boxworth depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter within each category do not differ significantly ($P > 0.05$).

Gleadthorpe

There was a significant response of total species number and the number of sown species to seed mix ($F_{2,42} = 7.1$, $P < 0.01$ and $F_{2,42} = 6.8$, $P < 0.001$, respectively). In both cases, values were significantly greater in association with the TG and FG seed mixes compared with the CS mix (Figure 6.9). No significant effect of seed mix was found for the number of unsown species.

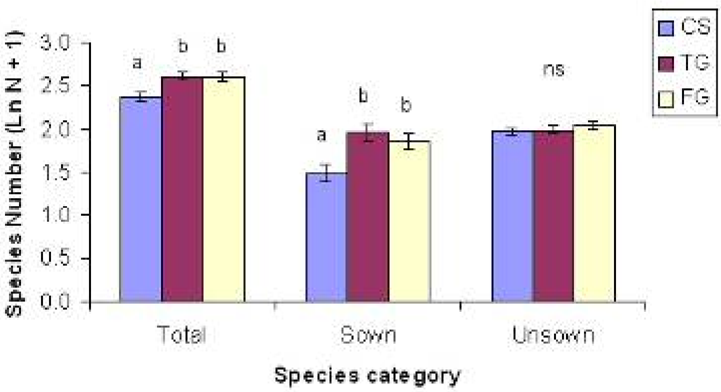


Figure 6.9. Total species number (species/0.25m^2) (± SE) at Gleadthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter within each category do not differ significantly ($P > 0.05$), ns = not significant.

High Mowthorpe

The significant responses of total species number and the number of sown species to seed mix were similar at this site ($F_{2,42}$ = 61.7, P < 0.001 and $F_{2,42}$ = 67.9, P < 0.001, respectively). Pairwise comparisons revealed that the TG mix was associated with the greatest values, being significantly greater than with the FG mix, which in turn was associated with values greater than with the CS mix (Figure 6.10). The influence of seed mix on the number of unsown species was not significant.

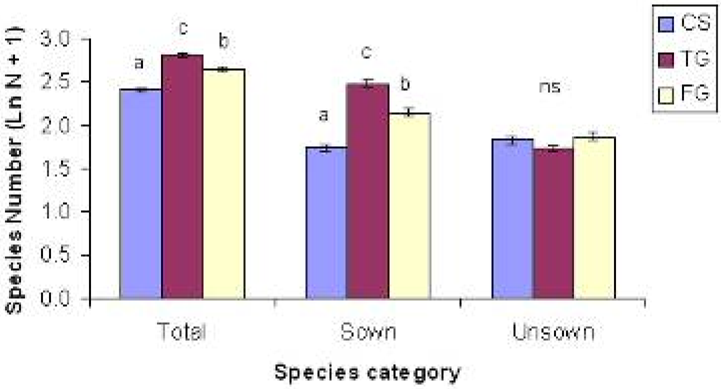


Figure 6.10. Total species number (species/0.25m^2) (± SE) at High Mowthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter within each category do not differ significantly (P > 0.05).

<u>Treatment responses June (2003, 2004 & 2006)</u>

Overall responses

Seed mix had a significant effect on values of total species number ($F_{2,139.3}$ = 38.4, P < 0.001). A greater number was associated with the TG and FG mixes compared with the CS mix (Figure 6.11). The interaction between seed mix and year was not significant, neither was the interaction between seed mix and sward treatment. However, a significant interaction between sward treatment and year was found ($F_{4,257.7}$ = 24.0, P < 0.001). In general, total species number decreased with time in association with cutting and graminicide, but increased/decreased with scarification (Figure 6.12).

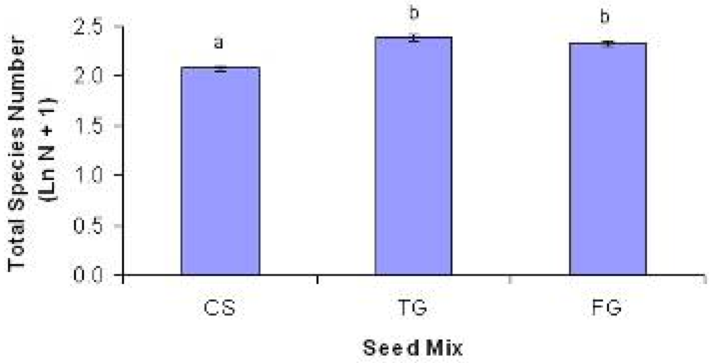


Figure 6.11. Values of total species number (species/0.25m^2) (± SE) across all sites depending on seed mix (CS = Countryside Stew ardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes w ith the same letter do not differ significantly ($P > 0.05$).

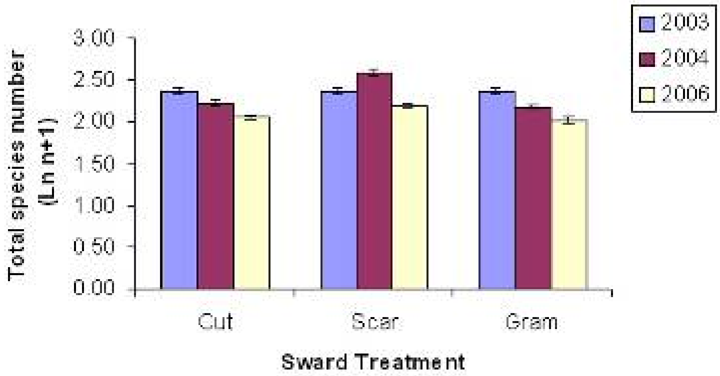


Figure 6.12. Values of total species number (species/0.25m^2) (± SE) across all sites according to sw ard treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

For the number of sow n species, significant interactions between seed mix and year ($F_{4,199.7} = 10.9$, $P < 0.001$) and sw ard treatment and year ($F_{4,199.7} = 4.7$, $P < 0.001$) were determined. Sow n species number decreased with time in association w ith the CS mix, but w as relatively stable during 2003 and 2004 in plots sow n w ith the TG and FG mixes (Figure 6.13). How ever, by 2006, numbers decreased. The response of sown species number to all sw ard treatments w as also associated w ith a reduction with time (Figure 6.14). The interactions betw een seed mix and sward treatment and seed mix, sw ard treatment and year w ere not significant.

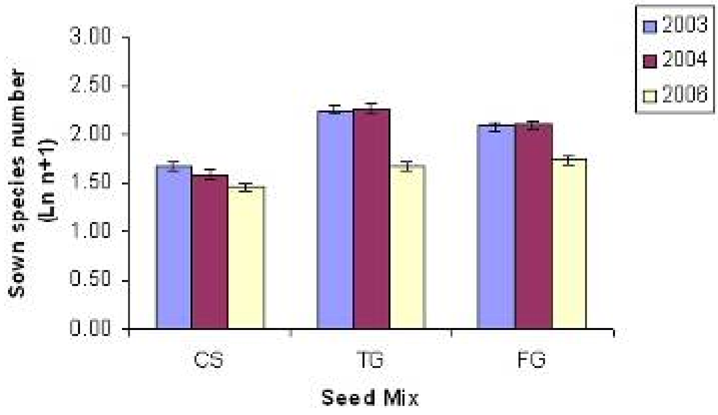


Figure 6.13. Values of sown species number (species/0.25m^2) (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

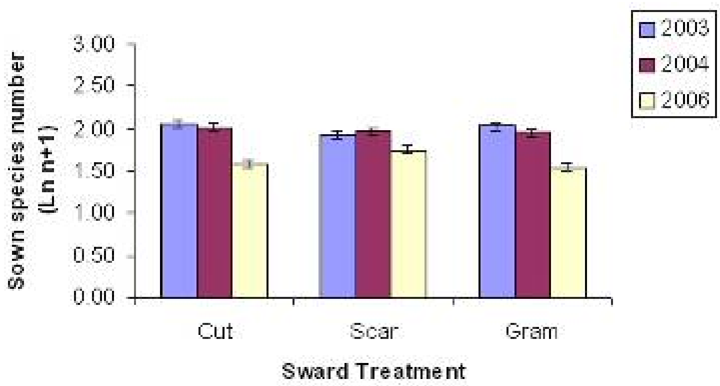


Figure 6.14. Values of sown species number (species/0.25m^2) (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Seed mix and sward treatment were both found to interact significantly with year with respect to the number of unsown species ($F_{4,242.1} = 5.0$, $P < 0.01$ and $F_{4,242.1} = 25.5$, $P < 0.001$, respectively). In general, numbers decreased with time irrespective of seed mix, but to a greater extent in plots sown with the CS mix (Figure 6.15). The interaction between sward treatment and year was mainly influenced by values in 2004, which was associated with a marked decrease in association with cutting and graminicide, but an increase with scarification (Figure 6.16).

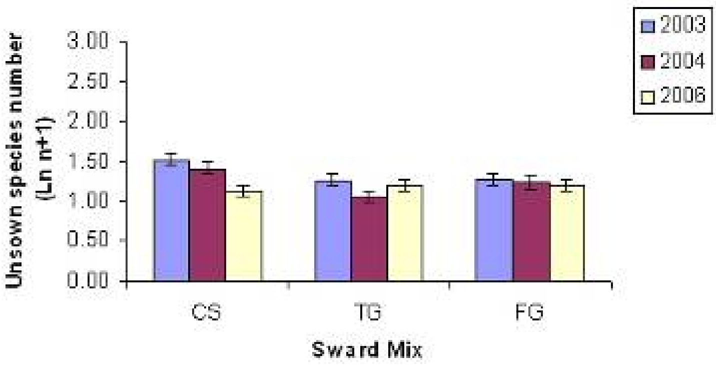


Figure 6.15. Values of unsown species number (species/0.25m^2) (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

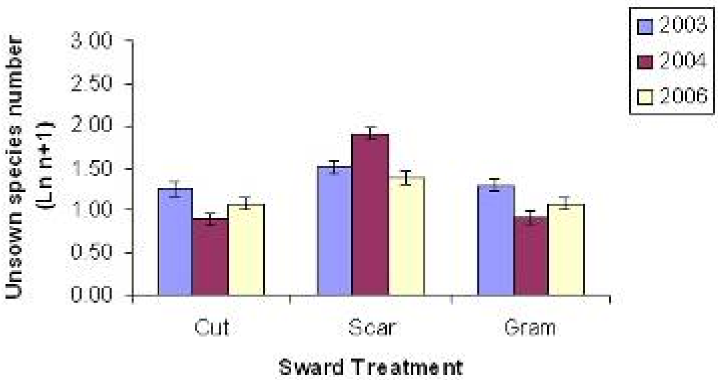


Figure 6.16. Values of unsown species number (species/0.25m^2) (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Individual site responses

Boxworth

Seed mix type had a significant effect on values of total species number ($F_{2,38.2} = 7.3$, $P < 0.01$) (Figure 6.17) and a greater number was associated with the TG and FG mixes compared with the CS mix ($P < 0.05$). No difference was found between the TG and FG mixes. The interaction between seed mix and year was not significant. In contrast, sward treatment was found to interact significantly with year ($F_{4,65.2} = 8.8$, $P < 0.001$) (Figure 6.18), indicating that treatment responses were not consistent over the three year period of observation. Values associated with the treatment of scarification explain much of the variation, increasing in 2004, but decreasing by 2006. In association with cutting and graminicide, values were generally stable with time. The interactions between seed mix and year, seed mix and sward treatment and seed mix, sward treatment and year were not significant.

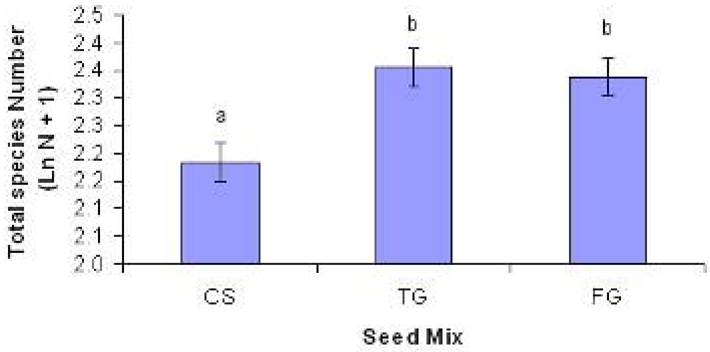


Figure 6.17. Values of total species number (species/0.25m^2) (± SE) at Boxworth depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes with the same letter do not differ significantly (*P* > 0.05).

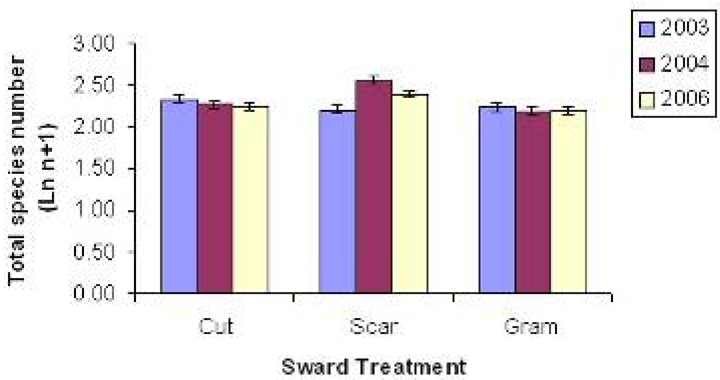


Figure 6.18. Values of total species number (species/0.25m^2) (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

The effects of seed mix and sward treatment on number of sown species were both found to interact significantly with year ($F_{4,76.2}$ = 35.0, *P* < 0.001 and $F_{4,76.2}$ = 20.1, *P* < 0.001, respectively). In 2006 the number of sown species increased in plots sown with the CS mix, but decreased in association with the TG and FG seed mixes (Figure 6.19). Furthermore, in 2003 and 2004, the number of sown species was greater with the TG and FG mixes, but in 2006, values were greater in association with the CS mix. By 2006, the number of sown species decreased in association with the treatments of spring cutting and graminicide, but remained relatively constant in plots treated with scarification (Figure 6.20). The interactions between seed mix and sward treatment and seed mix, sward treatment and year were not significant.

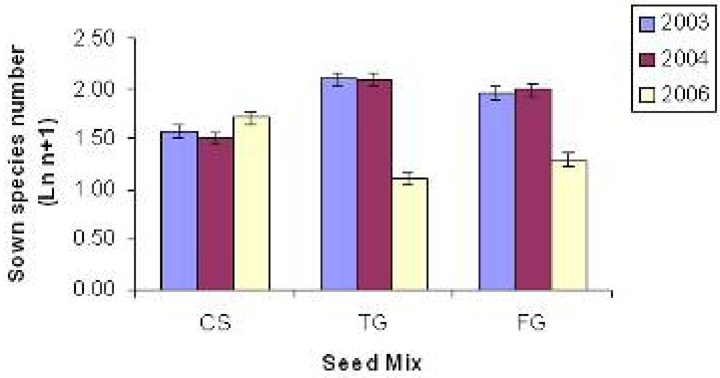


Figure 6.19. Values of sown species number (species/0.25m^2) (± SE) at Boxworth depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

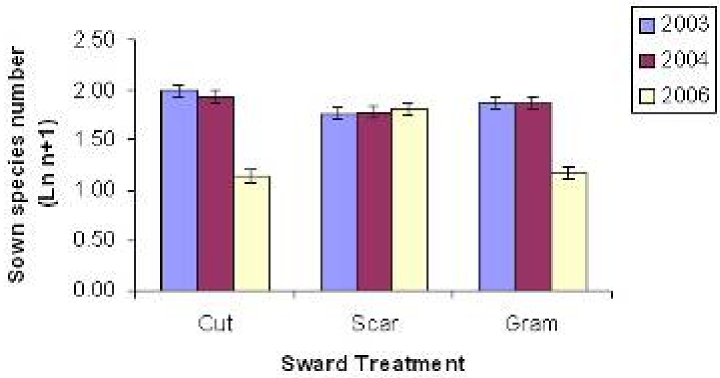


Figure 6.20. Values of sown species number (species/0.25m^2) (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

The effects of seed mix and sward treatment on numbers of unsown species both interacted significantly with year ($F_{4,85.6}$ = 21.0, P < 0.001 (Figure 6.21) and $F_{4,85.6}$ = 18.7, P < 0.001 (Figure 6.22), respectively). In association with the CS mix, the number of unsown species was greater in 2004 compared with 2003 and 2006, whilst with the TG and FG mixes numbers increased substantially in 2006 (Figure 6.21). For sward treatment, plots treated with either spring cutting or graminicide showed substantial increases in the number of unsown species in 2006 compared with years 2003 and 2004, whereas with scarification numbers increased between 2003 and 2004, but decreased between 2004 and 2006 (Figure 6.22). The interactions between seed mix and sward treatment and seed mix, sward treatment and year were not significant.

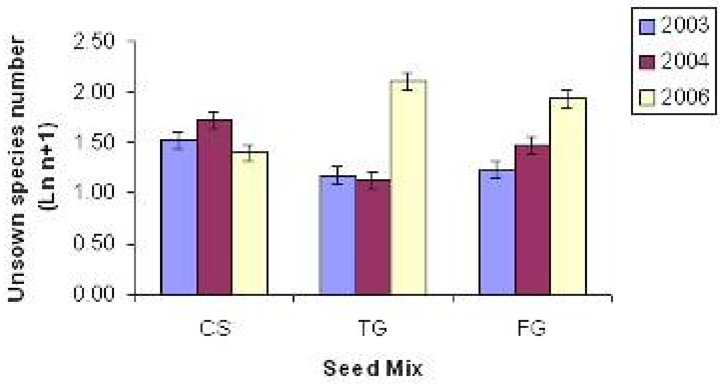


Figure 6.21. Values of unsown species number (species/0.25m^2) (± SE) at Boxworth depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

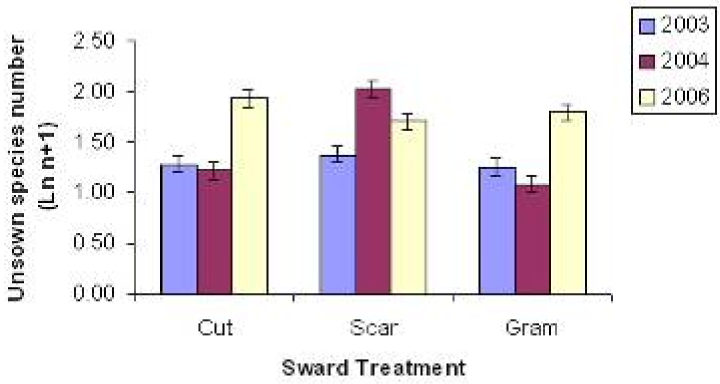


Figure 6.22. Values of unsown species number (species/0.25m^2) (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Gleadthorpe

The effects of seed mix and sward management on total species number were both found to interact significantly with year ($F_{4,65.3}$ = 2.9, P < 0.05 (Figure 6.23) and $F_{4,65.3}$ = 12.3, P < 0.001 (Figure 6.24), respectively). Irrespective of seed mix, total species number tended to decrease with time, but to a greater extent in plots sown with the CS mix. In association with the treatments of cutting and graminicide, values of total species number also decreased with time. However, with scarification values increased in 2004 relative to 2003, but decreased in 2006. The interactions between seed mix and sward treatment and seed mix, sward treatment and year were not significant.

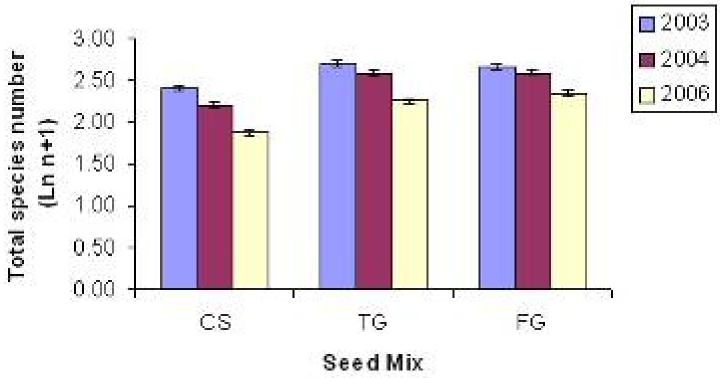


Figure 6.23. Values of total species number (species/0.25m^2) (± SE) at Gleadthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

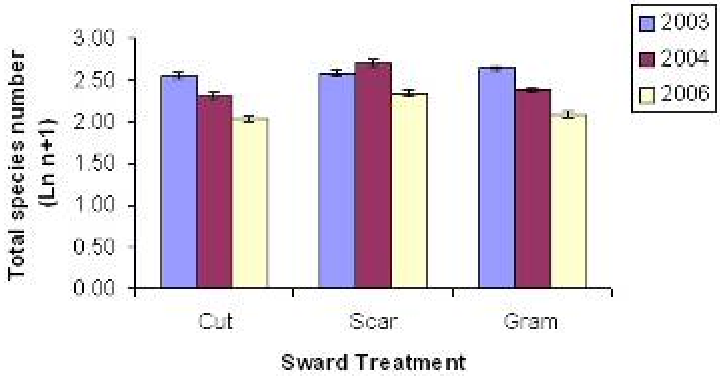


Figure 6.24. Values of total species number (species/0.25m^2) (± SE) at Gleadthorpe depending on sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

No significant effect of sward treatment was determined for values of sown species number and the interaction with year was not significant. Values tended to decrease by 2006 under all sward management treatments (Figure 6.25). The interaction between seed mix and year was significant for values of sown species number ($F_{4,80.1}$ = 3.9, P < 0.05) (Figure 6.26). In association with the FG mix, the number of species remained relatively constant between years, whilst in plots sown with the CS and TG mixes, values decreased by 2006 and especially in association with the CS mix.

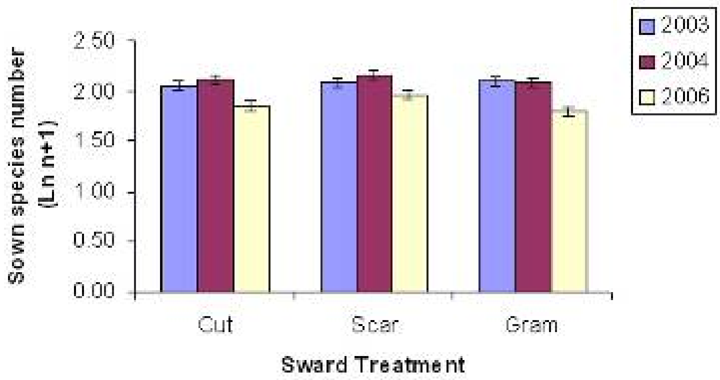


Figure 6.25. Values of sown species number (species/0.25m^2) (± SE) at Gleadthorpe depending on sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

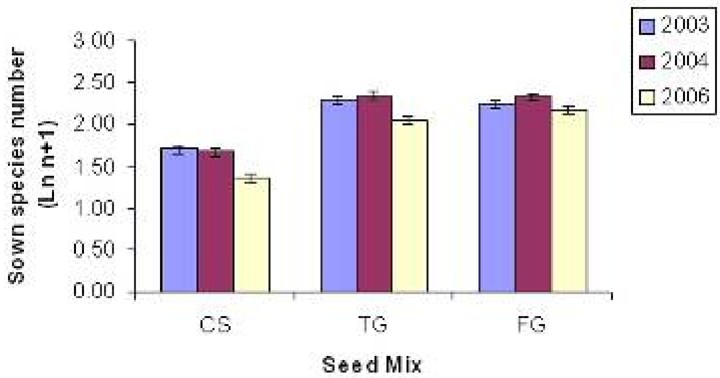


Figure 6.26. Values of sown species number (species/0.25m^2) (± SE) at Gleadthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

The number of unsown species was also significantly affected by seed mix ($F_{2,38.2}$ = 9.6, P < 0.001) and a greater number was recorded in association with the CS mix (Figure 6.27). The interaction between seed mix and year was not significant. In contrast, the interaction between sward treatment and year was significant ($F_{4,79.7}$ = 15.9, P < 0.001) (Figure 6.28). In association with cutting or graminicide numbers of unsown species decreased with time, especially between 2003 and 2004. However, in association with scarification, values increased in 2004, before decreasing in 2006 to a level greater than with cutting or graminicide. The interactions between seed mix, sward treatment and year for numbers of sown and unsown species were not significant.

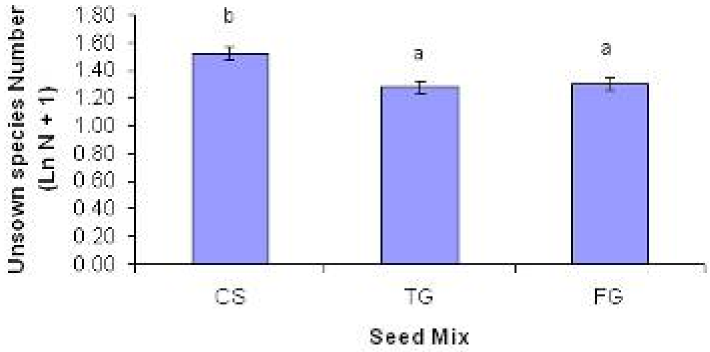


Figure 6.27. Values of unsown species number (species/0.25m^2) (± SE) at Gleadthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes with the same letter do not differ significantly (*P* > 0.05)

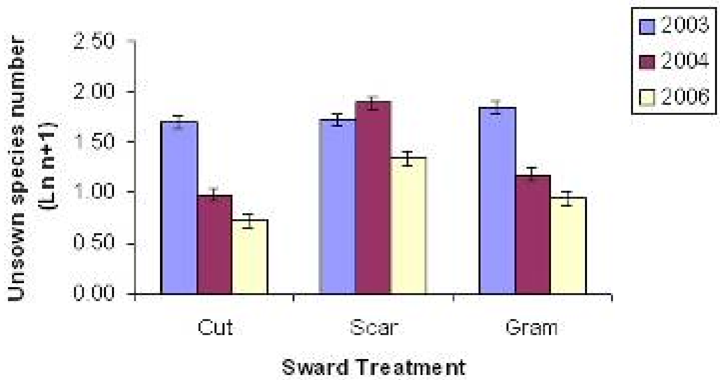


Figure 6.28. Values of unsown species number (species/0.25m^2) (± SE) at Gleadthorpe depending on sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

High Mowthorpe

The effects of seed mix and sward treatment on values of total species number were both found to interact significantly with year ($F_{4,62.6} = 23.1$, $P < 0.001$ and $F_{4,62.6} = 4.2$, $P < 0.01$, respectively). For all seed mixes, numbers of species decreased with time, but to a greater extent in plots sown with the CS mix (Figure 6.29). The response to sward treatment also showed a reduction in species number during the study, especially for cutting and graminicide treatments. However, in 2004, values associated with scarification increased, and then decreased in 2006 to values similar to the other treatments (Figure 6.30). A significant interaction between seed mix and sward treatment was also determined ($F_{4,36.1} = 4.9$, $P < 0.01$) (Figure 6.31), indicating that responses were not consistent between seed mixes and sward treatments. Sward treatments had similar total species numbers for the TG mix, while species numbers associated with the CS and FG mixes were greater in the scarification treatment, compared with cutting or graminicide.

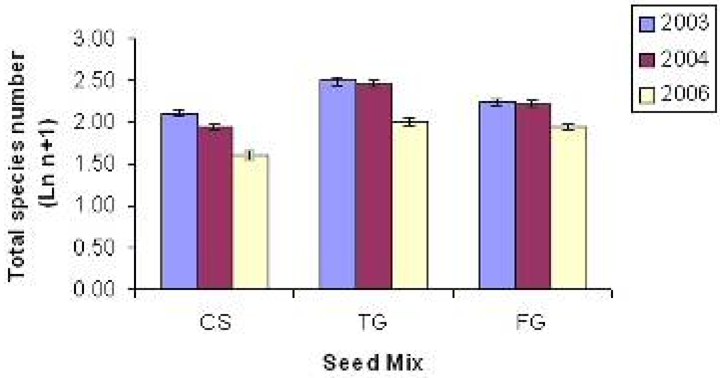


Figure 6.29. Values of total species number (species/0.25m^2) (± SE) at High Mowthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

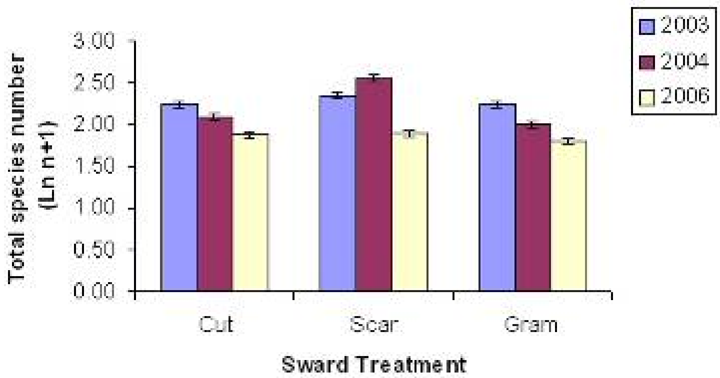


Figure 6.30. Values of total species number (species/0.25m^2) (± SE) at High Mowthorpe depending on sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

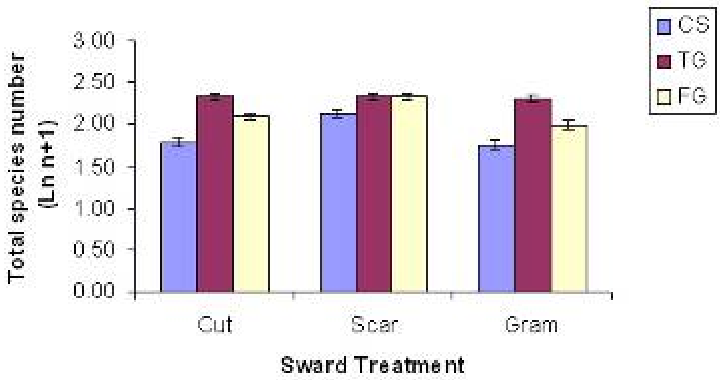


Figure 6.31. Values of total species number (species/0.25m^2) (± SE) at High Mowthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

Numbers of sown species responded to seed mix and sward treatment but also interacted with year ($F_{4,60.7} = 5.9$, $P < 0.001$ and $F_{4,60.7} = 5.9$, $P < 0.001$, respectively). Overall, numbers of sown species decreased between 2003 and 2006 and more consistently in plots sown with the CS and FG mixes. In contrast, greater numbers were maintained in plots sown with the TG mix during 2003 and 2004 (Figure 6.32). Values of sown species number also decreased with time and irrespective of sward treatment. However, in plots treated with cutting or scarification, numbers remained similar in 2003 and 2004, whilst values in plots treated with graminicide decreased more substantially. However, in 2006 values decreased by a greater extent in plots treated with scarification (Figure 6.33).

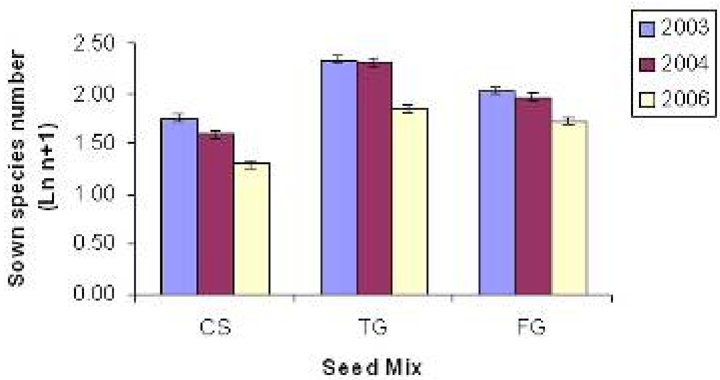


Figure 6.32. Values of sown species number (species/0.25m^2) (± SE) at High Mowthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

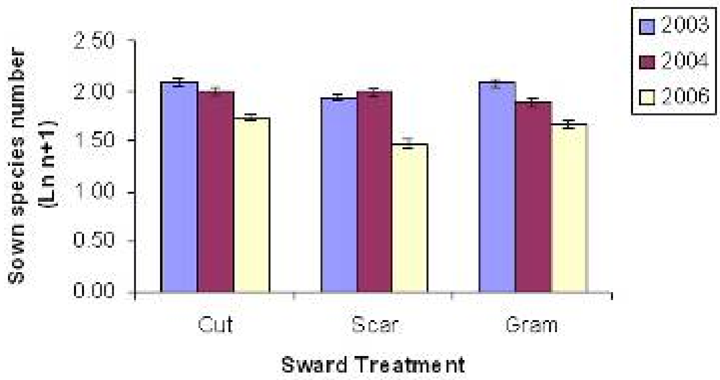


Figure 6.33. Values of sown species number (species/0.25m^2) (± SE) at High Mowthorpe depending on sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Seed mix had no significant effect on numbers of unsown species and all interactions involving this parameter were also not significant. Values of unsown species number with respect to year are presented in Figure 6.34. In contrast to the lack of effect of seed mix, a significant interaction between sward treatment and year was determined for the number of unsown species ($F_{4,64.0}$ = 21.7, P < 0.001). The response to cutting and graminicide were comparable as both decreased substantially after 2003 and maintained similar numbers in subsequent years (Figure 6.35). In contrast, the number of unsown species associated with scarification increased in 2004, but decreased in 2006.

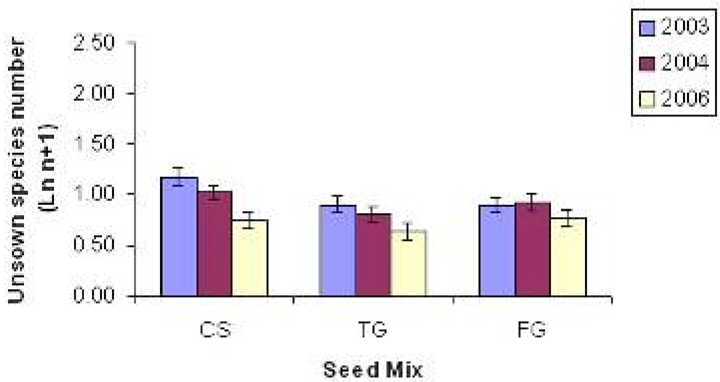


Figure 6.34. Values of unsown species number (species/0.25m^2) (± SE) at High Mowthorpe depending on seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

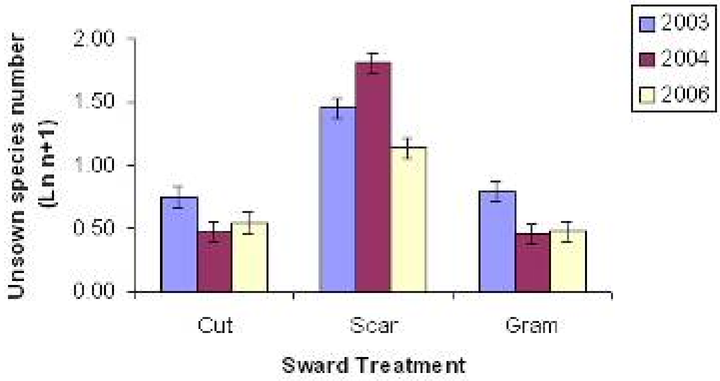


Figure 6.35. Values of unsown species number (species/0.25m^2) (± SE) at High Mowthorpe depending on sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

6.3.2.2 Species diversity (Simpson's unbiased index)

Establishment Year June 2002

Overall responses

Seed mix type was observed to have a significant effect on values of Simpson's diversity ($F_{2,118}$ = 44.7, P < 0.001). Pairwise comparisons determined that the greatest diversity was associated with the TG mix, being significantly greater than with the FG mix (P < 0.05), which in turn was associated with values significantly greater than with the CS mix (P < 0.05) (Figure 6.36).

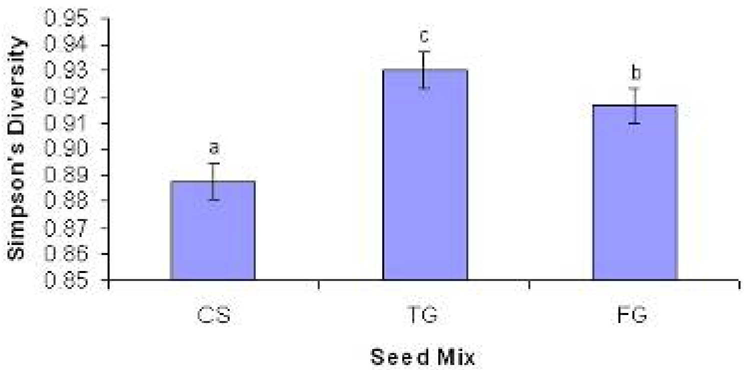


Figure 6.36. Simpson's diversity values (± SE) according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (P > 0.05).

Individual site responses

Boxworth

Values of Simpson's diversity were significantly influenced by seed mix ($F_{2,38}$ = 25.9, P < 0.001), and were significantly lower in association with the CS mix compared to the TG and FG mixes (Figure 6.37) (Pairwise comparisons, P < 0.05). No difference was found between the TG and FG mixes.

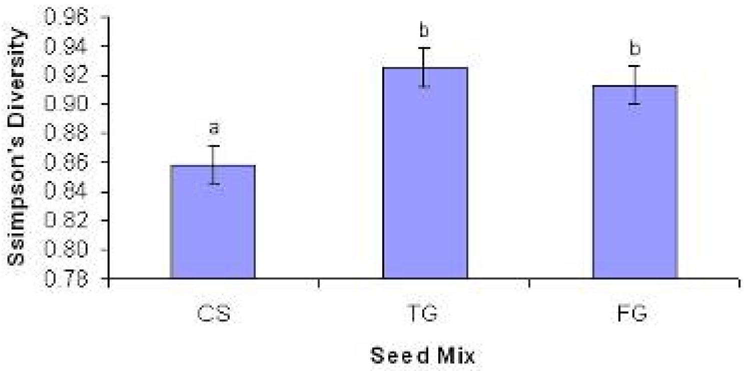


Figure 6.37. Simpson's diversity values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (*P* > 0.05).

Gleadthorpe

Values of Simpson's diversity were significantly influenced by seed mix ($F_{2,38}$ = 8.6, *P* < 0.01), and were significantly lower in association with the CS mix compared to the TG and FG mixes (Figure 6.38) (Pairwise comparisons, *P* < 0.05). No difference was found between the TG and FG mixes.

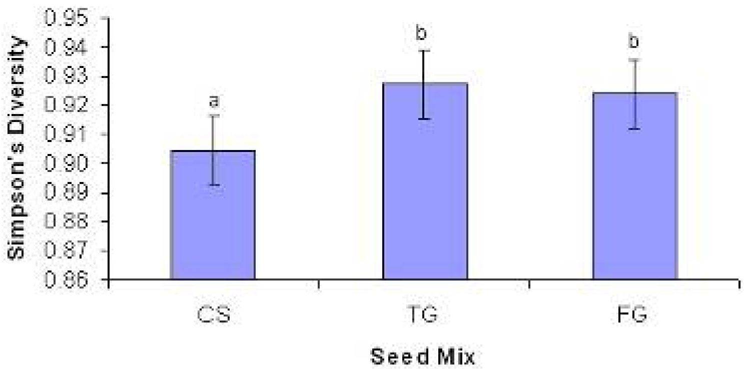


Figure 6.38. Simpson's diversity values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix).

High Mowthorpe

Seed mix type had a highly significant effect on values of Simpson's diversity ($F_{2,38}$ = 39.4, *P* < 0.001), with a greater diversity in association with the TG mix compared to the FG and CS mixes. The CS mix was associated with the lowest diversity (Figure 6.39).

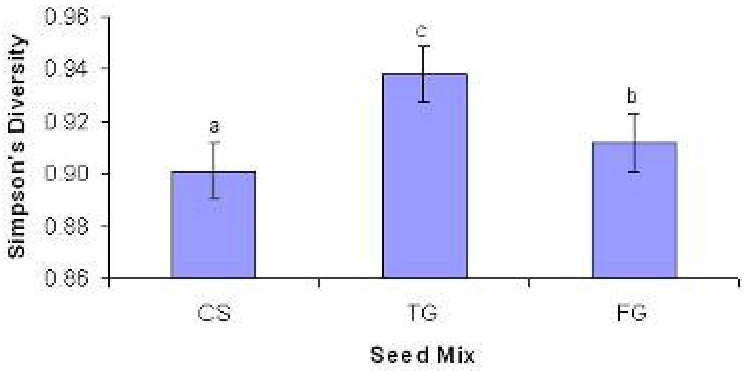


Figure 6.39. Simpson's diversity values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

Treatment responses June (2003, 2004 & 2006)

Overall responses

The effects of seed mix and sward treatment were found to interact significantly with year for values of Simpson's diversity ($F_{4,253.8} = 7.3$, $P < 0.001$ and $F_{4,253.8} = 13.7$, $P < 0.001$, respectively). Overall, values decreased with time irrespective of seed mix and sward treatment. However by 2006, values decreased to a greater extent in association with the CS mix (Figure 6.40), whilst diversity increased between 2003 and 2004 with scarification, compared to a continued decrease with cutting and graminicide (Figure 6.41).

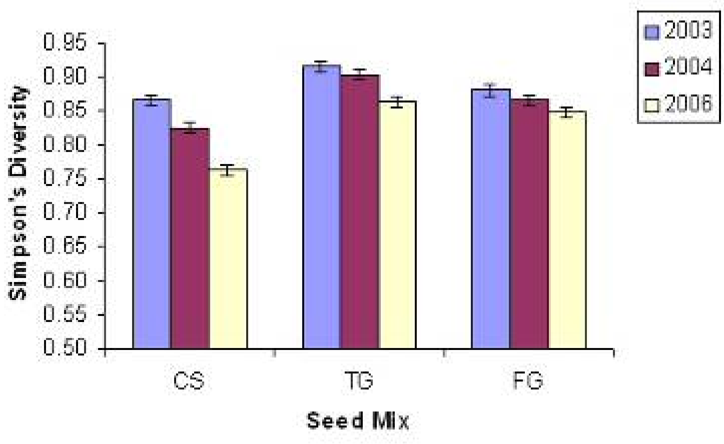


Figure 6.40. Simpson's diversity values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

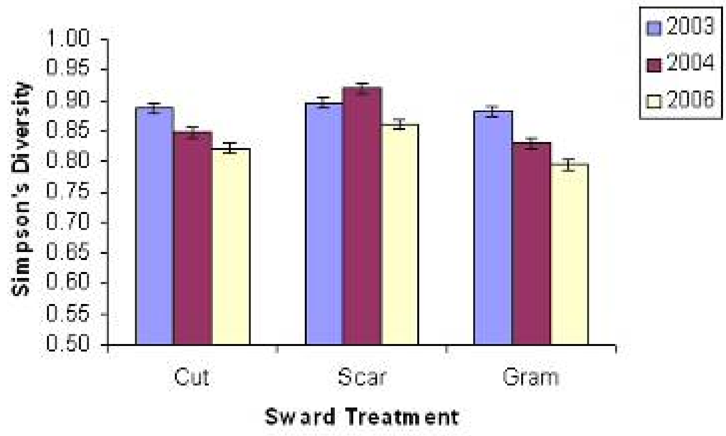


Figure 6.41. Simpson's diversity values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Individual site responses

Boxworth

Seed mix was found to have a significant effect on Simpson's diversity ($F_{2,45.1}$ = 6.8, P < 0.001), but the interaction with year, or with sward treatment and sward treatment and year were not significant. Diversity was significantly greater in association with the TG mix and no difference was found between the CS and FG mixes (Figure 6.42).

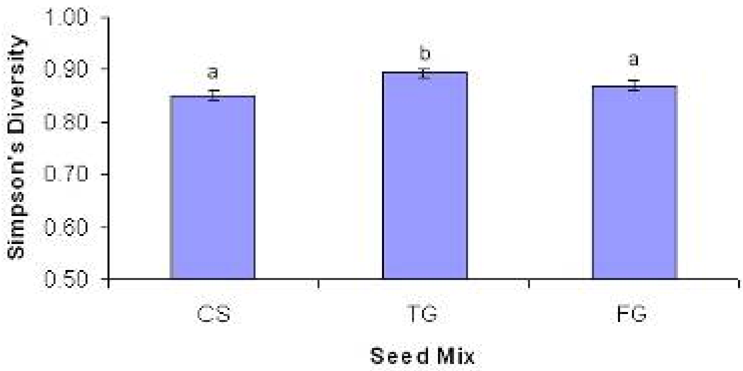


Figure 6.42. Simpson's diversity values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix).

The effect of sward treatment on diversity was shown to interact significantly with year ($F_{4,83.0}$ = 5.1, P < 0.01). In association with cutting and graminicide values were lower in 2004 and 2006 compared to 2003, whilst with scarification, values were greater in 2004 (Figure 6.43).

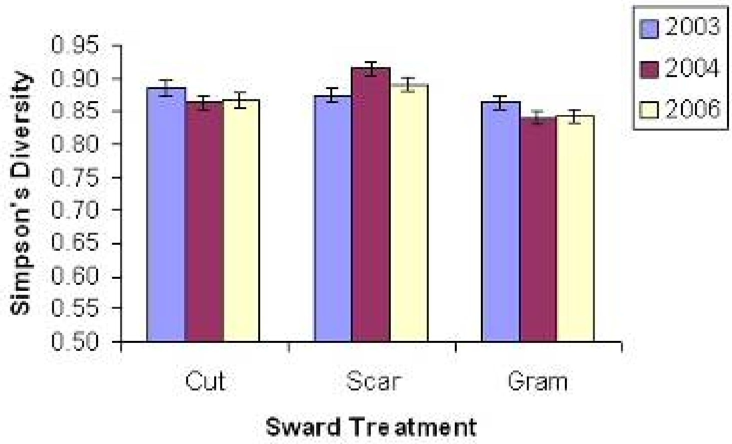


Figure 6.43. Simpson's diversity values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Gleadthorpe

The interaction between seed mix, sward treatment and year was found to be significant for values of Simpson's diversity ($F_{8,56.6}$ = 2.3, P < 0.05). This indicates that responses to seed mix and sward treatment were not consistent between and within years and that responses to sward treatment were not consistent with respect to seed mix (Figure 6.44). In general, values decreased in association with all seed mixes and sward treatments between 2003 and 2006. However, in association with scarification, values of diversity in 2004 increased in plots sown with either the TG or FG mix. A greater reduction in Simpson's diversity was also found in association with the CS mix, particularly in plots that were also treated with graminicide.

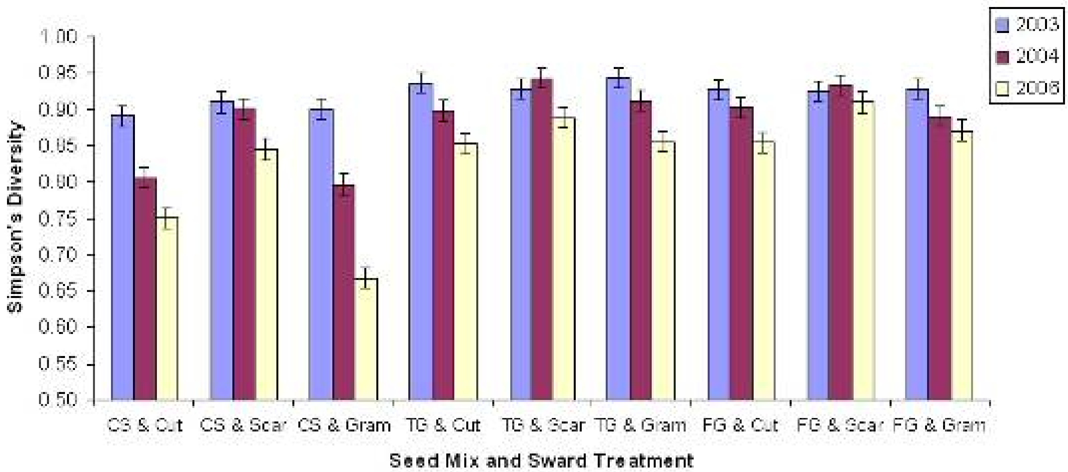


Figure 6.44. Simpson's diversity values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

High Mowthorpe

For values of Simpson's diversity significant interactions were found between seed mix and year ($F_{4,66.4} = 6.4$, $P < 0.001$) and sward treatment and year ($F_{4,66.4} = 7.4$, $P < 0.001$). Diversity decreased in association with all seed mixes with time, but to a greater extent in plots sown with the CS mix. Greater values of diversity were consistently recorded in the TG plots (Figure 6.45).

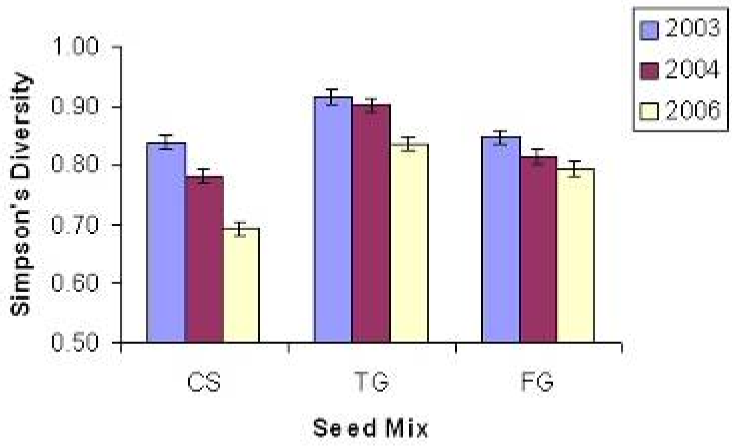


Figure 6.45. Simpson's diversity values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

The interaction between sward treatment and year indicated that diversity increased with time in plots treated with cutting or graminicide. However, in association with scarification, values increased in 2004, but decreased substantially by 2006 (Figure 6.46).

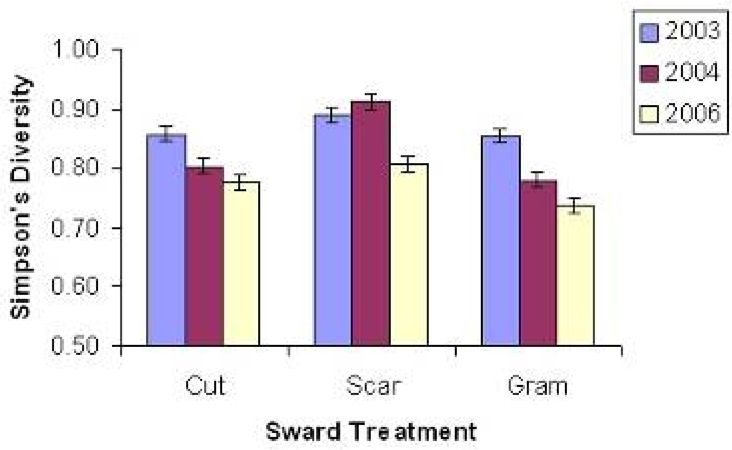


Figure 6.46. Simpson's diversity values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and sward treatment was also determined ($F_{4,36.0}$ = 3.6, P < 0.05). The diversity of plots treated with scarification were similar, whilst with cutting and graminicide, values were greater in association with the TG mix (Figure 6.47).

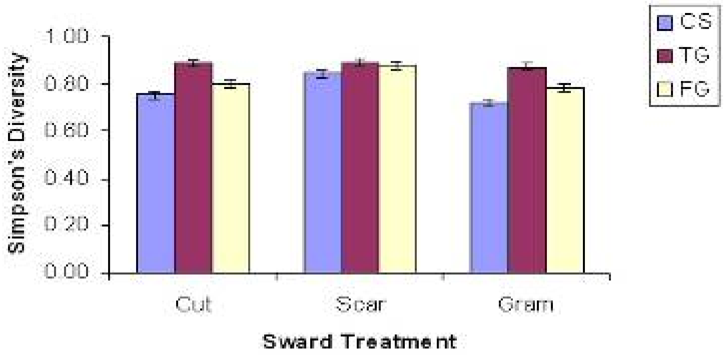


Figure 6.47. Simpson's diversity values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

6.3.2.3 Shannon evenness (September)

Establishment Year September 2002

Overall responses

Seed mix type was observed to have a significant effect on values of Shannon evenness ($F_{2,118}$ = 48.5, P < 0.001). Pairwise comparisons determined that the greatest evenness was associated with the TG and FG mixes, being significantly greater than with the CS mix (P < 0.05) (Figure 6.48).

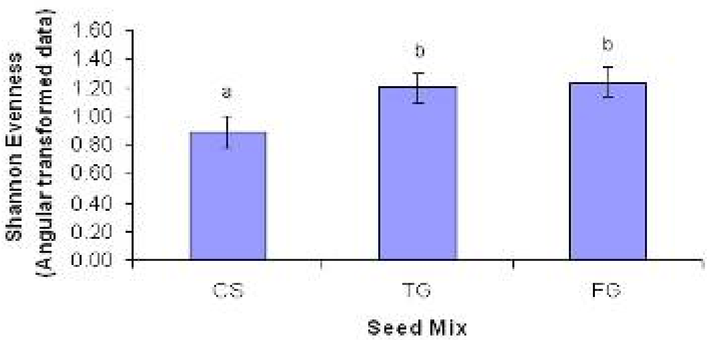


Figure 6.48. Shannon evenness values (± SE) in September 2002 across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (P > 0.05).

Individual site responses

Boxworth

Values of Shannon evenness were significantly influenced by seed mix ($F_{2,38} = 11.2$, $P < 0.001$), and were significantly lower in association with the CS mix compared with the TG and FG mixes (Figure 6.49) (Pairwise comparisons, $P < 0.05$). No difference was found between the TG and FG mixes.

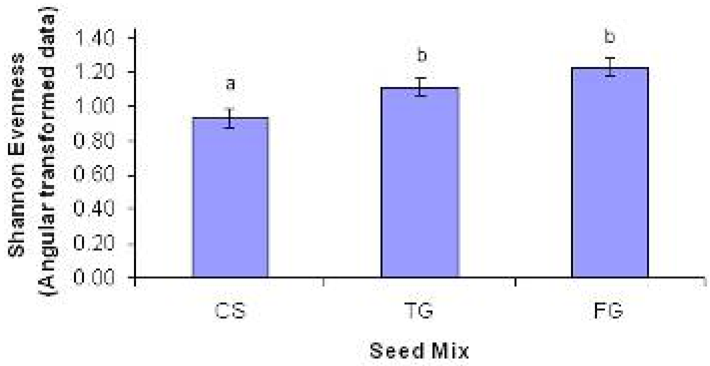


Figure 6.49. Shannon evenness values (± SE) in September 2002 at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

Gleadthorpe

Values of Shannon evenness were significantly influenced by seed mix ($F_{2,38} = 9.5$, $P < 0.001$), and were significantly lower in association with the CS mix compared with the TG and FG mixes (Figure 6.50) (Pairwise comparisons, $P < 0.05$). No difference was found between the TG and FG mixes.

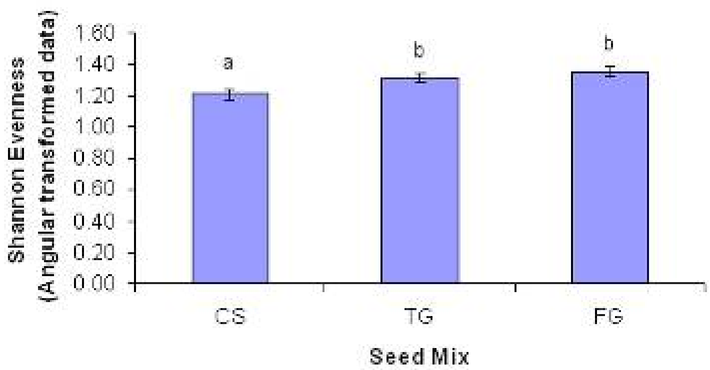


Figure 6.50. Shannon evenness values (± SE) in September 2002 at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

High Mowthorpe

Values of Shannon evenness were significantly influenced by seed mix ($F_{2,38}$ = 72.0, P < 0.001), and were significantly lower in association with the CS mix compared with the TG and FG mixes (Figure 6.51) (Pairwise comparisons, P < 0.05). No difference was found between the TG and FG mixes.

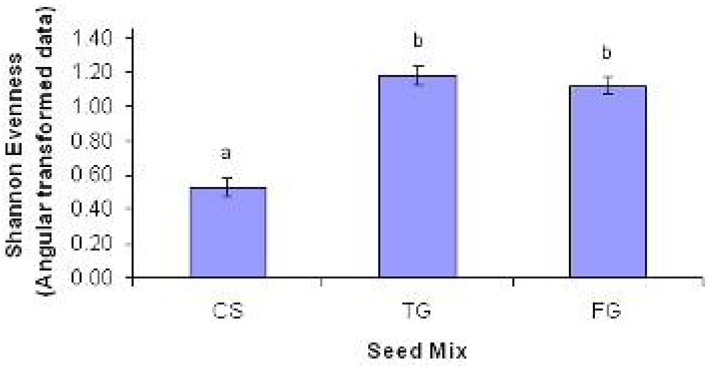


Figure 6.51. Shannon evenness values (± SE) in September 2002 at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (P > 0.05).

Treatment responses September (2003, 2004 & 2006)

Overall responses

The effects of seed mix and sward treatment were found to interact significantly with year for values of Shannon evenness ($F_{4,178.3}$ = 5.1, P < 0.01 and $F_{4,178.3}$ = 3.2, P < 0.05, respectively). Values were consistently lower in association with the CS mix and increased between years, especially from 2003 to 2004 (Table 6.21). However, in association with the TG and FG mixes, values of Shannon evenness decreased in 2006, but continued to increase in plots sown with the CS mix.

Table 6.21. Shannon evenness values (± SE) (angular transformed data) across sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Seed Mix	Yr 2003	Yr 2004	Yr 2006
CS	0.75 (± 0.03)	0.93 (± 0.03)	0.97 (± 0.03)
TG	1.23 (± 0.03)	1.30 (± 0.03)	1.22 (± 0.03)
FG	1.23 (± 0.03)	1.36 (± 0.03)	1.28 (± 0.03)

Values of Shannon evenness were generally greater in plots treated with scarification or graminicide than with cutting. The significant interaction between sward treatment and year revealed that responses also differed between years (Table 6.22). In 2004, values increased under all treatments, but in 2006 values decreased in plots treated with cutting or scarification.

Table 6.22. Shannon evenness values (± SE) (angular transformed data) across sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Sward Treatment	Yr 2003	Yr 2004	Yr 2006
Cut	1.04 (± 0.03)	1.11 (± 0.03)	1.08 (± 0.03)
Scar	1.10 (± 0.03)	1.29 (± 0.03)	1.20 (± 0.03)
Gram	1.07 (± 0.03)	1.19 (± 0.03)	1.20 (± 0.03)

A significant interaction was also determined between seed mix and sward treatment ($F_{4,125.3}$ = 2.5, P < 0.05) indicating that the responses of the seed mixes were not consistent for each sward treatment (Table 6.23). Cutting was associated with the lowest values of evenness in plots sown with either the CS or TG mix, while scarification was associated with the greatest evenness in plots sown with CS. In association with the TG and FG seed mixes, the graminicide treatment was associated with the greatest evenness values, although there was negligible difference between scarification and graminicide in the TG plots. The interaction between seed mix, sward treatment and year was not significant.

Table 6.23. Shannon evenness values (± SE) (angular transformed data) across sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

Seed Mix	Cut	Scar	Gram
CS	0.76 (± 0.05)	1.04 (± 0.05)	0.85 (± 0.05)
TG	1.19 (± 0.05)	1.28 (± 0.05)	1.29 (± 0.05)
FG	1.28 (± 0.05)	1.28 (± 0.05)	1.31 (± 0.05)

Individual site responses

Boxworth

A significant interaction between seed mix and year was found for values of Shannon evenness ($F_{4,77.6}$ = 6.2, P < 0.001). In 2004 values had increased in association with all seed mixes and especially the CS mix (Table 6.24). However, in 2006, values decreased in plots sown with the TG and FG mixes, whilst values in the CS plots, values continued to increase.

Table 6.24. Shannon evenness values (± SE) (angular transformed data) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Seed Mix	Yr 2003	Yr 2004	Yr 2006
CS	0.93 (± 0.04)	1.23 (± 0.04)	1.26 (± 0.04)
TG	1.24 (± 0.04)	1.35 (± 0.04)	1.24 (± 0.04)
FG	1.25 (± 0.04)	1.39 (± 0.04)	1.30 (± 0.04)

The interaction between sward treatment and year was not significant, neither was the three-way interaction between seed mix, sward treatment and year. However, a significant interaction between seed mix and sward treatment was determined ($F_{4,37.5}$ = 3.2, P < 0.05). Greater values of evenness were determined in plots sown with the CS and TG mixes when treated with scarification (Table 6.25). In contrast, the FG mix was associated with greater values of evenness when treated with cutting or graminicide.

Table 6.25. Shannon evenness values (± SE) (angular transformed data) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

Seed Mix	Cut	Scar	Gram
CS	1.03 (± 0.04)	1.27 (± 0.04)	1.13 (± 0.04)
TG	1.20 (± 0.04)	1.33 (± 0.04)	1.31 (± 0.04)
FG	1.34 (± 0.04)	1.28 (± 0.04)	1.32 (± 0.04)

Gleadthorpe

Sward treatment was not shown to have a significant effect on values of Shannon evenness at Gleadthorpe. All possible interactions between sward treatment, seed mix and year were also not significant. Seed mix was the only factor to have a significant effect ($F_{2,48.8}$ = 62.9, P < 0.001). Values were greater in plots sown with the TG (1.28 ± 0.02) and FG mix (1.33 ± 0.02) compared with those sown with the CS mix (0.96 ± 0.02) (P < 0.05) (angular transformed values).

High Mowthorpe

A significant interaction between sward treatment and year was determined for values of Shannon evenness at High Mowthorpe ($F_{4,77.2}$ = 2.8, P < 0.05). The treatments of cutting and scarification were associated with greater values in 2004 compared with 2003 and 2006. In contrast, values in plots treated with graminicide increased between years (Table 6.26).

Table 6.26. Shannon evenness values (± SE) (angular transformed data) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Sward Treatment	Yr 2003	Yr 2004	Yr 2006
Cut	0.86 (± 0.06)	0.92 (± 0.06)	0.88 (± 0.06)
Scar	0.93 (± 0.06)	1.20 (± 0.06)	1.09 (± 0.06)
Gram	0.89 (± 0.06)	1.02 (± 0.06)	1.11 (± 0.06)

A significant interaction between seed mix and sward treatment was also determined ($F_{4,36.2}$ = 3.6, P < 0.05) indicating that responses of the seed mixes to the sward treatments were not consistent. However, regardless of seed mix, values were lower in association with cutting. Scarification promoted the greatest values in plots sown with the CS mix, while graminicide was associated with the greatest values in plots sown with the TG and FG mixes (Table 6.27). Interactions between seed mix and year and seed mix, sward treatment and year were not significant.

Table 6.27. Shannon evenness values (± SE) (angular transformed data) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

Seed Mix	Cut	Scar	Gram
CS	0.32 (± 0.07)	0.79 (± 0.07)	0.51 (± 0.07)
TG	1.14 (± 0.07)	1.22 (± 0.07)	1.25 (± 0.07)
FG	1.20 (± 0.07)	1.21 (± 0.07)	1.26 (± 0.07)

6.3.2.4 Plant community composition

Establishment Year June 2002

Overall responses – Principal Component Analysis (PCA)

The separation along axis one has revealed that despite the overlap and close proximity of several points on the ordination diagram (with respect to the different seed mixes) (Figure 6.52), distinct plant communities have developed. The percentage of the total variance explained by axis one was 15.0% compared with 13.1% for axis two. The similarities between the communities reflect the species composition of the three seed mixes (Figure 6.52). For example, although *Festuca rubra* is shown to be strongly associated with plots sown with the FG seed mix, it was a component of all three mixes. Key community species associated with the TG mix are all sown species: *Dactylis glomerata*, *Dipsacus fullonum*, *Festuca pratensis*, *Holcus lanatus*, *Leucanthemum vulgare* and *Phleum pratense*. In addition to *F. rubra*, the FG seed mix was strongly associated with *Cynosurus cristatus*. The CS mix was mainly associated with unsown species such as *Avena fatua*, *Papaver rhoeas* and *Tripleurospermum inodorum*.

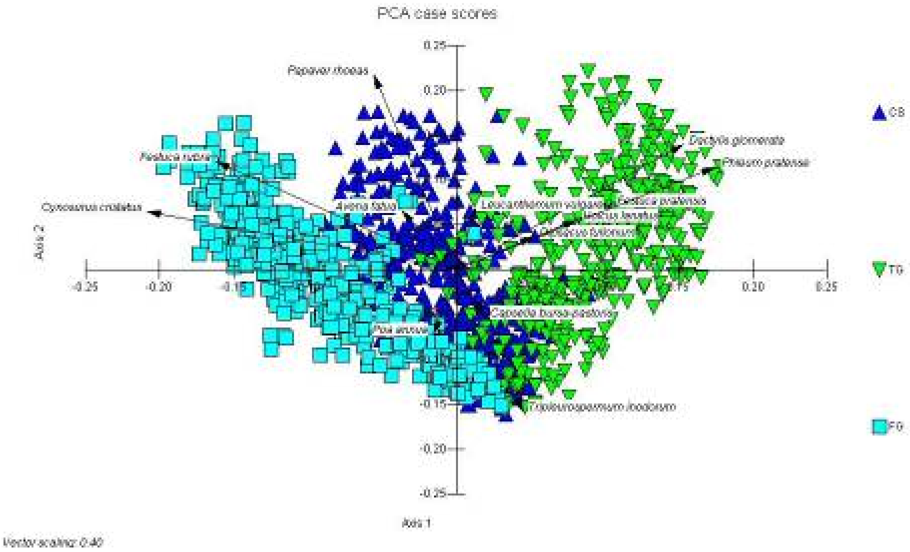


Figure 6.52. Results of Principal Component Analysis (PCA) of species composition data from all three sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), presented as a Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

Individual site responses

Boxworth

PCA determined that the percentage of the total variance explained by axis one was 17.9% compared with 13.1% for axis two. Variability within communities with respect to seed mix was high, with the formation of “sub-communities” (Figure 6.53). This can be attributed to variation between margin replicate blocks situated in different fields but also at different aspects within fields. The sown grasses were the key community indicators in both the TG and FG mixes, for example *P. pratense* and *D. glomerata* with the TG mix and *C. cristatus* and *F. rubra* in association with the FG mix. The CS mix had a greater association with unsown species, e.g. *T. inodorum* and *Sinapis arvensis*.

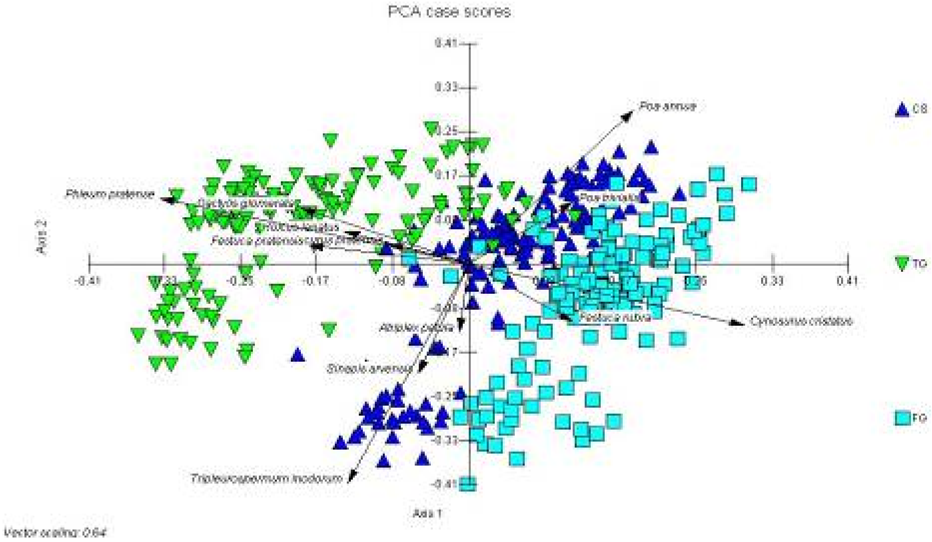


Figure 6.53. Results of Principal Component Analysis (PCA) of species composition data at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), presented as a Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

Gleadthorpe

The percentage of the total variance explained by axis one was 19.5% compared with 11.3% for axis two. Considerable overlap between plots sown with the CS and TG mixes was determined (Figure 6.54), which demonstrated a strong influence of unsown species at this site (e.g. *Capsella bursa-pastoris*, *Stellaria media* and *T. Inodorum*). The plant community established with the FG mix was more distinct and indicative of several sown species (e.g. *F. rubra*, *C. cristatus*, *Plantago lanceolata*, R*umex acetosa* and *Silene vulgaris*).

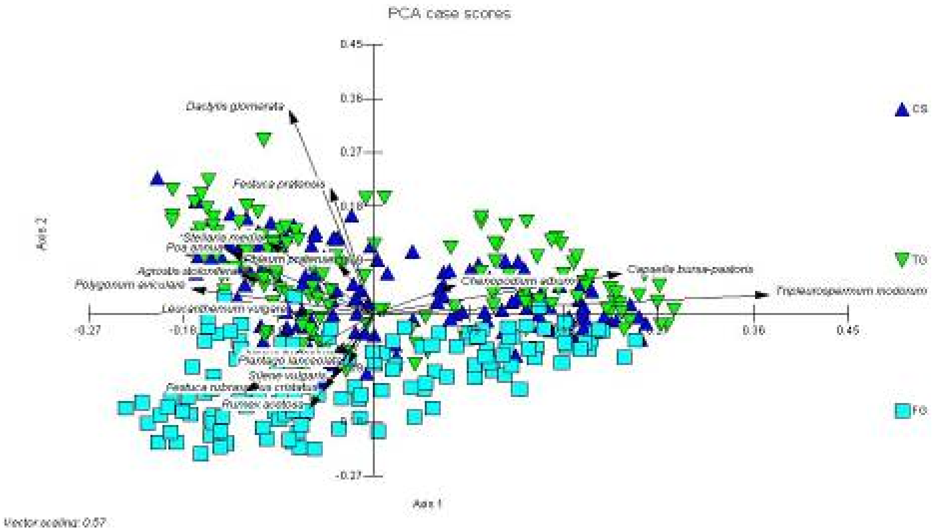


Figure 6.54. Results of Principal Component Analysis (PCA) of species composition data at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), presented as a Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

High Mowthorpe

The percentage of the total variance explained by axis one was 24.8% compared with 15.8% for axis two. Plant communities at this site were distinct with respect to seed mix, although as found at Boxworth, “sub-communities” within seed mixes were also formed, attributed to differences between margin replicate blocks that were situated in different fields but also different aspects within fields (Figure 6.55). Key community indicator species associated with the FG mix were *C. cristatus*, *F. rubra* and *Rhinanthus minor*, while the TG mix was depicted by *D. glomerata*, *F. pratensis*, *H. lanatus* and *P. pratense*. The CS mix was mainly associated with the unsown species *Papaver rhoeas* and *C. bursa-pastoris*, although the “sub-community” of the CS mix was strongly associated with the unsown grass *A. fatua*.

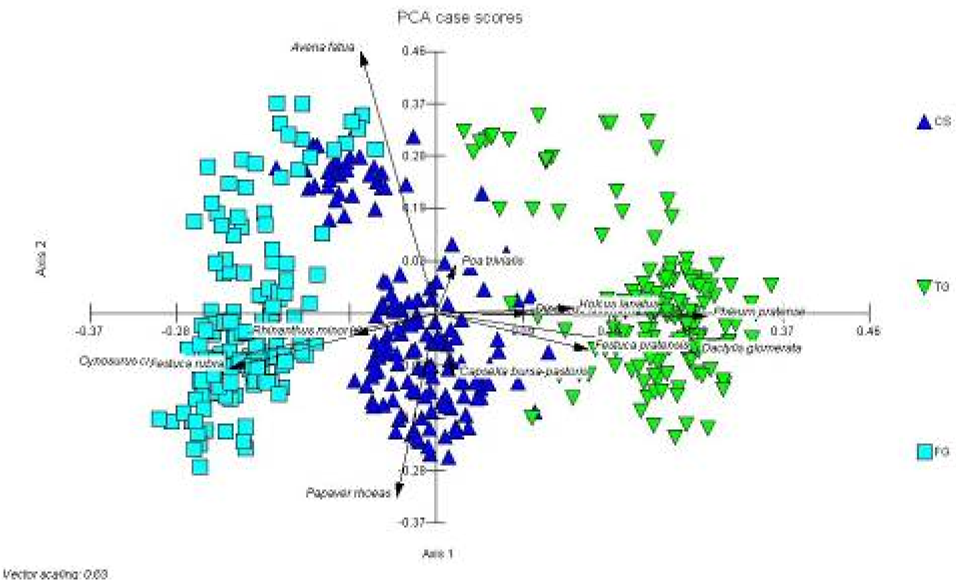


Figure 6.55. Results of Principal Component Analysis (PCA) of species composition data at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), presented as a Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

Treatment responses (2003, 2004 & 2006)

Boxworth

In 2003, the percentage of the total variance explained by axis one was 17.5% compared with 15.9% for axis two. Plant communities tended to be more strongly influenced by seed mix than sward treatment, with the presence of fairly distinct communities according to seed mix, especially for the FG mix (Figure 6.56). Key community indicator species associated with the FG mix were *F. rubra* and *C. cristatus*, while the TG mix was depicted by *D. glomerata*, *F. pratensis* and *P.*

pratense. The CS mix had no key indicator species. “Sub-communities” w ithin seed mixes w ith respect to sward treatment w ere not apparent.

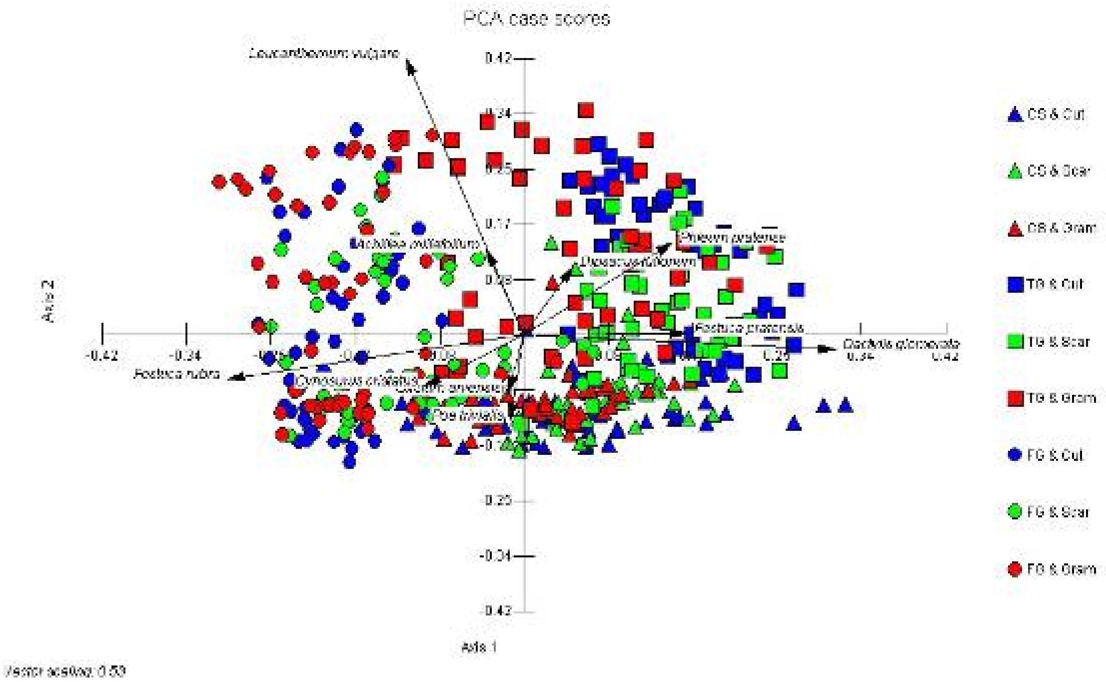


Figure 6.56. Results of Principal Component Analysis (PCA) of species composition data at Boxw orth 2003 according to seed mix (CS = Countryside Stew ardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

In 2004, the percentage of the total variance explained by axis one was 16.9% compared w ith 14.5% for axis two. In contrast to 2003, sward treatment, in particular scarification, tended to have a strong influence on sw ard composition (Figure 6.57). Sw ard composition in plots treated w ith cutting or graminicide w as more strongly influenced by seed mix. Key community indicator species associated w ith the treatment of scarification w ere the unsow n species, *Poa annua* and *Poa trivialis*. Plots sow n w ith the FG mix and treated w ith cutting or graminicide w ere strongly associated w ith *F. rubra*, while *L. vulgare* w as associated w ith the TG mix.

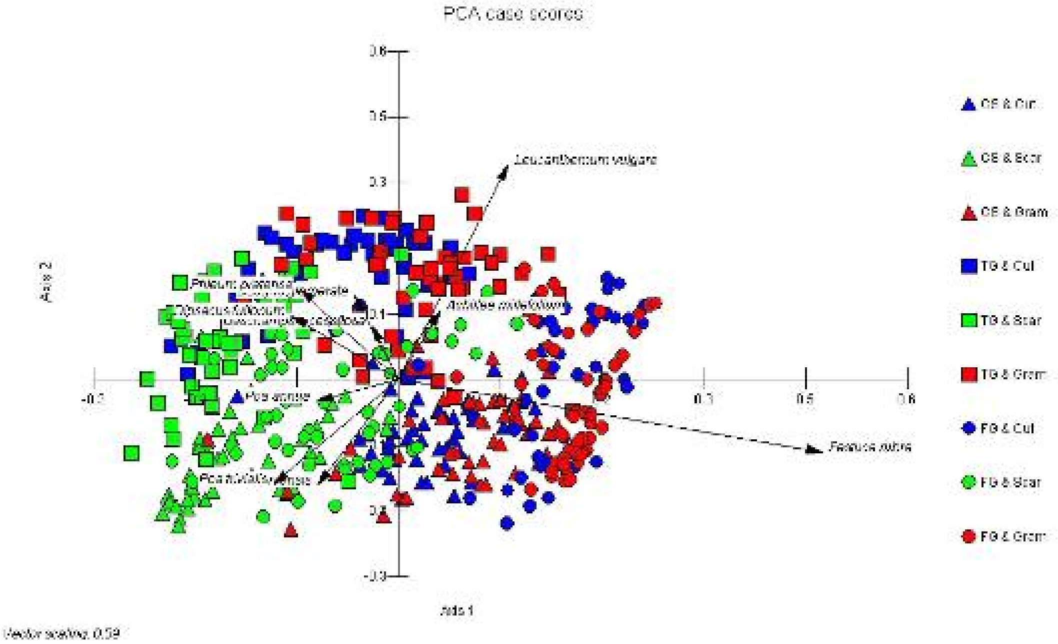


Figure 6.57. Results of Principal Component Analysis (PCA) of species composition data at Boxworth 2004 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

In 2006, the percentage of total variance explained by axis one was 14.8% and 10.3% for axis two. A similar trend to 2004 with respect to sward composition was observed, with scarification having a strong influence on sward composition (Figure 6.58). In addition, differences between the treatments of cutting and graminicide were more apparent for the other seed mixes, especially the TG mix. Key community indicator species associated with the treatment of scarification were the unsown species, *Poa trivialis, Cirsium arvense, Picris echioides*, *Ranunculus repens* and *Rumex sanguineus*. Plots sown with the TG mix and treated graminicide were associated with *L. vulgare* and *Galium mollugo* and TG plots treated with cutting were associated with *Dipsacus fullonum*, *Deschampsia cespitosa* and *Daucus carota*. The FG mix was strongly associated with *F. rubra*.

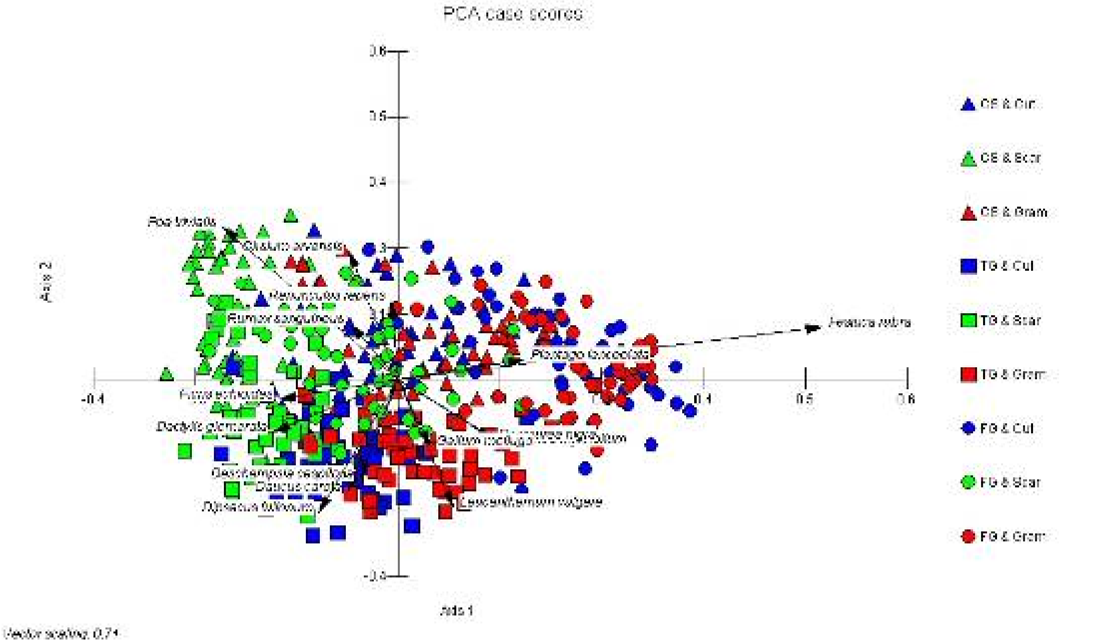


Figure 6.58. Results of Principal Component Analysis (PCA) of species composition data at Boxworth 2006 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

Gleadthorpe

In 2003, the percentage of the total variance explained by axis one was 22.4% compared with 12.7% for axis two. Plant communities were more strongly influenced by seed mix than sward treatment (Figure 6.59). Key community indicator species associated with the FG mix were *F. rubra*, *C. cristatus*, *Lotus corniculatus* and *Plantago lanceolata*. The TG mix was depicted by *D. glomerata*, *Festuca pratensis*, *Holcus lanatus*, *P. pratense* and *Vicia cracca*. *Achillea millefolium* and *L. vulgare* were key species in both the FG and TG sown plots. The CS mix was mainly associated with unsown species e.g. *Poa annua*, *Tripleurospermum inodorum* and *Matricaria matricarioides*. "Sub-communities" within seed mixes with respect to sward treatment were not apparent.

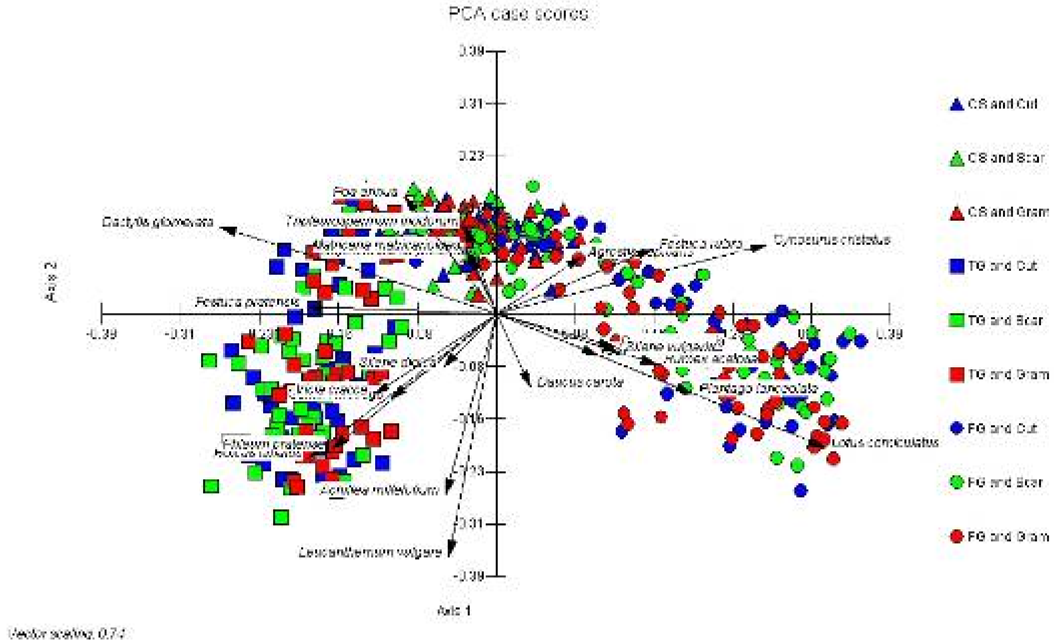


Figure 6.59. Results of Principal Component Analysis (PCA) of species composition data at Gleadthorpe 2003 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

In 2004, the percentage of the total variance explained by axis one was 23.0% compared with 15.0% for axis two. The effects of sward treatment were more apparent, with a move towards "sub-communities" within seed mixes. However, the main driver of plant community composition continued to be seed mix type (Figure 6.60). *Lotus corniculatus* and *F. rubra* were the key community indicator species for the FG mix, while *L. vulgare, A. millefolium, Vicia cracca* and *Holcus lanatus* were the main indicator species for plots sown with the TG mix. *D. glomerata* was a key species in plots sown with the TG and CS mixes. The CS mix was also associated with *Agrostis capillaris*.

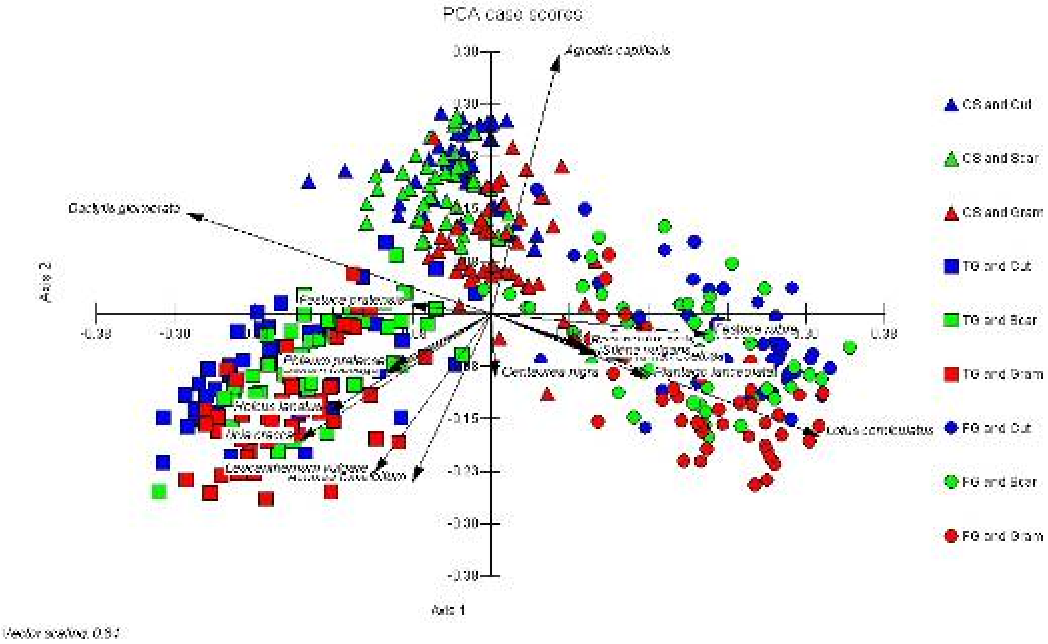


Figure 6.60. Results of Principal Component Analysis (PCA) of species composition data at Gleadthorpe 2004 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

In 2006, the percentage of total variance explained by axis one was 22.4% and 11.7% for axis two. In contrast to previous years, a greater response to sward treatment was observed (Figure 6.61). Communities continued to be distinct with respect to seed mix, but within these communities "sub-communities" had developed. The strongest treatment effect appeared to be that of graminicide and was associated with *Festuca rubra* as a key indicator species. Specifically, in plots sown with the FG mix, *Lotus corniculatus* was the key indicator species for the graminicide treatment, while in plots sown with the TG mix, *Vicia cracca*, *Galium mollugo* and *Achillea millefolium* were the key species.

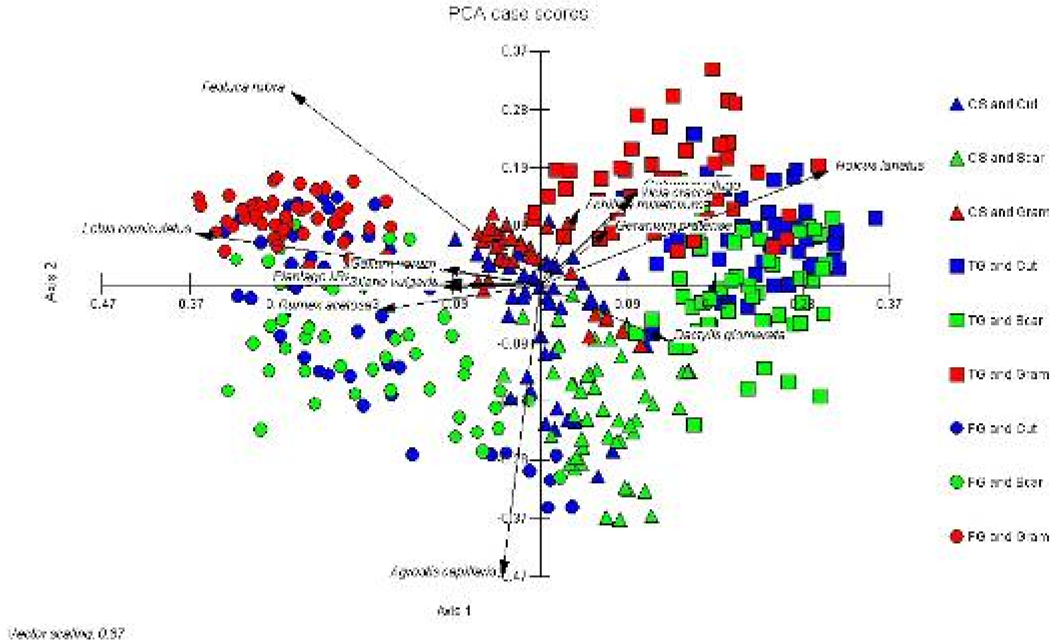


Figure 6.61. Results of Principal Component Analysis (PCA) of species composition data at Gleadthorpe 2006 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

High Mowthorpe

In 2003, the percentage of the total variance explained by axis one was 32.8% compared with 17.5% for axis two. Plant communities were strongly influenced by seed mix rather than sward treatment, with the presence of distinct communities according to seed mix (Figure 6.62). Key community indicator species associated with the FG mix were *F. rubra* and *Ranunculus acris*, while the TG mix was depicted by *F. pratensis, Holcus lanatus* and *P. pratense*. *Poa pratensis* was the key indicator species for the CS mix. *D. glomerata* was observed to be a key species in plots sown with the CS and TG mixes, while *L. vulgare* was a key species in plots sown with the TG and FG mixes; *Cynosurus cristatus* was a key species in the CS and FG plots. Distinct "sub-communities" within seed mixes with respect to sward treatment were not apparent, although the treatment of scarification was associated with some divergence in plots sown with the FG mix.

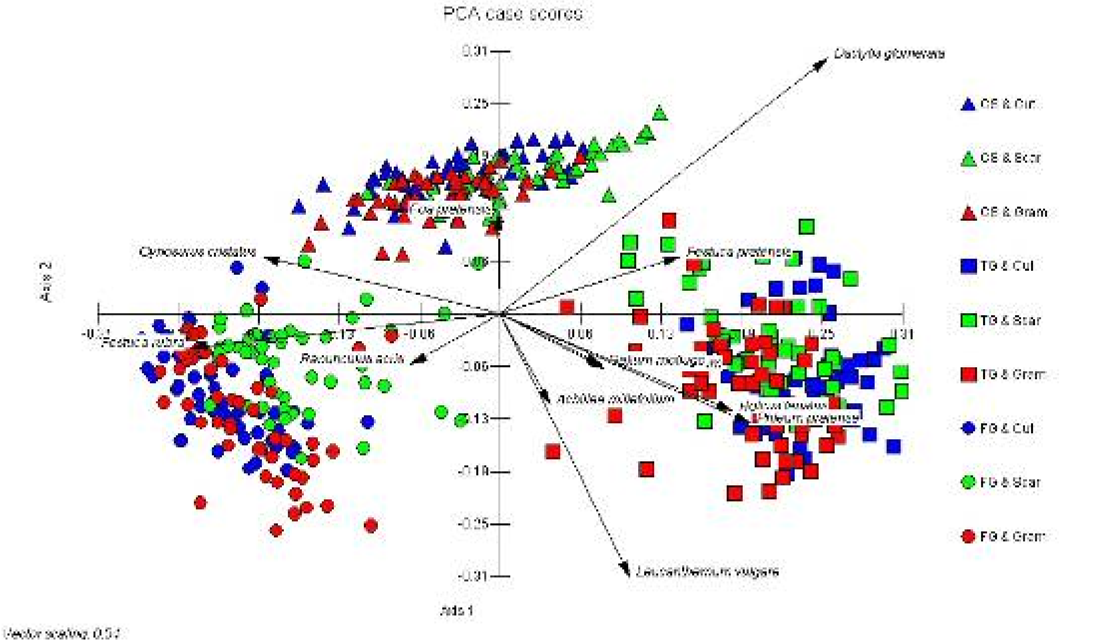


Figure 6.62. Results of Principal Component Analysis (PCA) of species composition data at High Mowthorpe 2003 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

In 2004, the percentage of the total variance explained by axis one was 31.8% compared with 12.9% for axis two. Seed mix continued to have the strongest influence on sward composition at High Mowthorpe, although distinctions within seed mixes with respect to sward treatment were more apparent than in 2003. In particular, plots sown with the TG mix and treated with graminicide, and FG plots treated with scarification, were the main “sub-communities” observed (Figure 6.63). *F. rubra, L. corniculatus* and *Rhinanthus minor* were the key community indicator species associated with the FG plots, while *H. lanatus*, *P. pratense*, *Galium mollugo*, *Dipsacus fullonum* and *Deschampsia cespitosa* were indicator species for plots sown with the TG mix. *Poa pratensis* was the only species specifically associated with the CS plots. *D. glomerata* was a key species for the TG and CS mixes and *L. vulgare* and *Achillea millefolium* were key species for the TG and FG mixes.

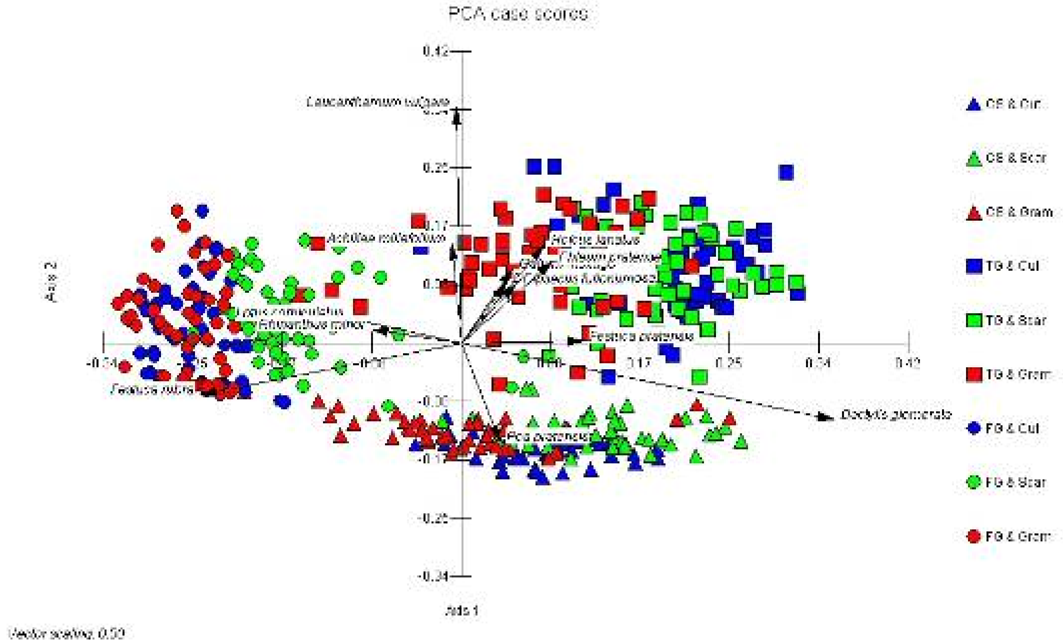


Figure 6.63. Results of Principal Component Analysis (PCA) of species composition data at High Mowthorpe 2004 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

In 2006, the percentage of total variance explained by axis one was 30.8% and 13.6% for axis two. In contrast to previous years, distinct plant communities were observed with respect to seed mix and sward treatment (Figure 6.64). In association with the TG mix, distinct communities developed under the treatments of cutting and graminicide, while with scarification, the community composition was similar to that of the CS plots that were treated with scarification. Plots sown with the FG mix developed a distinct community in association with scarification, while FG plots treated with cutting or graminicide were similar in composition. Responses of the CS mix to sward treatment were less marked. Key indicator species for the FG mix were *L. corniculatus*, *Plantago lanceolata* and *R. acris*, while *F. rubra* was a key species for the FG plots treated with cutting or graminicide and TG plots treated with graminicide. *Alopecurus pratensis*, *D. glomerata* and *Deschampsia cespitosa* were key species for TG plots that were cut, while *G. mollugo* was a key species for TG plots that were either cut or treated with graminicide.

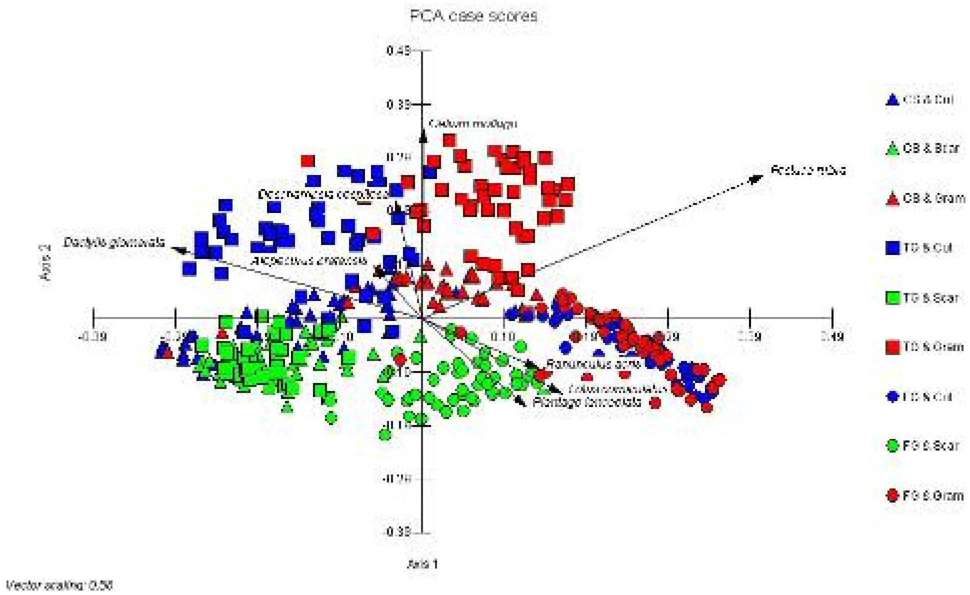


Figure 6.64. Results of Principal Component Analysis (PCA) of species composition data at High Mowthorpe 2006 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) presented as an Euclidean bi-plot displaying only vectors longer than 1/10 the total length of either axis.

6.3.2.5 Bare ground

Establishment Year June & September 2002

Overall responses

During the establishment year (2002) no significant effect of seed mix type was determined for values of percentage bare ground in June and September (Figure 6.65).

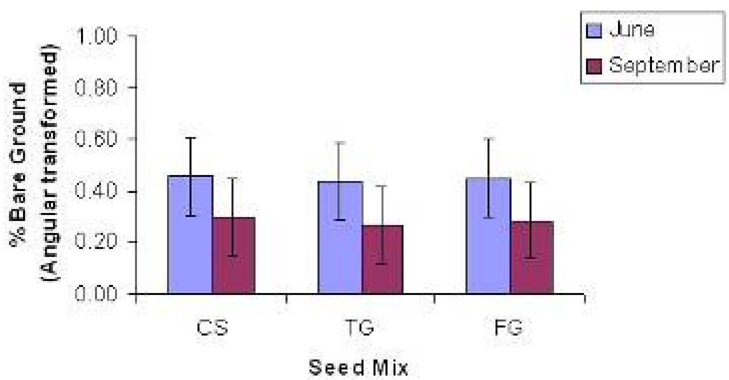


Figure 6.65. Percentage bare ground values (± SE) (angular transformed) across all sites in June and September 2002 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and month of assessment.

Individual site responses

Boxworth

No significant effect of seed mix was found for values of percentage bare ground, although values decreased between sampling dates (Figure 6.66).

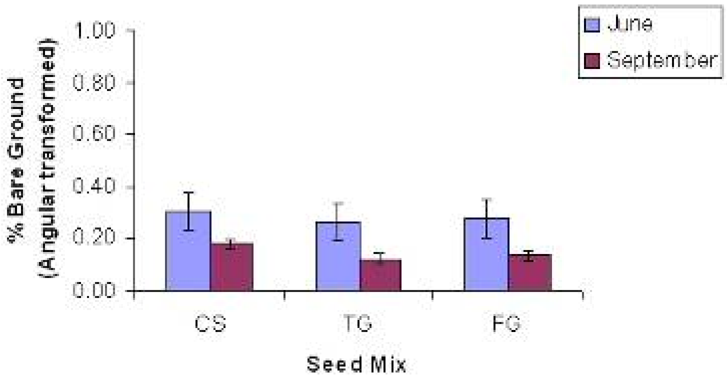


Figure 6.66. Percentage bare ground values (± SE) (angular transformed) at Boxworth in June and September 2002 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and month of assessment.

Gleadthorpe

No significant effect of seed mix was found for values of percentage bare ground (Figure 6.67).

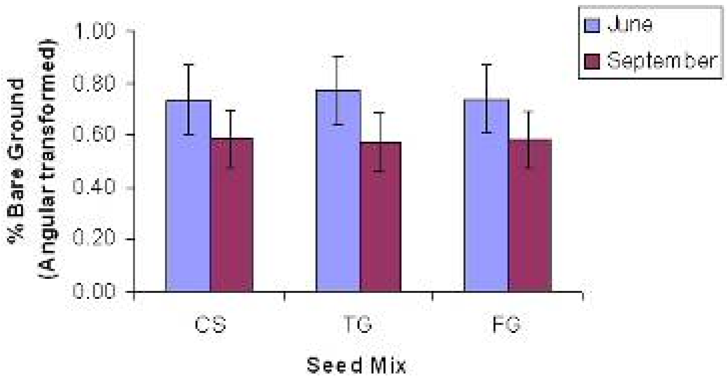


Figure 6.67. Percentage bare ground values (± SE) (angular transformed) at Gleadthorpe in June and September 2002 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) andmonth of assessment.

High Mow thorpe

No significant effect of seed mix w as found for values of percentage bare ground, although values decreased betw een sampling dates (Figure 6.68).

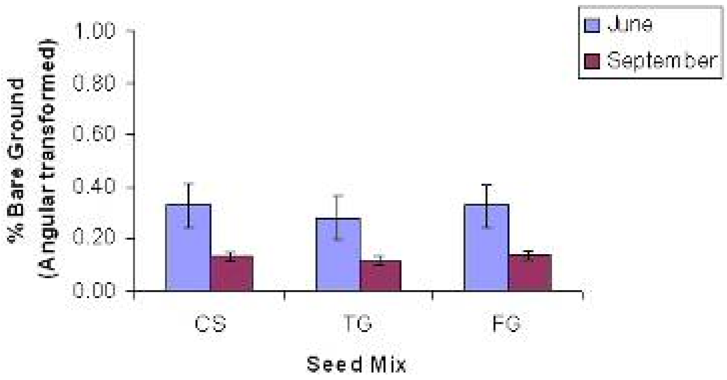


Figure 6.68. Percentage bare ground values (± SE) (angular transformed) at High Mow thorpe in June and September 2002 according to seed mix (CS = Countryside Stew ardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) andmonth of assessment.

Treatment responses June & September (2003, 2004 & 2006)

Overall responses

June

Analysis across all sites revealed that seed mix had no significant effect on values of bare ground. In contrast, a significant interaction betw een sward treatment and year was determined ($F_{4,244.2} = 2.9$, $P < 0.05$). Values w ere consistently greater in association w ith the scarification treatment, but values w ere low er in association w ith all treatments in 2004 compared w ith 2003 and 2006 (Figure 6.69).

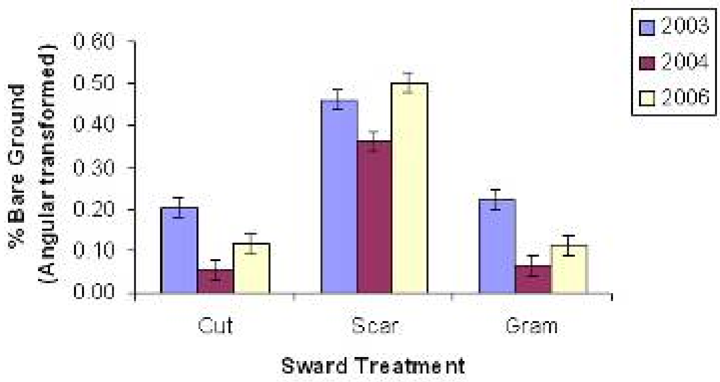


Figure 6.69. Percentage bare ground values (± SE) (angular transformed) across all sites in June according to sw ard treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

September

Analysis across all sites revealed that seed mix had no significant effect on values of bare ground in September. However, a significant interaction between sward treatment and year was determined ($F_{4,199.9}$ = 14.4, P < 0.001). Values were greater in association with scarification in 2003 (Figure 6.70).

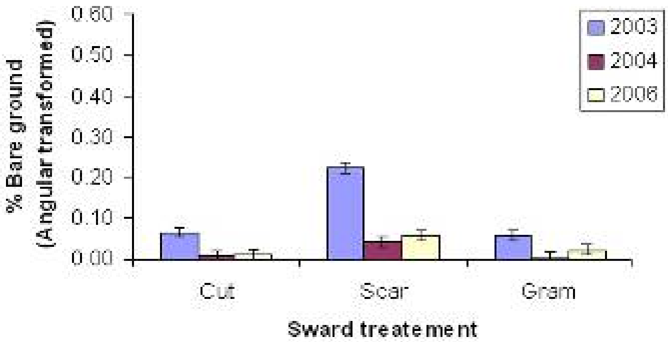


Figure 6.70. Percentage bare ground values (± SE) (angular transformed) across all sites in September according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Individual site responses

Boxworth

June

Seed mix had no significant effect on vales of bare ground. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,89.1}$ = 6.7, P < 0.001). Values were greater in association with scarification compared with the treatments of cutting and graminicide. In association with scarification values decreased between years, whilst with cutting and graminicide, values were lower in 2004 compared with 2003 and 2006 (Figure 6.71).

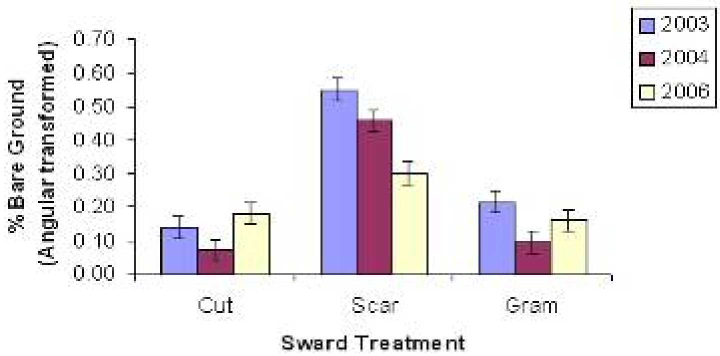


Figure 6.71. Percentage bare ground values (± SE) (angular transformed) at Boxworth in June according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

September

The effect of seed mix on values of bare ground recorded in September was not significant. However, a significant interaction between sward treatment and year was determined ($F_{4,66.7}$ = 24.7, P < 0.001). In general, values were greater in 2003, especially in association with scarification (Figure 6.72)

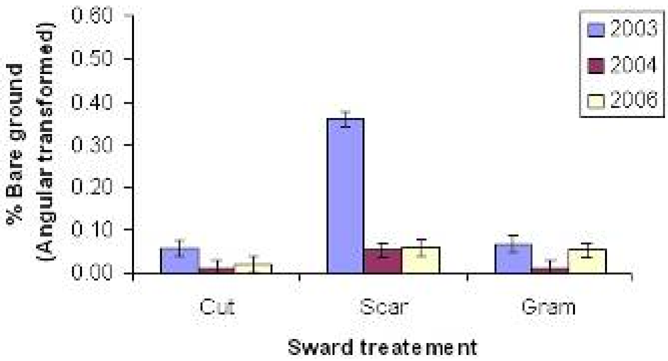


Figure 6.72. Percentage bare ground values (± SE) (angular transformed) at Boxworth in September according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Gleadthorpe

June

A significant interaction between seed mix and year was determined for values of bare ground at Gleadthorpe in June ($F_{4,64.9}$ = 6.4, P < 0.001). Variation due to year was determined, with values decreasing between years in association with the FG mix, compared with lower values in 2004 in plots sown with either the CS or TG mix (Figure 6.73).

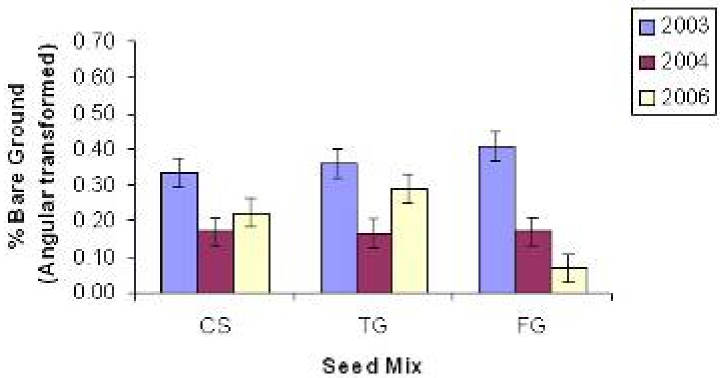


Figure 6.73. Percentage bare ground values (± SE) (angular transformed) at Gleadthorpe in June according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction was also determined between sward treatment and year ($F_{4,64.9} = 5.6$, $P < 0.01$). In 2003 values were similar across all treatments, however in subsequent years, values decreased in association with cutting and graminicide, but remained relatively high in the scarified plots (Figure 6.74).

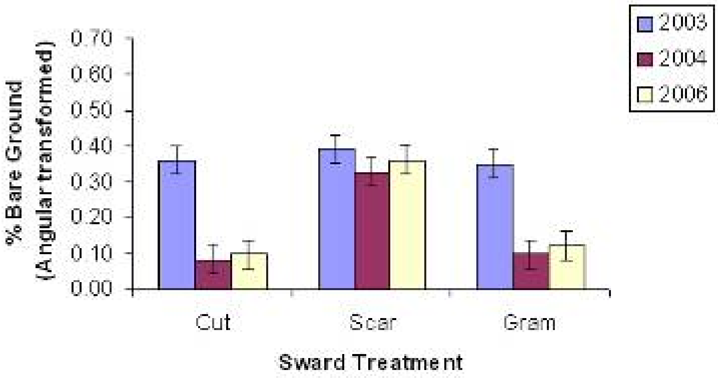


Figure 6.74. Percentage bare ground values (± SE) (angular transformed) at Gleadthorpe in June according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

September

Treatment effects of seed mix and sward treatment were not significant for values of bare ground recorded in September. However, a significant year effect was determined ($F_{2,68.5} = 29.7$, $P < 0.001$), with greater values in 2003 compared with 2004 and 2006 (Figure 6.75).

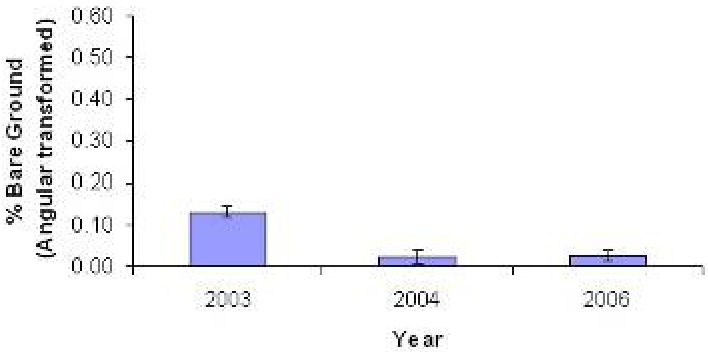


Figure 6.75. Percentage bare ground values (± SE) (angular transformed) at Gleadthorpe in September according to year.

High Mowthorpe

June

Seed mix had no significant effect on values of bare ground recorded in June. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,61.2} = 84.2$, $P < 0.001$). Values were considerably greater in association with scarification, especially in 2006 (Figure 6.76). The interaction between seed mix and sward treatment, and the interaction between seed mix, sward treatment and year were not significant.

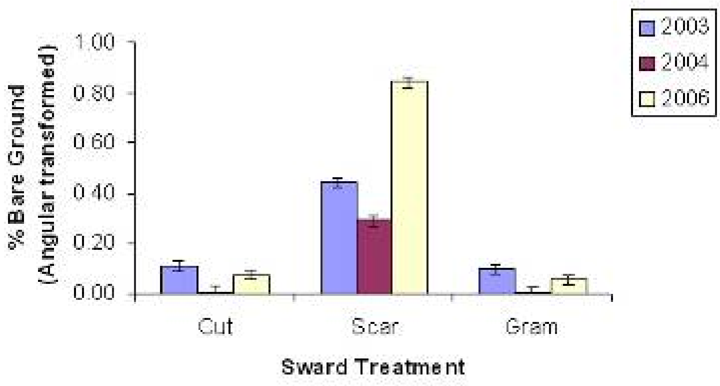


Figure 6.76. Percentage bare ground values (± SE) (angular transformed) at High Mowthorpe in June according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

September

A significant interaction between seed mix, sward treatment and year was determined ($F_{8,55.3}$ = 2.7, P < 0.05). This indicates that responses to seed mix and sward treatment were not consistent between and within years and that responses to sward treatment were not consistent with respect to seed mix. Overall, values were greater in association with scarification, particularly in 2003.

6.3.2.6 Litter cover

Establishment Year June & September 2002

For both sampling dates assumptions of normal distribution and equal variance were not met and sites were analysed individually using the Kruskal-Wallis non-parametric method. No significant effects of seed mix on litter cover were determined. In June, values of litter cover did not exceed a mean of 2.2% at any of the sites. However, values increased at all sites in September. At Boxworth values ranged from 8.1 (±1.7) to 11.6 (±4.7); at Gleadthorpe, values ranged from 1.7 (±0.2) to 2.2 (±0.4) and at High Mowthorpe 7.5 (±2.2) to 12.0 (±4.9).

Treatment responses June & September (2003, 2004 & 2006)

Overall responses

Across all sites and years, no significant effects of seed mix, sward treatment and year were found for values of litter cover recorded in June. Regardless of treatment and year, values ranged from 6.6 to 8.5% (inverse $\log_e$ transformed means). In September, year had a significant effect on values of litter cover ($F_{2,229.3}$ = 291.7, P < 0.001), being significantly greater in 2003 compared with subsequent years (Figure 6.77). Seed mix and sward treatment had no significant effect on values of litter cover. The interactions between these parameters and year were also not significant.

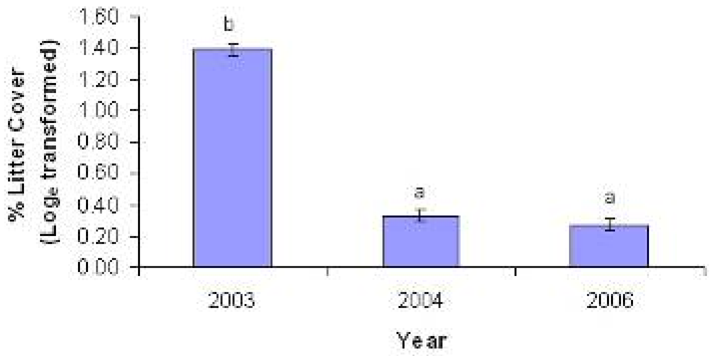


Figure 6.77. Percentage litter cover (± SE) across all sites in September depending on year. Values with same letter do not differ significantly ($P > 0.05$).

Individual site responses

Boxworth

In June, values of percentage litter cover varied significantly with respect to seed mix ($F_{2,40.0} = 4.9$, $P < 0.05$). Pairwise comparisons revealed that values were significantly lower in association with the TG mix compared with the FG mix (Figure 6.78). The interaction between seed mix and year was not significant.

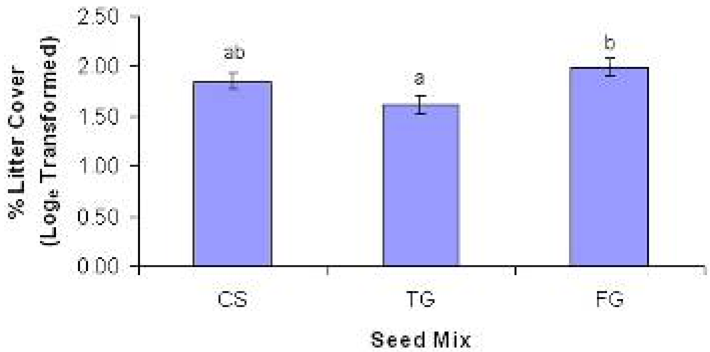


Figure 6.78. Percentage litter cover (± SE) at Boxworth in June across all years according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix).

A significant effect of sward treatment on values of litter cover was also determined in June ($F_{2,40.0} = 3.6$, $P < 0.05$). Pairwise comparisons determined that values were significantly lower in association with the graminicide treatment compared with cutting and scarification (Figure 6.79). The interaction between seed mix and year was not significant.

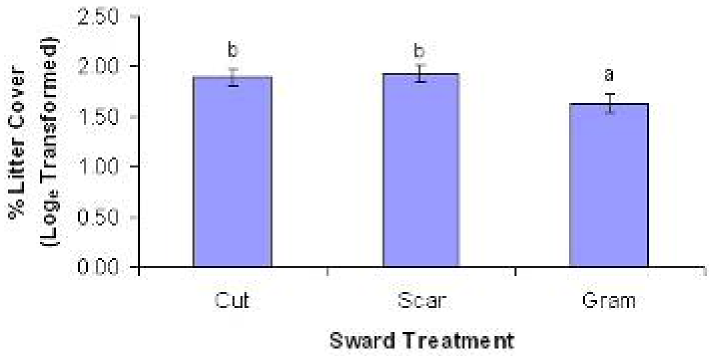


Figure 6.79. Percentage litter cover (± SE) at Boxworth in June across all years according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

In September, values of percentage litter cover were not affected significantly by seed mix or sward treatment. However, a significant year effect was determined ($F_{2,94.1}$ = 143.0, P < 0.001), with values decreasing significantly with time (Figure 6.80). The interactions between seed mix, sward treatment and year were not significant.

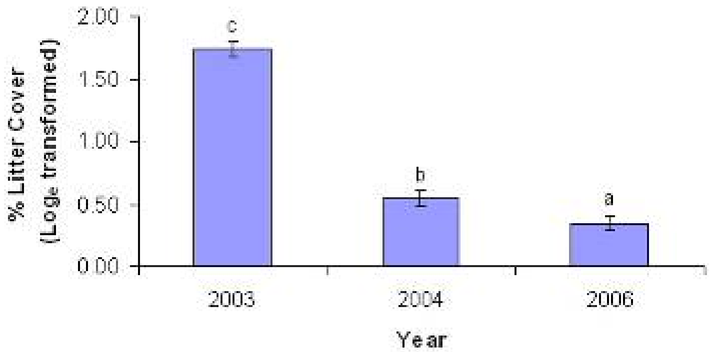


Figure 6.80. Percentage litter cover (± SE) at Boxworth in September depending on year. Values with same letter do not differ significantly (P > 0.05).

Gleadthorpe

No significant effects of seed mix, sward treatment and year were found for values of litter cover in June. Regardless of treatment and year, values ranged from 5.4 to 6.6% (inverse $\log_e$ transformed means). In September, year had a significant effect on values of litter cover ($F_{2,80.3}$ = 86.6, P < 0.001), being significantly greater in 2003 compared with subsequent years (Figure 6.81). Seed mix and sward treatment had no significant effect on values of litter cover. The interactions between these parameters and year were also not significant.

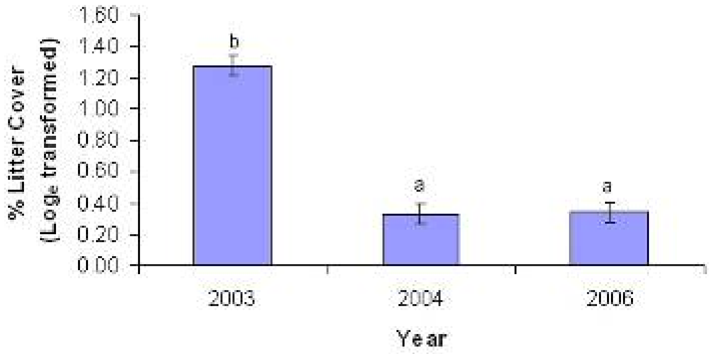


Figure 6.81. Percentage litter cover (± SE) at Gleadthorpe in September depending on year. Values with same letter do not differ significantly ($P > 0.05$).

High Mowthorpe

No significant effects of seed mix, sward treatment or year were found for values of litter cover recorded in June. Regardless of treatment and year, values ranged from 9.3 to 13.5% (inverse $\log_e$ transformed means). In September, a significant interaction between seed mix and year was determined $F_{4,77.5} = 3.3$, $P < 0.05$). Values of litter cover were greater in 2003, especially in plots sown with the TG mix (Figure 6.82).

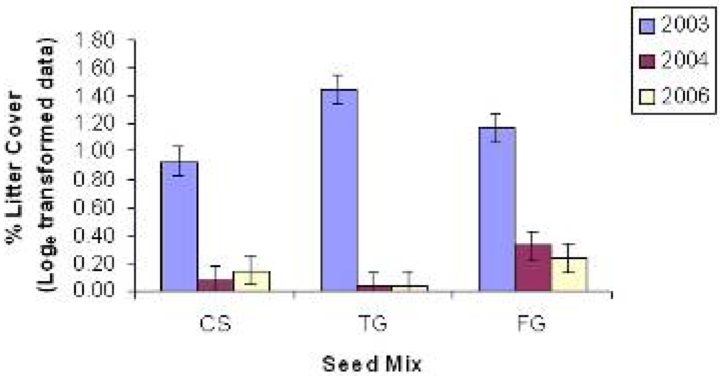


Figure 6.82. Percentage litter cover (± SE) at High Mowthorpe in September according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

6.3.2.7 Vegetation structure

Coarse grain - Establishment Year June and September 2002

Data for both sampling times did not meet the assumptions of normal distribution and equal variance so sites were analysed individually using the Kruskal-Wallis non-parametric method. However, no significant effect of seed mix was found for values of vegetation height at all sites in both June and September. At Boxworth and High Mowthorpe, values were lower in September compared with June (Figure 6.83 and Figure 6.84, respectively), whilst at Gleadthorpe, values were marginally greater in September (Figure 6.85).

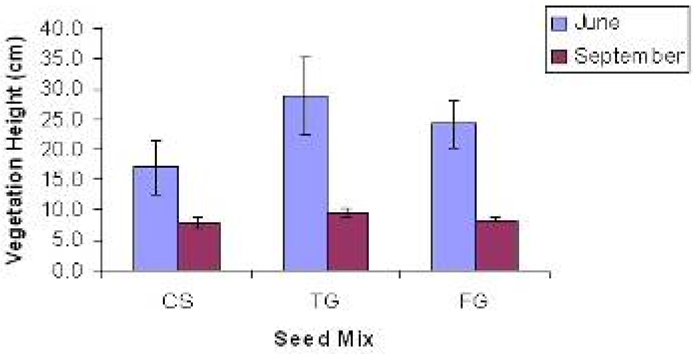


Figure 6.83. Vegetation height (cm) (± SE) at Boxworth in June and September 2002 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix).

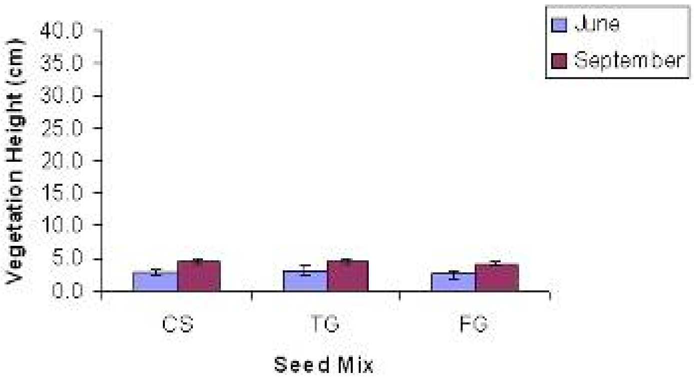


Figure 6.84. Vegetation height (cm) (± SE) at Gleadthorpe in June and September 2002 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix).

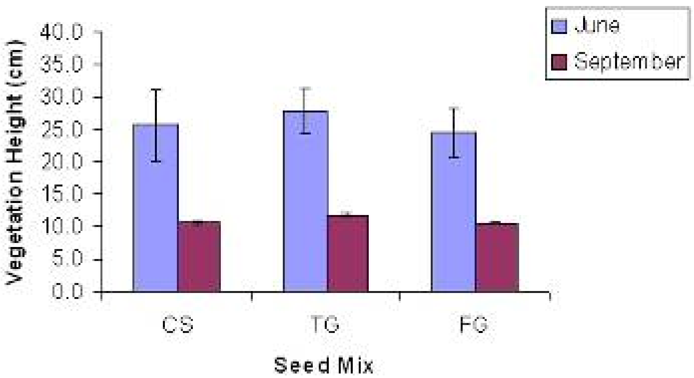


Figure 6.85. Vegetation height (cm) (± SE) at High Mowthorpe in June and September 2002 according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix).

Coarse grain - treatment responses (2003, 2004 & 2006)

Overall responses

June

Across all sites in June, seed mix type had no significant effect on values of coarse grain structure (vegetation height). The interaction between seed mix and year was also not significant. In contrast, significant effects of sward treatment ($F_{2,321.7}$ = 5.0, P < 0.01) and year ($F_{2,215.9}$ = 44.1, P < 0.001) were determined. Compared with scarification, vegetation height was significantly greater with cutting (Figure 6.86). The interaction between sward treatment and year was not significant.

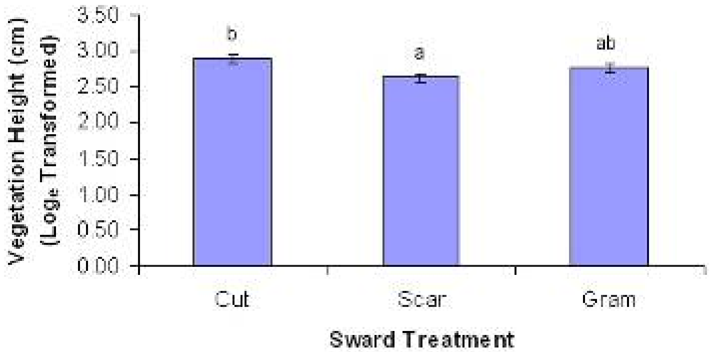


Figure 6.86. Vegetation height (cm) (± SE) ($\log_e$ transformed) across all sites in June according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly (P > 0.05).

The year effect indicated that values differed significantly between years and were greater in 2003 compared with 2004 and 2006 (Figure 6.87).

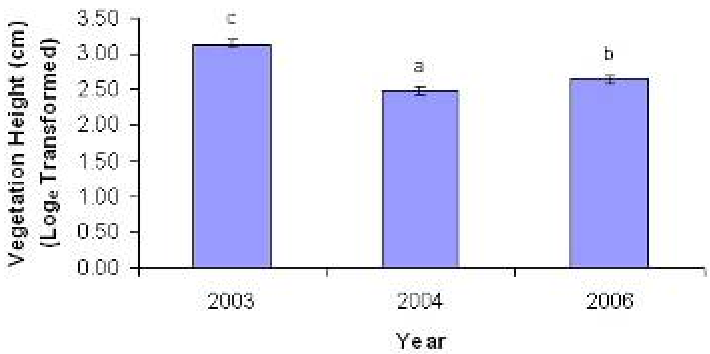


Figure 6.87. Vegetation height (cm) (± SE) ($\log_e$ transformed) across all sites in June according to year. Years with the same letter do not differ significantly (P > 0.05).

September

Seed mix was found to have a significant effect on values of vegetation height recorded in September ($F_{2,128.3}$ = 6.5, P < 0.01). Values were significantly lower in association with the FG mix (Figure 6.88).

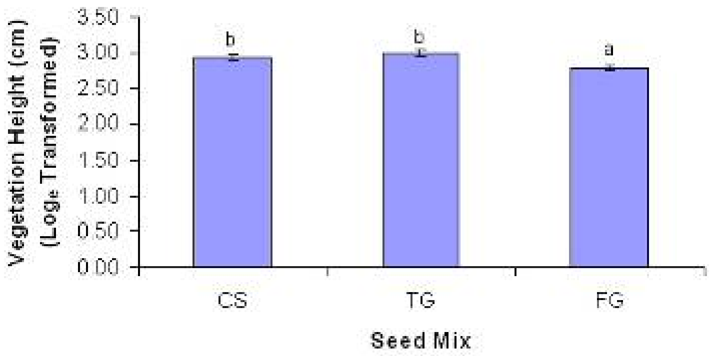


Figure 6.88. Vegetation height (cm) (± SE) across all sites in September according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (P > 0.05).

A significant interaction between sward treatment and year was determined ($F_{4,200.8}$ = 5.4, P < 0.001) (Figure 6.89).

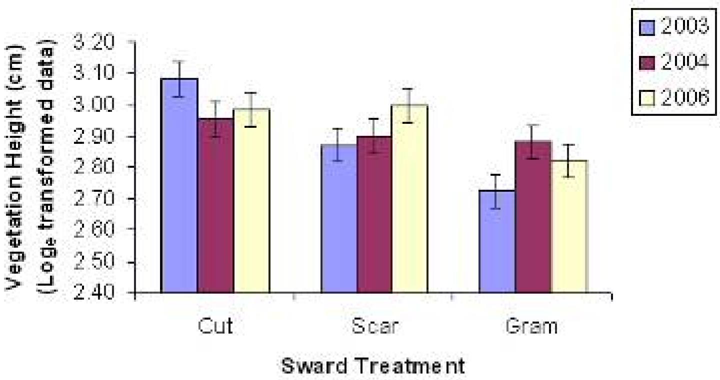


Figure 6.89. Vegetation height (cm) (± SE) (Log_e transformed) across all sites in September according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Individual site responses

Boxworth

June

No significant treatment effect of seed mix was found for values of vegetation height at Boxworth and interactions between year and sward treatment were also not significant. However, the interaction between sward treatment and year was significant ($F_{4,89.4} = 5.2$, $P < 0.01$) (Figure 6.90).

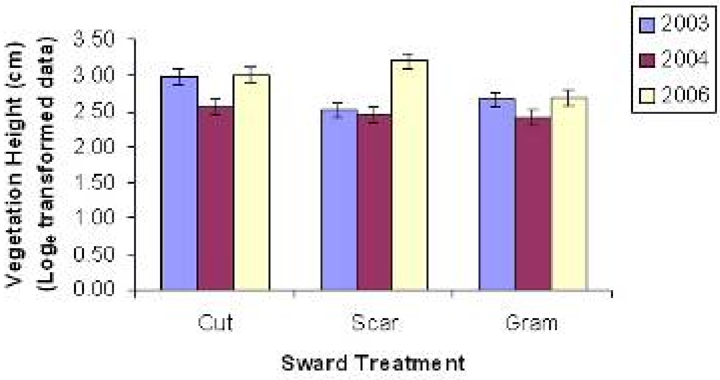


Figure 6.90. Vegetation height (cm) (± SE) ($\log_e$ transformed) at Boxworth in June according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

September

Across all years, seed mix had no significant effect on values of vegetation height recorded in September. The interaction between seed mix and year was also not significant. However, the interaction between sward treatment and year was significant ($F_{4,73.3} = 6.5$, $P < 0.001$). In association with cutting, vegetation height was greater in 2003. In contrast, values increased between years in association with scarification, but remained relatively constant in plots treated with graminicide (Figure 6.91).

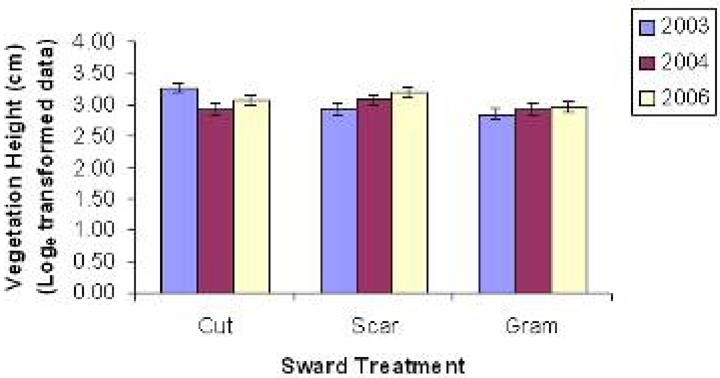


Figure 6.91. Vegetation height (cm) (± SE) ($\log_e$ transformed) at Boxworth in September according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Gleadthorpe

June

The treatment effects of seed mix and sward treatment were not significant. However, a significant year effect was determined ($F_{2,67.6} = 43.7$, $P < 0.001$), with a greater vegetation height in 2003 compared with subsequent years (Figure 6.92).

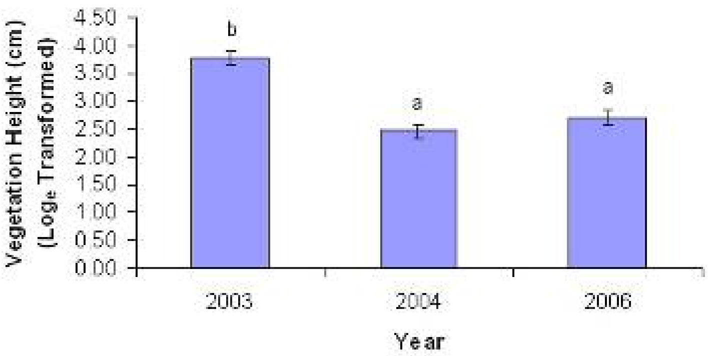


Figure 6.92. Vegetation height (cm) (± SE) (log_e transformed) at Gleadthorpe in June according to year. Years with the same letter do not differ significantly ($P > 0.05$).

September

Across all years, seed mix had no significant effect on vegetation height values recorded at Gleadthorpe in September. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,70.4} = 3.7$, $P < 0.01$). Overall, values were greater in 2006 compared with 2003 under all sward treatments (Figure 6.93).

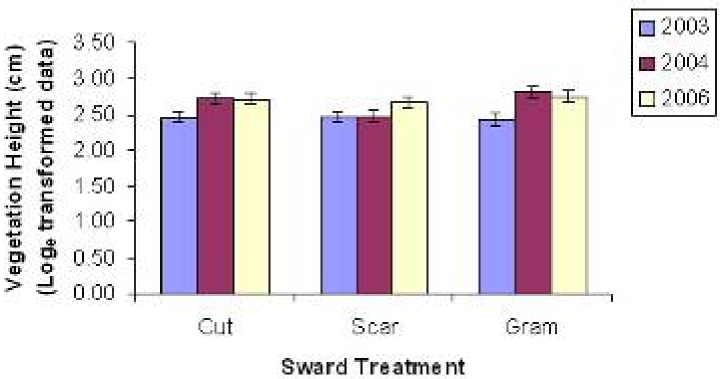


Figure 6.93. Vegetation height (cm) (± SE) (log_e transformed) at Gleadthorpe in September according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

High Mowthorpe

June

A significant interaction between seed mix and sward treatment was found for values of vegetation height in June ($F_{4,37.3}$ = 3.4, P < 0.05). Values were generally lower in association with scarification. Cutting was associated with the greatest values of vegetation height, especially in plots sown with the CS mix. However, a negligible difference was found between cutting and graminicide for plots sown with the FG mix (Figure 6.94).

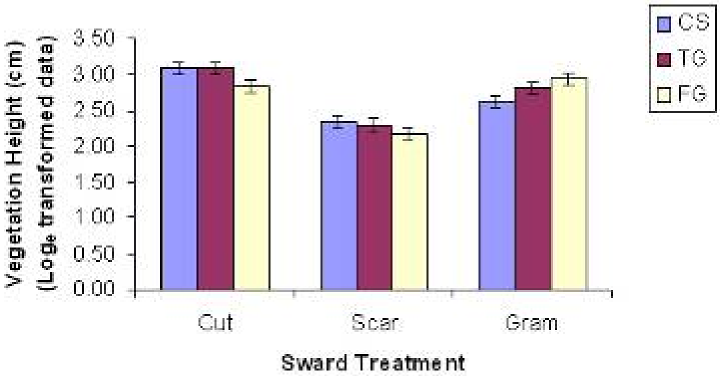


Figure 6.94. Vegetation height (cm) (± SE) (log_e transformed) at High Mowthorpe in June according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant interaction between seed mix and year was also determined ($F_{4,78.0}$ = 6.1, P < 0.001). Values decreased between years, but after an initial decrease in plots sown with the FG mix, values then remained constant (Figure 6.95).

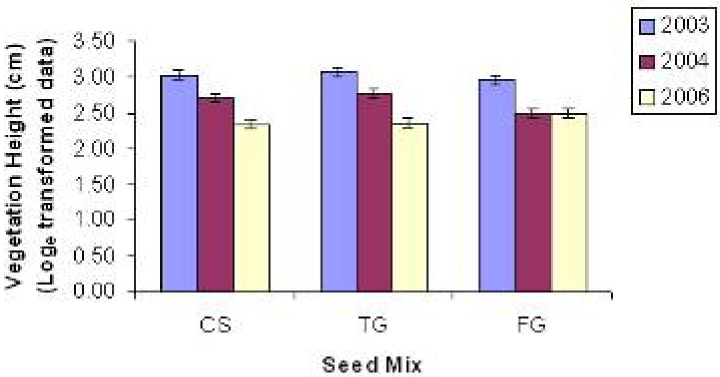


Figure 6.95. Vegetation height (cm) (± SE) (log_e transformed) at High Mowthorpe in June according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

The interaction between sward treatment and year was also significant ($F_{2,67.6} = 43.7$, $P < 0.001$). Vegetation height was observed to decrease between years and to a greater extent in plots treated with scarification (Figure 6.96).

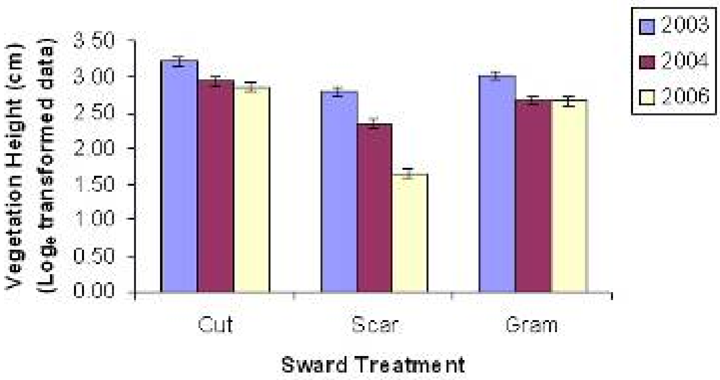


Figure 6.96. Vegetation height (cm) (± SE) ($\log_e$ transformed) at High Mowthorpe in June according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

September

Across all years, seed mix had a significant effect on values of vegetation height recorded ($F_{2,36.4} = 23.0$, $P < 0.001$). Values were significantly lower in association with plots sown with the FG mix (Figure 6.97). The interaction between seed mix and year was not significant.

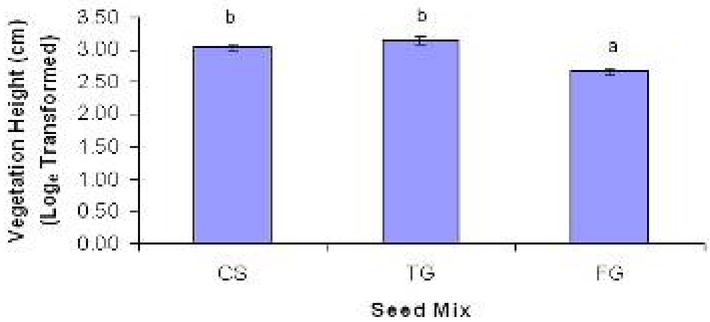


Figure 6.97. Vegetation height (cm) (± SE) ($\log_e$ transformed) at High Mowthorpe in September according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mix treatments with the same letter do not differ significantly (P > 0.05).

A significant interaction was found between sward treatment and year ($F_{4,61.1} = 3.1$, $P < 0.05$). Values decreased between years in association with cutting, but remained relatively constant in plots treated with scarification or graminicide (Figure 6.98).

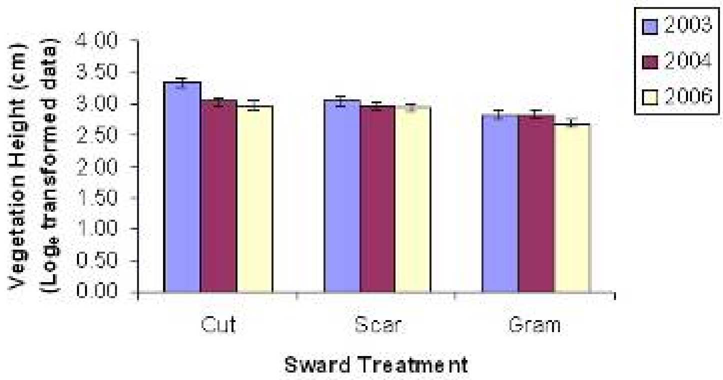


Figure 6.98. Vegetation height (cm) (± SE) ($\log_e$ transformed) at High Mowthorpe in September according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Fine grain - treatment responses June (2003, 2004 & 2006)

Architectural complexity was characterised for six functional groups: 1) dead litter, 2) fine grasses, 3) tussock grasses, 4) other grasses, 5) leguminous forbs and 6) non-leguminous forbs, and "total architectural complexity" (all components combined).

Overall responses

For values of dead litter architectural complexity, a significant interaction between seed mix, sward treatment and year was determined ($F_{12,204.7} = 1.9$, $P < 0.05$). Values were negligible in 2003, and in general, increased by 2004/2006. Scarification was associated with low values across all seed mixes, but FG plots treated with graminicide also had low values of dead litter architectural complexity (Figure 6.99).

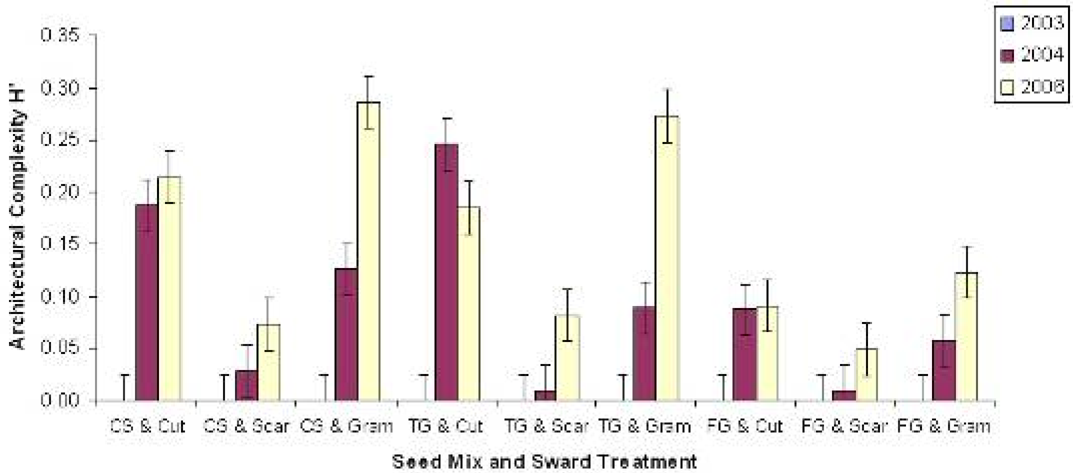


Figure 6.99. Architectural complexity (Shannon-Wiener diversity H') of the dead litter component (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Architectural complexity of the fine grass component varied with seed mix and sward treatment. There was significant interaction between these two factors ($F_{4,143.4}$ = 3.4, P < 0.05). In scarified plots, values were consistently lower for all seed mixes, than in plots of other treatments. The greatest values of fine grass architectural complexity were found in plots sown with the FG mix (Figure 6.100).

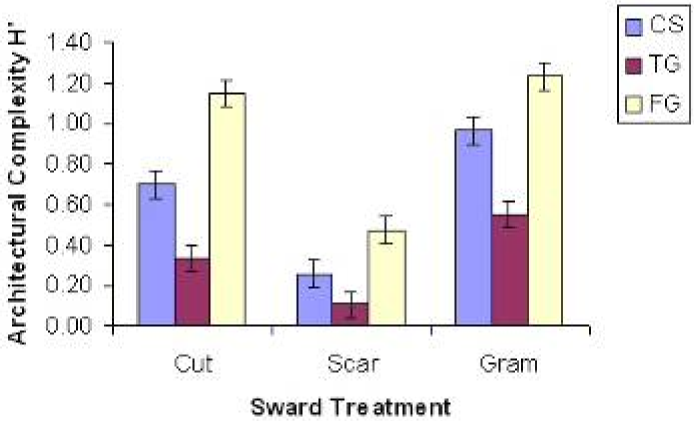


Figure 6.100. Architectural complexity (Shannon-Wiener diversity H') of the fine grass component (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix).

A significant interaction between seed mix and year was also determined ($F_{4,258.2}$ = 4.2, P < 0.01). Values decreased between years in plots sown with the CS and FG seed mixes. However, in the TG plots, values peaked in 2004 (Figure 6.101).

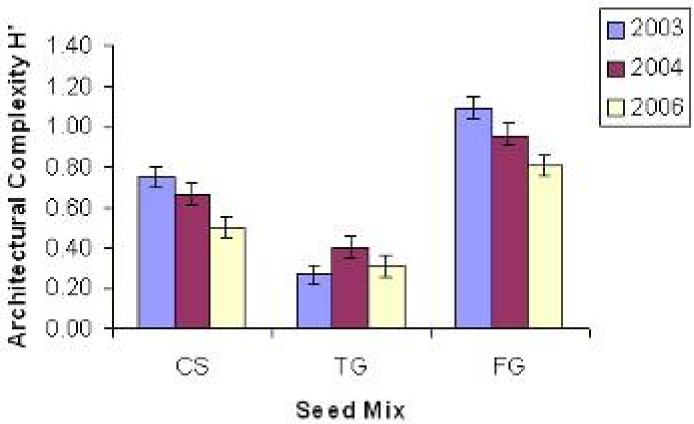


Figure 6.101. Architectural complexity (Shannon-Wiener diversity H') of the fine grass component (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined ($F_{4,258.2} = 5.7$, $P < 0.001$). Values decreased between years in scarified plots, but remained fairly constant in the graminicide treatment. In the cut plots, values decreased after 2004 (Figure 6.102).

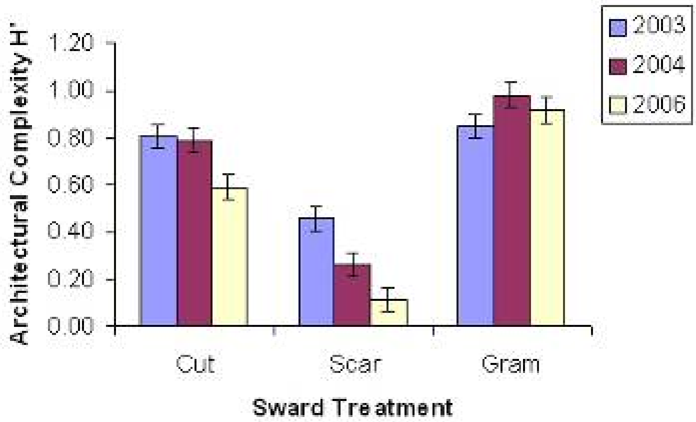


Figure 6.102. Architectural complexity (Shannon-Wiener diversity H') of the fine grass component (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for the architectural complexity of the "other grass" component ($F_{4,241.2} = 3.6$, $P < 0.01$). Responses were observed to vary considerably between and within seed mixes (Figure 6.103).

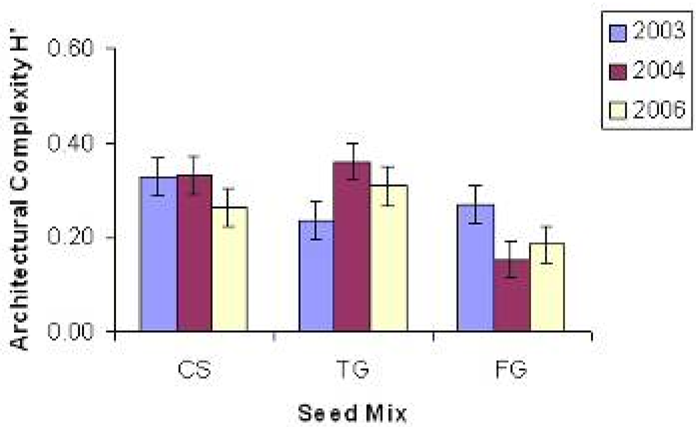


Figure 6.103. Architectural complexity (Shannon-Wiener diversity H') of the other grass component (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined ($F_{4,241.2}$ = 3.6, P < 0.01). In association with all treatments, the architectural complexity of the “other grass” component decreased between years and by 2006 values were lowest with graminicide (Figure 6.104).

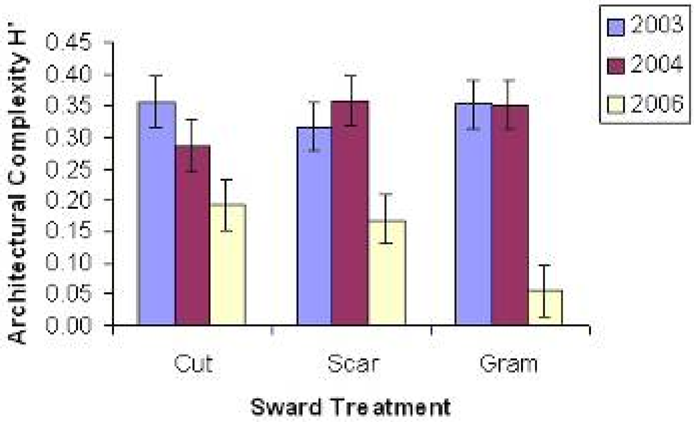


Figure 6.104. Architectural complexity (Shannon-Wiener diversity H’) of the other grass component (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and sward treatment was determined for values of tussock grass architectural complexity ($F_{4,155.5}$ = 3.6, P < 0.01). Values were negligible in plots sown with the FG mix. Under all sward treatments values in plots sown with the CS and TG mixes were similar. The greatest architectural complexity was found in association with cutting (Figure 6.105).

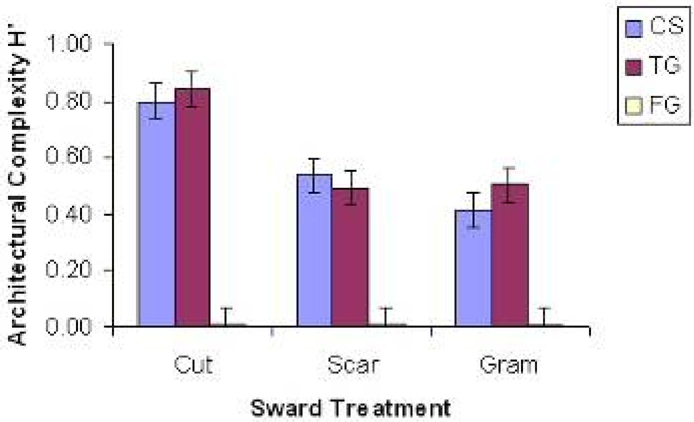


Figure 6.105. Architectural complexity (Shannon-Wiener diversity H’) of the tussock grass component (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was also determined ($F_{4,275.3}$ = 8.4, P < 0.001). Values were negligible in association with the FG mix across all years of study. In association with plots sown with the CS and TG mixes, values of tussock grass architectural complexity followed the same pattern, having similar values in 2003 and 2004, which then decreased by 2006 (Figure 6.106).

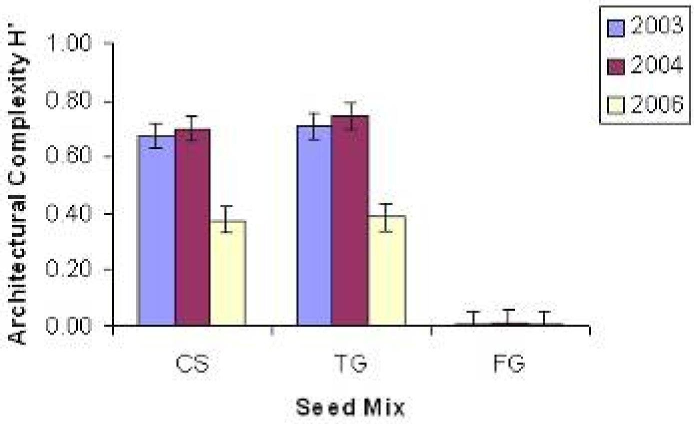


Figure 6.106. Architectural complexity (Shannon-Wiener diversity H') of the tussock grass component (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between seed mix and year was determined for values of legume architectural complexity ($F_{4,255.3}$ = 5.2, P = 0.01). Values were very low for the legume component, but were observed to increase between years in association with the FG mix. In plots sown with the TG mix, values increased from 2003, but decreased by 2006. Values remained negligible in association with the CS mix (Figure 6.107). Sward treatment had no significant effect.

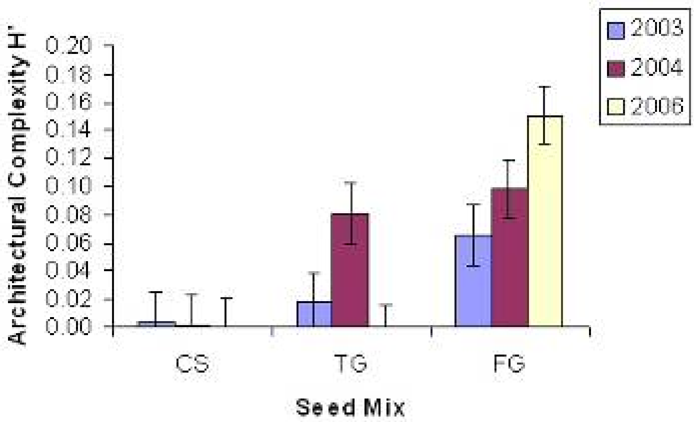


Figure 6.107. Architectural complexity (Shannon-Wiener diversity H') of the legume component (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between seed mix and year was determined for values of non-leguminous forb architectural complexity ($F_{4,202.1}$ = 2.7, P < 0.05). Values increased between years in plots sown with the CS mix, but peaked in 2004 in association with the TG and FG mixes (Figure 6.108). Overall, values of non-leguminous forb architectural complexity were greater in plots sown with the FG mix.

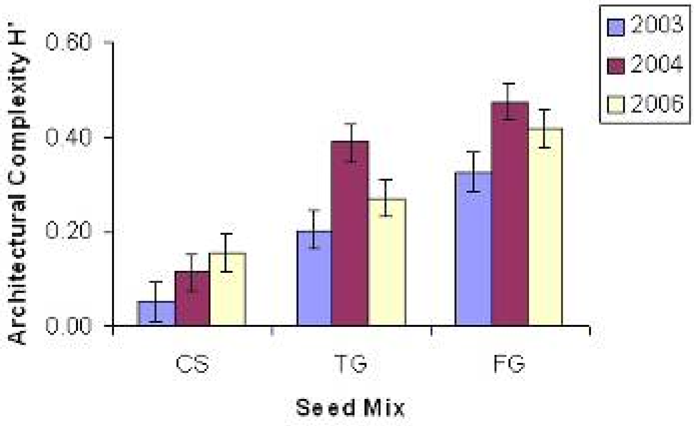


Figure 6.108. Architectural complexity (Shannon-Wiener diversity H') of the non-leguminous forb component (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined for values of non-leguminous forb architectural complexity ($F_{4,202.1}$ = 3.8, P < 0.01). Values of complexity increased between years in association with graminicide, but to a greater extent with scarification. In contrast, values remained relatively constant in plots that were cut (Figure 6.109).

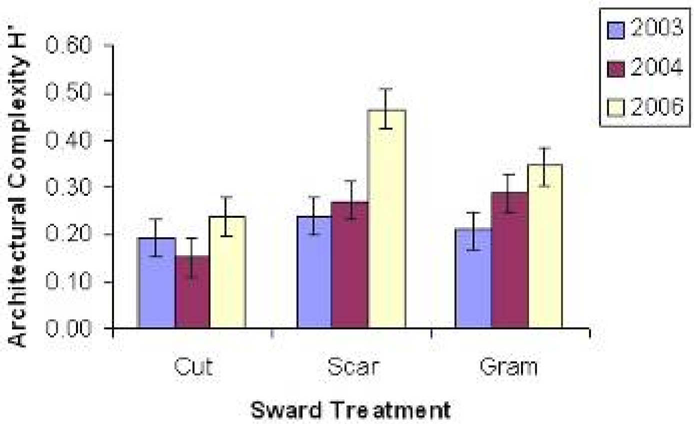


Figure 6.109. Architectural complexity (Shannon-Wiener diversity H') of the non-leguminous forb component (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for values of total architectural complexity ($F_{4,237.8} = 4.6$, $P = 0.001$). In plots sown with the FG mix, values remained relatively constant between years, whilst in association with the CS and TG plots, values reached a maximum architectural complexity in 2004 (Figure 6.110).

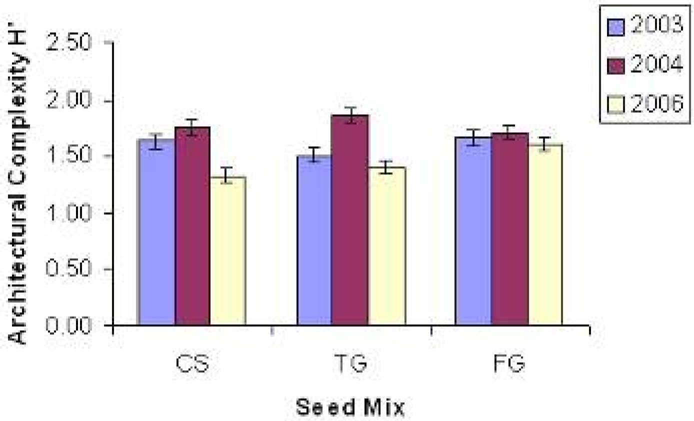


Figure 6.110. Total architectural complexity (Shannon-Wiener diversity H') (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant sward treatment effect was also determined ($F_{2,126.5} = 29.4$, $P < 0.001$). Values of total architectural complexity were significantly lower in plots treated with scarification ($P < 0.05$) and no difference was found between cutting and graminicide (Figure 6.111).

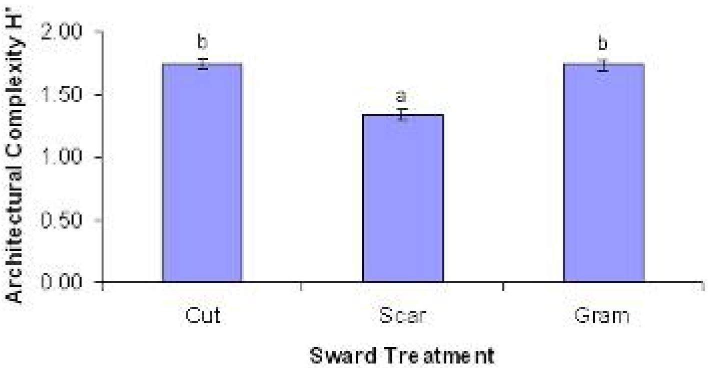


Figure 6.111. Total architectural complexity (Shannon-Wiener diversity H') (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

Individual site responses

Boxworth

A significant interaction between seed mix and year was determined for values of dead litter architectural complexity ($F_{4,68.9}$ = 3.5, $P < 0.05$). Values were observed to increase between years and were greater in association with the CS mix by 2006 (Figure 6.112).

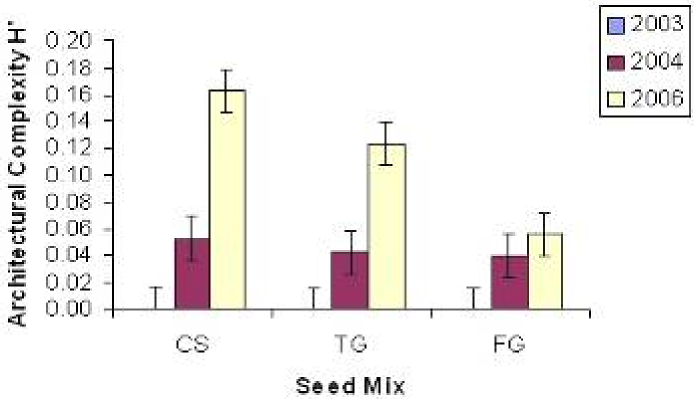


Figure 6.112. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the dead litter component at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined for values of dead litter architectural complexity ($F_{4,68.9}$ = 4.8, $P < 0.01$). Values increased between years and were consistently lower in plots treated with scarification (Figure 6.113).

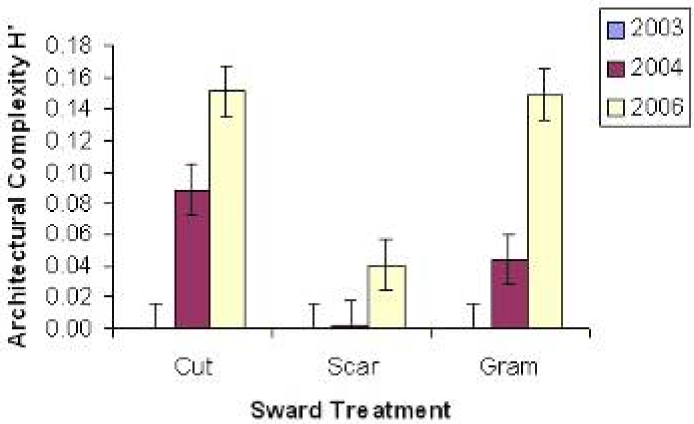


Figure 6.113. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the dead litter component at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and sward treatment was determined for values of dead litter architectural complexity ($F_{4,47.0}$ = 10.8, P < 0.001). Values of complexity were consistently lower in association with scarification. The greatest values were associated with the FG mix (Figure 6.114).

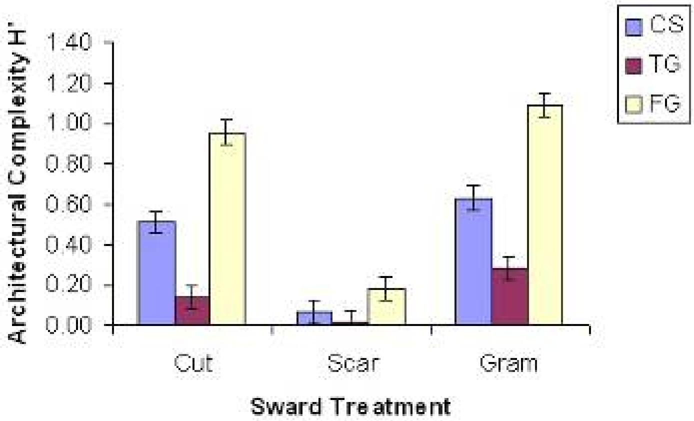


Figure 6.114. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the dead litter component at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant interaction between seed mix by year was also determined ($F_{4,87.7}$ = 3.9, P < 0.01). Values remained constantly lower in plots sown with the TG mix during all years. In contrast, values decreased between years in plots sown with the CS and FG mixes. Values were always greater in the FG plots (Figure 6.115).

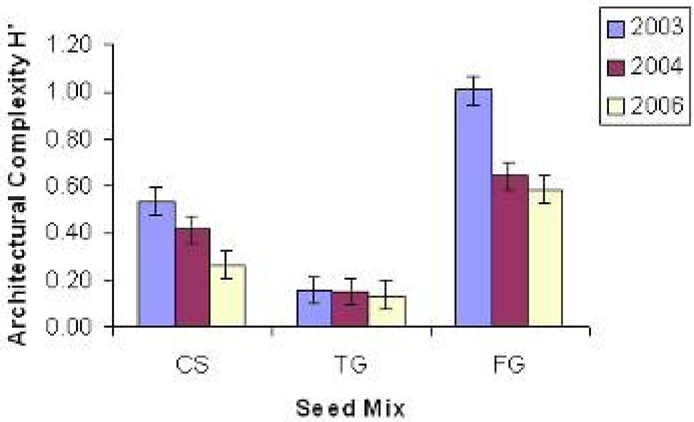


Figure 6.115. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the fine grass component at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Seed mix had no significant effect on values of other grass architectural complexity. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,80.0} = 3.6$, $P < 0.01$). In plots that were cut or treated with graminicide, values of complexity remained relatively constant between years. However, values with scarification, values were observed to increase from 2003 to 2004. In all years, values were substantially lower in plots treated with graminicide (Figure 6.116).

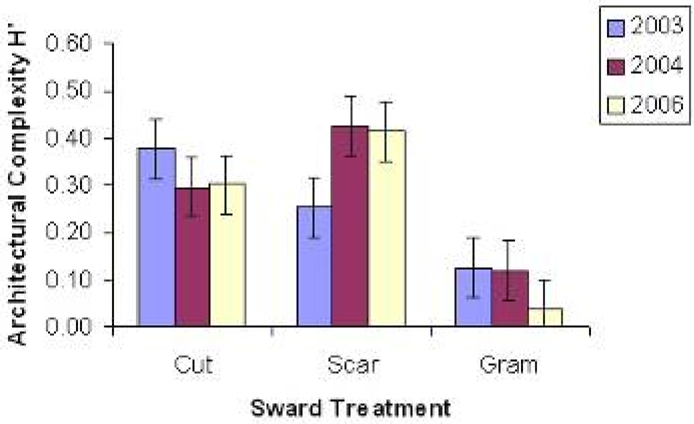


Figure 6.116. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the other grass component at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

The interaction between seed mix and year for values of tussock grass architectural complexity was marginally significant ($F_{4,75.9} = 2.5$, $P = 0.051$). Individually, seed mix and year both had strong significant effects ($F_{2,37.7} = 22.4$, $P < 0.001$ and $F_{2,75.9} = 6.0$, $P < 0.01$, respectively). With respect to seed mix, values were significantly greater in plots sown with the CS and TG mixes compared with the FG mix ($P < 0.05$) (Figure 6.117). Architectural complexity of the tussock grass component remained constant during 2003 and 2004, but decreased significantly in 2006 ($P < 0.05$) (Figure 6.118).

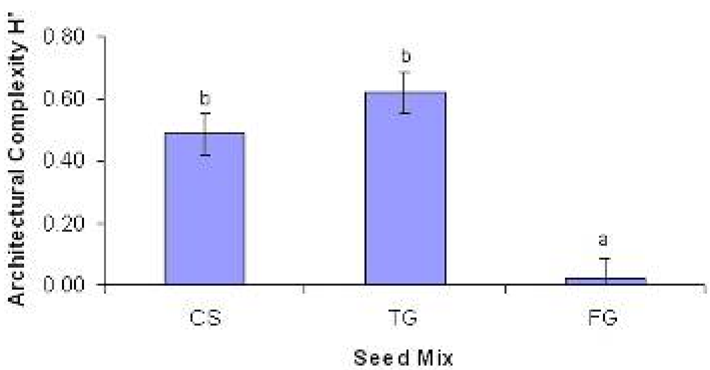


Figure 6.117. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the tussock grass component at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes with the same letter do not differ significantly ($P > 0.05$).

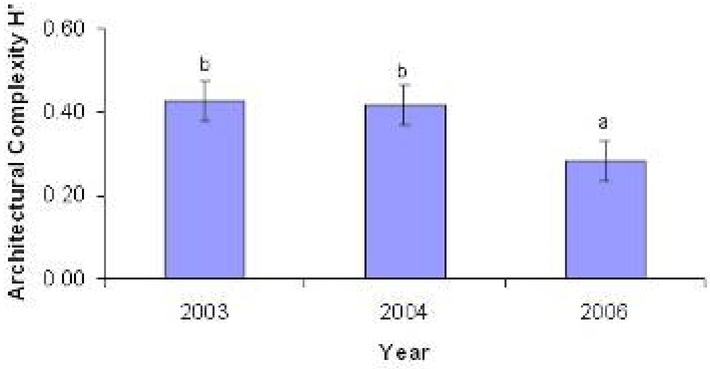


Figure 6.118. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the tussock grass component at Boxworth according to year. Years with the same letter do not differ significantly ($P > 0.05$).

Sward treatment also had a significant effect on values of tussock grass architectural complexity ($F_{2,37.9} = 7.2$, $P < 0.01$). Values were significantly greater in plots that were cut ($P < 0.05$). No significant difference was found between the treatments of scarification and graminicide (Figure 6.119).

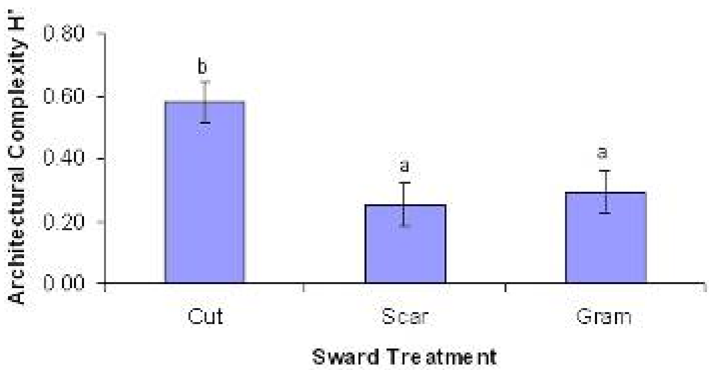


Figure 6.119. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the tussock grass component at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between seed mix and year was determined for values of legume architectural complexity ($F_{4,68.6} = 3.0$, $P < 0.05$). Values of complexity were negligible for all seed mixes, especially CS and TG. The greatest value of architectural complexity was observed in 2006, in plots sown with the FG mix (Figure 6.120). Sward treatment had no significant effect on values of legume architectural complexity.

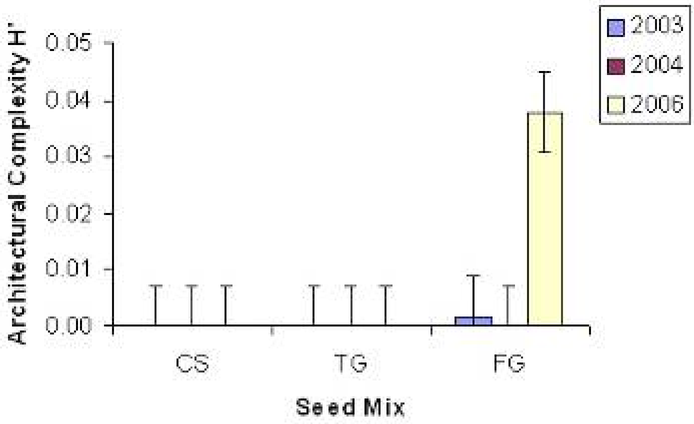


Figure 6.120. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the legume component at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant effect of seed mix was determined for values of non-leguminous forb architectural complexity ($F_{2,45.0} = 6.3$, $P < 0.01$). Values were significantly greater in plots sown with the FG mix, compared with the CS mix ($P < 0.05$). No difference was found between the FG and TG mixes, or between the CS and TG mixes (Figure 6.121).

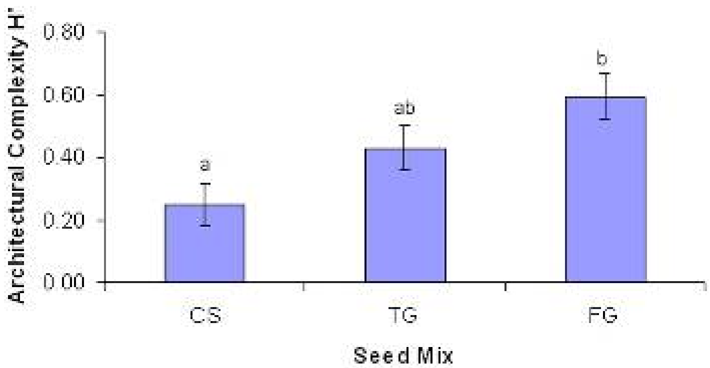


Figure 6.121. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the non-leguminous component at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was also determined ($F_{2,84.8} = 5.5$, $P = 0.001$). In 2003, values were lower in association with scarification and greatest in plots treated with graminicide. However, with time, values increased in plots treated with scarification and by 2006, values were greater in association with this treatment (Figure 6.122).

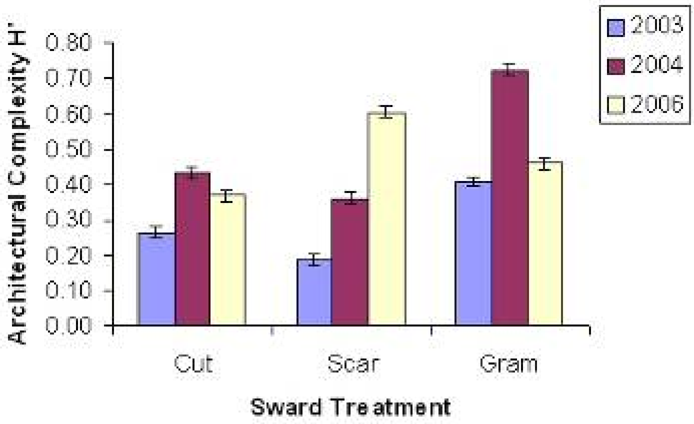


Figure 6.122. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the non-leguminous forb component at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

No significant effect of seed mix was found for total values of architectural complexity. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,71.4} = 6.0$, $P < 0.001$). In 2003 and 2004 values were consistently lower in association with scarification. However, in 2006, values decreased in plots treated with cutting and graminicide and the treatments had similar architectural complexity values (Figure 6.123).

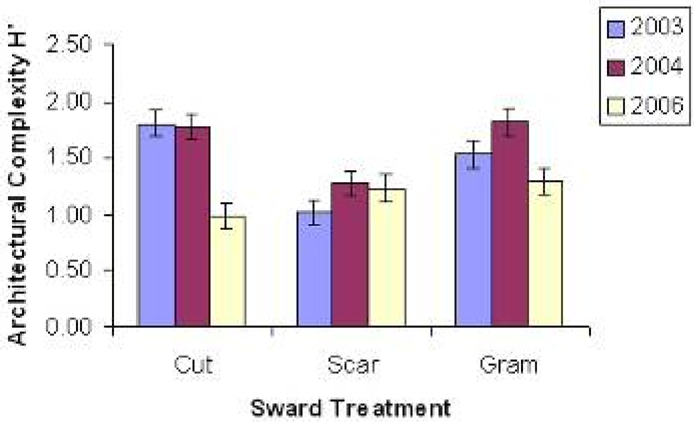


Figure 6.123. Total values of architectural complexity (Shannon-Wiener diversity H') (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Gleadthorpe

Seed mix had no significant effect on values of dead litter architectural complexity. In contrast, a significant interaction between sward treatment and year was determined

($F_{4,89.0}$ = 4.3, $P < 0.01$). Values of architectural complexity were highly variable between treatments and years, but all were negligible in 2003 (Figure 6.124).

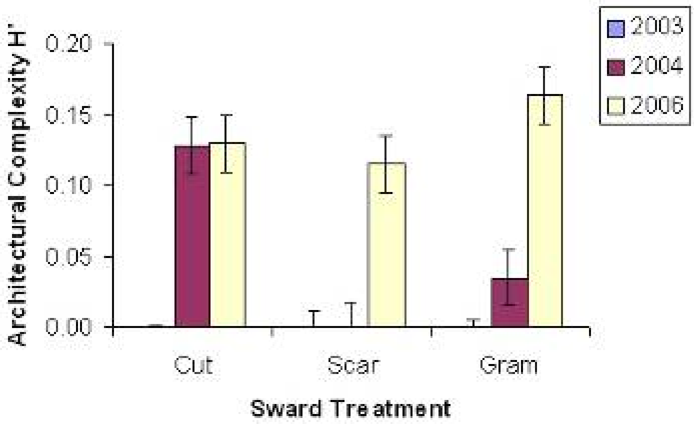


Figure 6.124. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the dead litter component at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for values of fine grass architectural complexity ($F_{2,41.4}$ = 27.7, $P < 0.001$). Values were significantly lower in plots sown with the TG mix ($P < 0.05$) and no difference was found between the CS and FG mixes (Figure 6.125).

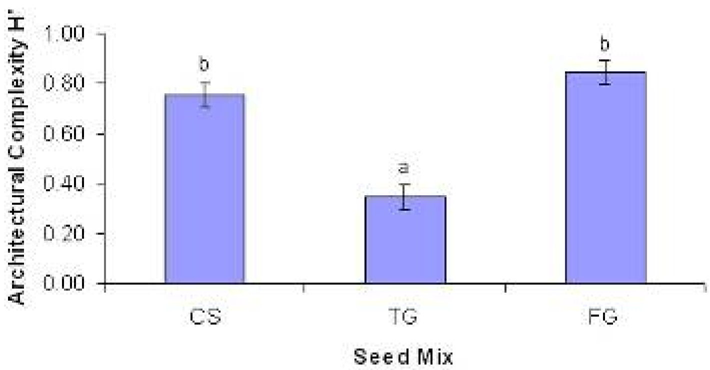


Figure 6.125. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the fine grass component at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was also determined ($F_{4,66.4}$ = 9.1, $P < 0.001$). Values in 2003 were similar between treatments, but decreased thereafter in scarified plots. In contrast, values of fine grass architectural complexity increased between years in plots that were either cut or treated with graminicide, and to a greater extent with graminicide (Figure 6.126).

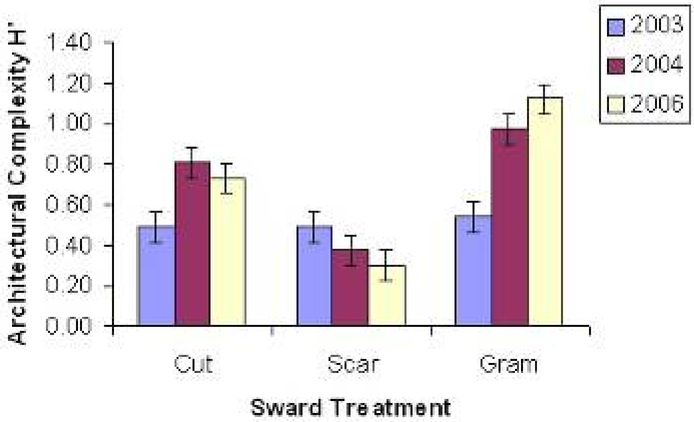


Figure 6.126. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the fine grass component at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for values of other grass architectural complexity ($F_{4,78.1} = 3.8$, $P < 0.01$). In plots sown with the CS or FG mix, values of other grass architectural complexity remained relatively constant across all years. In contrast, values were observed to increase in the TG plots after 2003 and were similar for 2004 and 2006 (Figure 6.127).

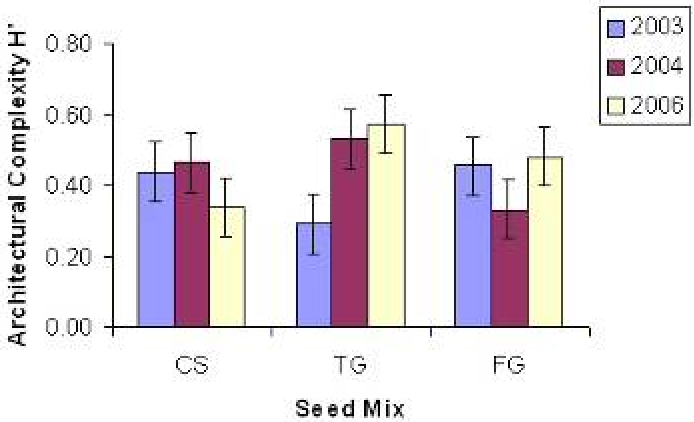


Figure 6.127. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the other grass component at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

There was a significant interaction between sward treatment and year for other grass architectural complexity ($F_{4,78.1}$ = 2.7, $P < 0.05$). Values were consistently lower in plots that were treated with graminicide, whilst in association with cutting and scarification, values increased between 2003 and 2006 (Figure 6.128).

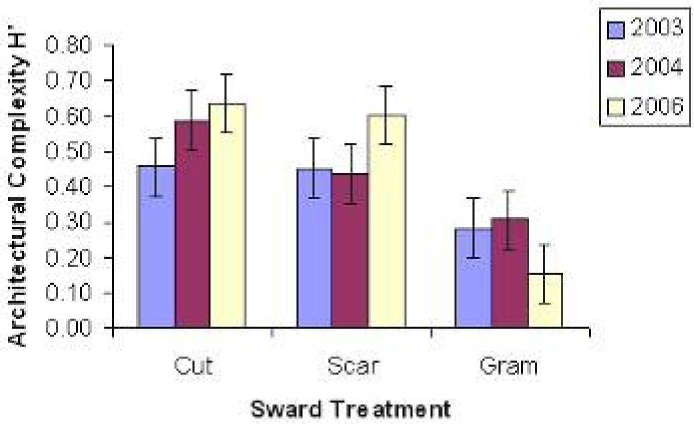


Figure 6.128. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the other grass component at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for values of tussock grass architectural complexity ($F_{2,38.6}$ = 28.0, $P < 0.001$). Values were significantly lower in plots sown with the FG mix ($P < 0.05$), and no difference was found between the CS and TG mixes (Figure 6.129). Interactions with seed mix and the other model parameters were not significant. No significant effect of sward treatment was determined.

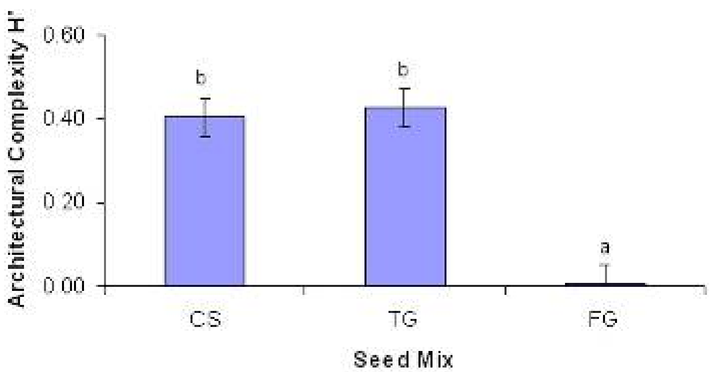


Figure 6.129. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the tussock grass component at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes with the same letter do not differ significantly ($P > 0.05$).

A significant year effect for values of tussock grass architectural complexity was found ($F_{2,80.3} = 5.5$, $P < 0.01$). Values were significantly greater in 2003 and 2004 compared with 2006 ($P < 0.05$) and no difference was found between values in 2003 and 2004 (Figure 6.130).

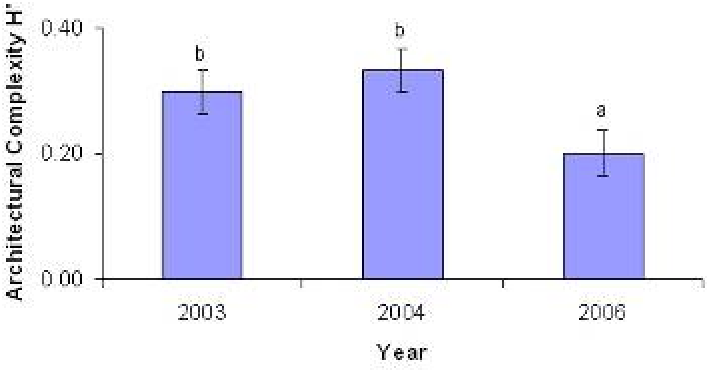


Figure 6.130. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the tussock grass component at Gleadthorpe according to year. Years with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between seed mix and year was determined for values of legume architectural complexity ($F_{4,89.7} = 4.0$, $P < 0.01$). Values were negligible in plots sown with the CS mix and overall, greater in association with the FG mix, increasing between years. In plots sown with the TG mix, values peaked in 2004 (Figure 6.131). Sward treatment had no significant effect on values of legume architectural complexity.

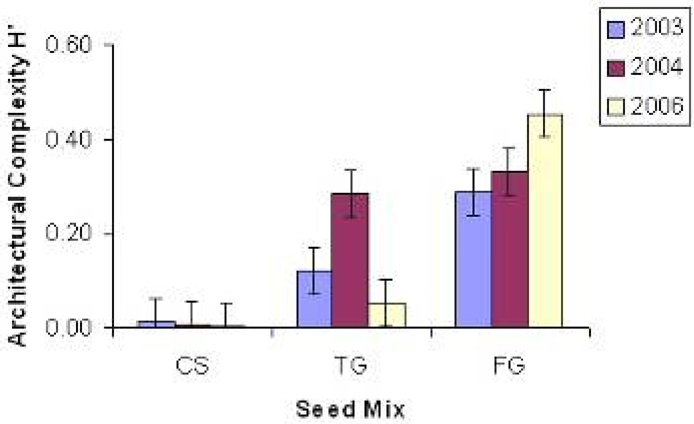


Figure 6.131. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the legume component at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant effect of seed mix was determined for values of non-leguminous forb architectural complexity ($F_{2,40.0} = 16.1$, $P < 0.001$). The greatest architectural complexity was in plots sown with the FG mix ($P < 0.05$), which was significantly greater than with the TG mix, which in turn was significantly greater than with the CS mix (Figure 6.132).

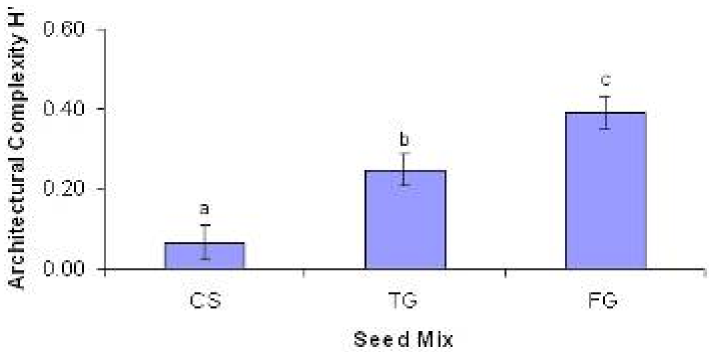


Figure 6.132. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the non-leguminous forb component at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mixes with the same letter do not differ significantly ($P > 0.05$).

A significant effect of year on values of non-leguminous forb architectural complexity was also determined ($F_{2,65.1} = 5.3$, $P < 0.01$). Values were significantly lower in 2003 ($P < 0.05$) and no difference was found in architectural complexity between 2004 and 2006 (Figure 6.133).

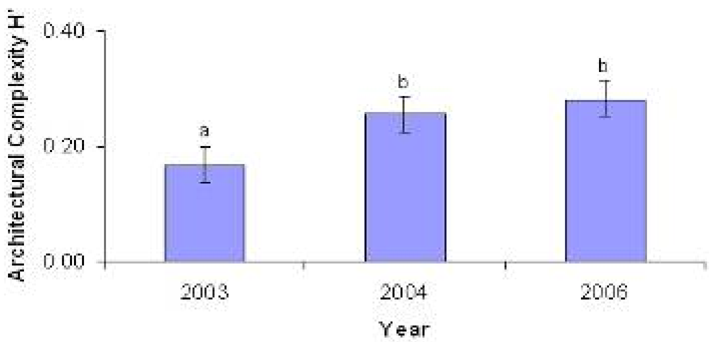


Figure 6.133. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the non-leguminous forb component at Gleadthorpe according to year. Years with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between seed mix and year was determined for values of total architectural complexity ($F_{4,79.7} = 3.2$, $P < 0.05$). Relative to 2003, values were greater in 2004/2006 for all seed mixes and by 2006 were greater in plots sown with the FG mix (Figure 6.134).

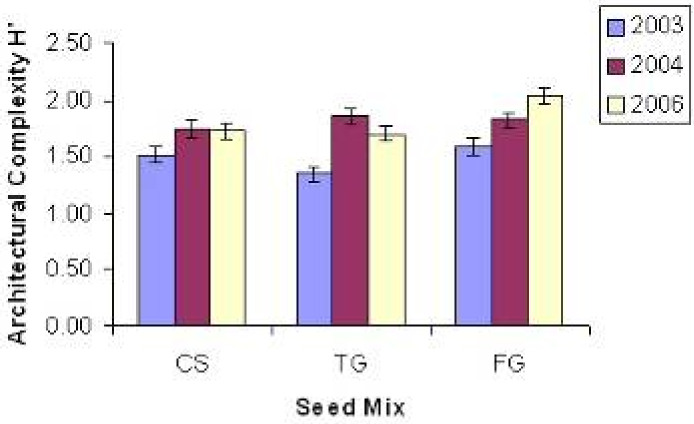


Figure 6.134. Total architectural complexity (Shannon-Wiener diversity H') (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined for values of total architectural complexity ($F_{4,79.7}$ = 3.6, P < 0.01). In 2003, values of complexity were similar across all treatments. Values increased between years under all treatments, but to a greater extent in plots that were cut or treated with graminicide (Figure 6.135).

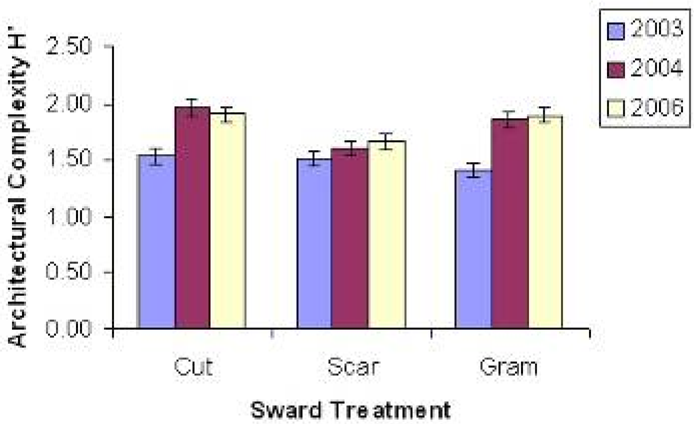


Figure 6.135. Total architectural complexity (Shannon-Wiener diversity H') (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

High Mowthorpe

A significant interaction between seed mix and sward treatment was determined for values of dead litter architectural complexity ($F_{4,55.4}$ = 4.9, P < 0.01). For all seed mixes, values of complexity were consistently lower in plots that were scarified. The cutting treatment promoted the greatest dead litter architectural complexity in the TG plots, while plots sown with the CS mix had the greatest architectural complexity in plots treated with graminicide (Figure 6.136).

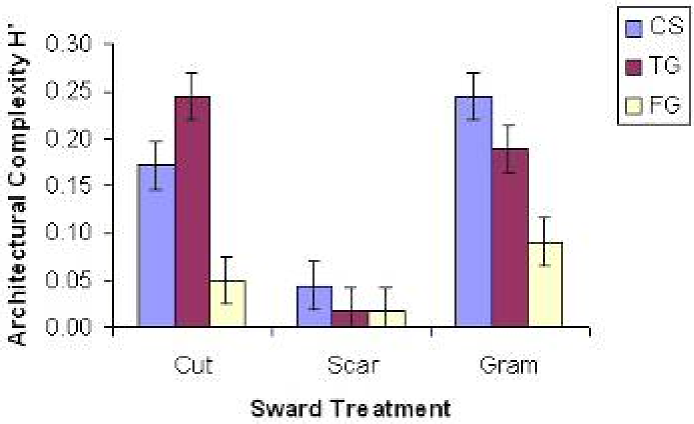


Figure 6.136. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the dead litter component at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant interaction between seed mix and year was also determined for values of dead litter architectural complexity ($F_{4,88.1}$ = 4.6, $P < 0.01$). Values were negligible in 2003, but increased with all seed mixes in 2004/2006. Values were similar in the CS and TG mixes and much lower in plots sown with the FG mix (Figure 6.137).

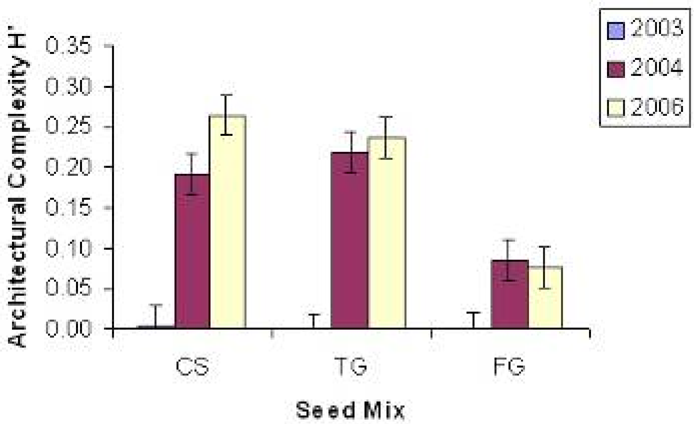


Figure 6.137. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the dead litter component at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was determined for values of dead litter architectural complexity ($F_{4,88.1}$ = 16.0, P < 0.001).Values were negligible for all treatments in 2003 and remained relatively low in plots treated with scarification. Values of dead litter architectural complexity increased between 2004 and 2006, but decreased over the same time period in plots that were cut (Figure 6.138).

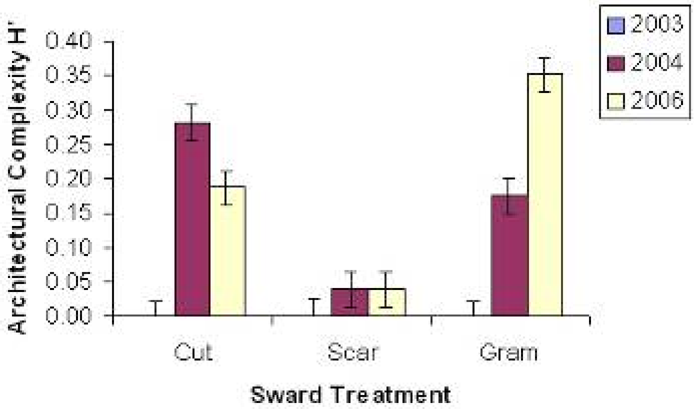


Figure 6.138. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the dead litter component at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix, sward treatment and year was determined for values of fine grass architectural complexity ($F_{12,36.7}$ = 3.0, P < 0.01). Overall, values of complexity were greatest in plots sown with the FG mix that were also cut or treated with graminicide. By 2006, values in plots treated with scarification were negligible, irrespective of seed mix (Figure 6.139).

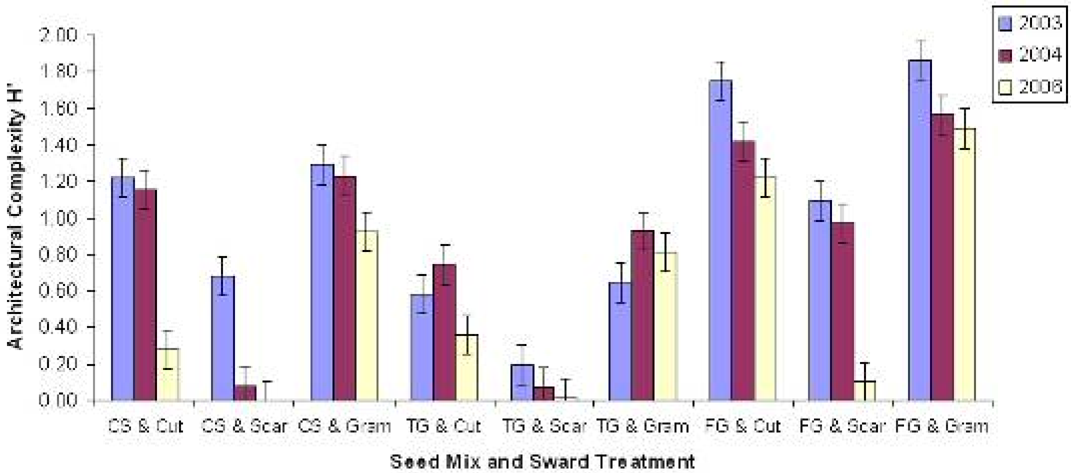


Figure 6.139. Architectural complexity (Shannon-Wiener diversity H') of the fine grass component (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

As with the fine grass component, there was a significant interaction between seed mix, sward treatment and year for other grass architectural complexity ($F_{12,46.8}$ = 2.5, P < 0.05). For the FG mix, values decreased dramatically from 2003 to 2004, especially in cut plots, but for cut, TG plots, they increased. Graminicide treatment was associated with a decrease in values for all seed mixes, whilst the response to scarification was varied for seed mixes and years (Figure 6.140).

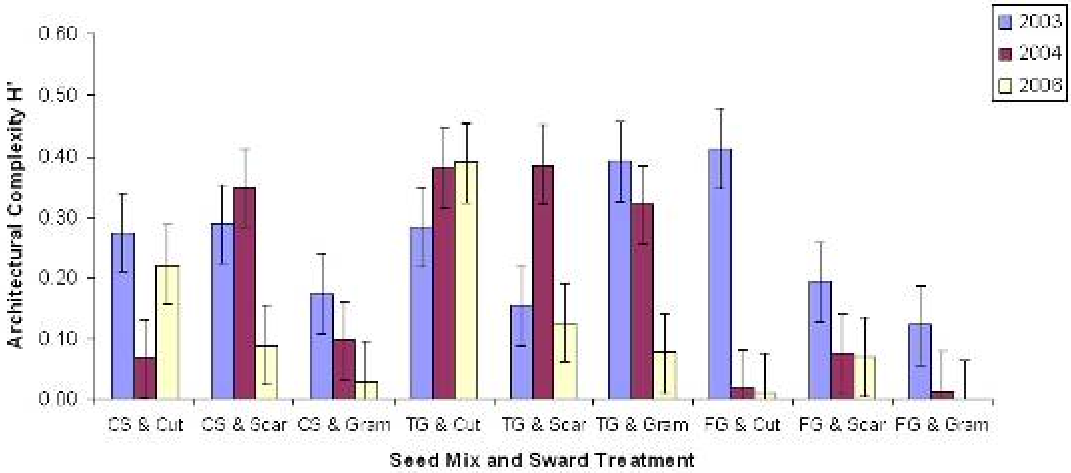


Figure 6.140. Architectural complexity (Shannon-Wiener diversity H') of the other grass component (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix, sward treatment and year was also determined for values of tussock grass architectural complexity ($F_{8,57.7}$ = 2.4, P < 0.05). Values were negligible across all years and sward treatments in plots that were sown with the FG mix. By 2006, values had decreased substantially in the CS and TG plots that received scarification. Overall, values were greatest in plots that were cut (Figure 6.141).

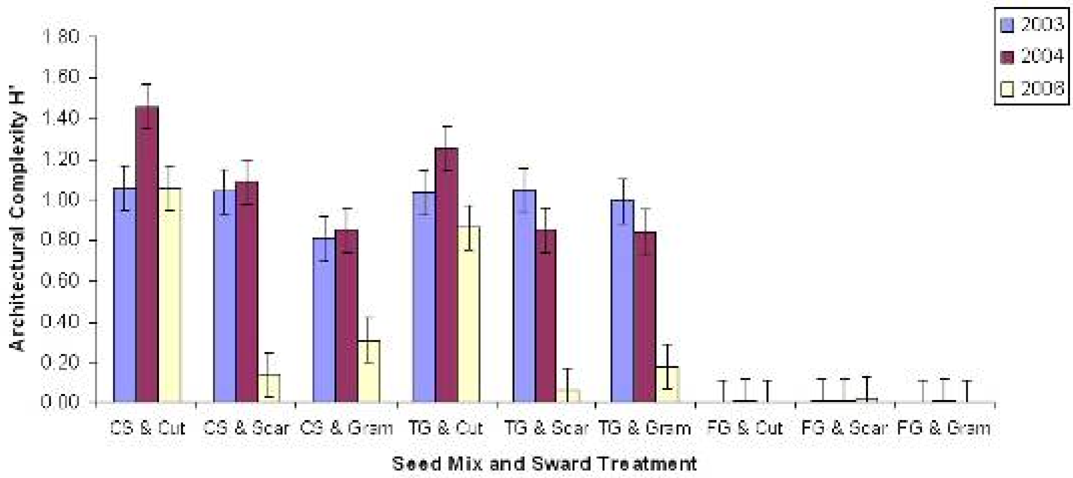


Figure 6.141. Architectural complexity (Shannon-Wiener diversity H') of the tussock grass component (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring graminicide application) and year.

A significant interaction between seed mix and sward treatment was determined for values of legume architectural complexity ($F_{4,35.9} = 3.3$, $P < 0.05$). Values were negligible in all plots sown with the CS mix. In association with cutting and graminicide, values were greater in plots sown with the FG mix (Figure 6.142).

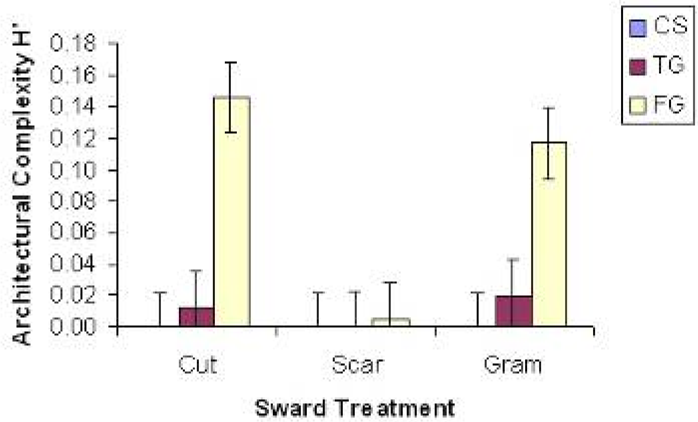


Figure 6.142. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the legume component at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant interaction between seed mix and year was determined for values of non-leguminous forb architectural complexity ($F_{4,87.1} = 2.5$, $P < 0.05$). Values of complexity were lower in association with the CS mix across all years. In plots sown with the TG and FG mixes, values increased between 2003 and 2004, but decreased by 2006. Greater values were maintained in association with the FG mix (Figure 6.143).

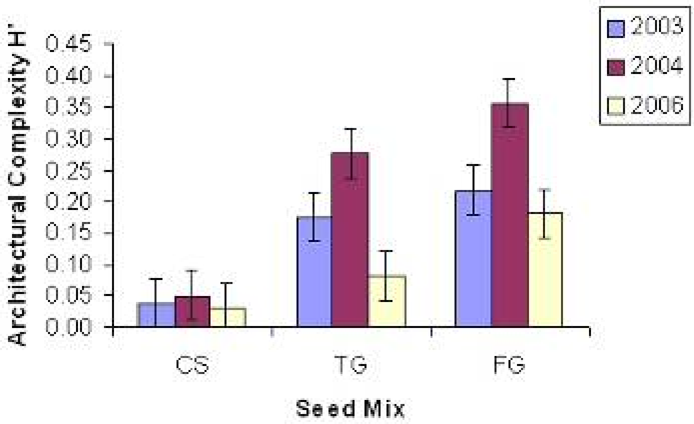


Figure 6.143. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the non-leguminous forb component at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined ($F_{4,87.1}$ = 4.8, P < 0.01). In 2003, values were similar across sward treatments, but in 2004 values increased in plots treated with scarification and graminicide and tended to decrease with time in plots that were cut. Values peaked in 2004 in plots treated with scarification and graminicide (Figure 6.144).

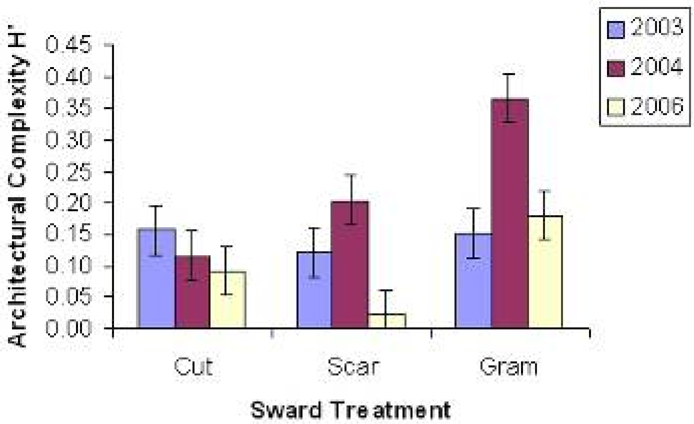


Figure 6.144. Architectural complexity (Shannon-Wiener diversity H') (± SE) of the non-leguminous component at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for values of total architectural complexity ($F_{4,62.0}$ = 3.9, P < 0.001). Within years, values were similar across all seed mixes. In general, values were lower in 2006 compared with 2003 and 2004 (Figure 6.145).

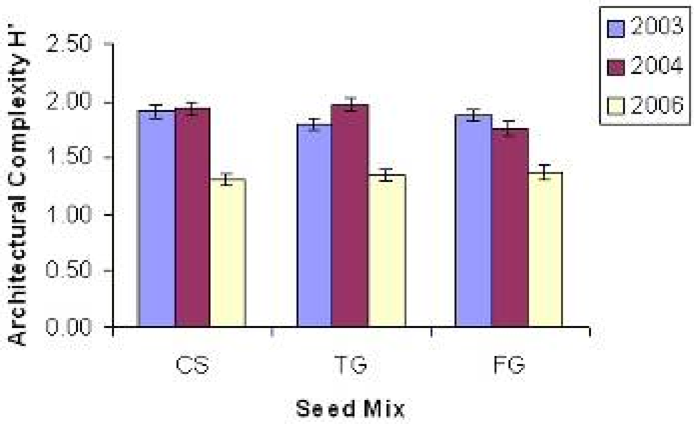


Figure 6.145. Total architectural complexity (Shannon-Wiener diversity H') (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined for values of total architectural complexity ($F_{4,62.0}$ = 32.3, P < 0.001). Values were consistently lower in plots treated with scarification, especially in 2006. In plots treated with cutting and graminicide values of architectural complexity were similar within years and were observed to decrease by 2006 (Figure 6.146).

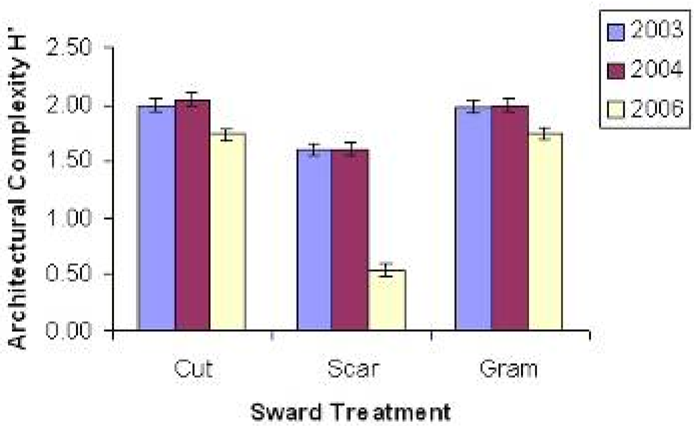


Figure 6.146. Total architectural complexity (Shannon-Wiener diversity H') (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring graminicide application) and year.

6.3.2.8 Plant Resource Abundance

The provision of plant resources was determined with respect to the sown grasses, sown forbs, unsown grasses, unsown forbs and total resource abundance. Within these groups, four resource categories were created: 1) vegetative, 2) flowering shoots/buds, 3) Flowers open, & 4) Seed/fruit that is forming, ripe or dehiscent. Values of resource abundance were determined for individual species for each quadrat by multiplying the proportion of each reproductive status represented, by a species percentage cover value. As such, the units of resource abundance are based on values of cover abundance.

Treatment responses June (2003, 2004 & 2006)

Overall responses

Sown Grasses

A significant interaction between seed mix, sward treatment and year was determined for the vegetative resource of sown grasses ($F_{12,143.3}$ = 1.9, P < 0.05). Overall, values were generally lower in association with scarification and lower in 2003 compared with subsequent years (Figure 6.147).

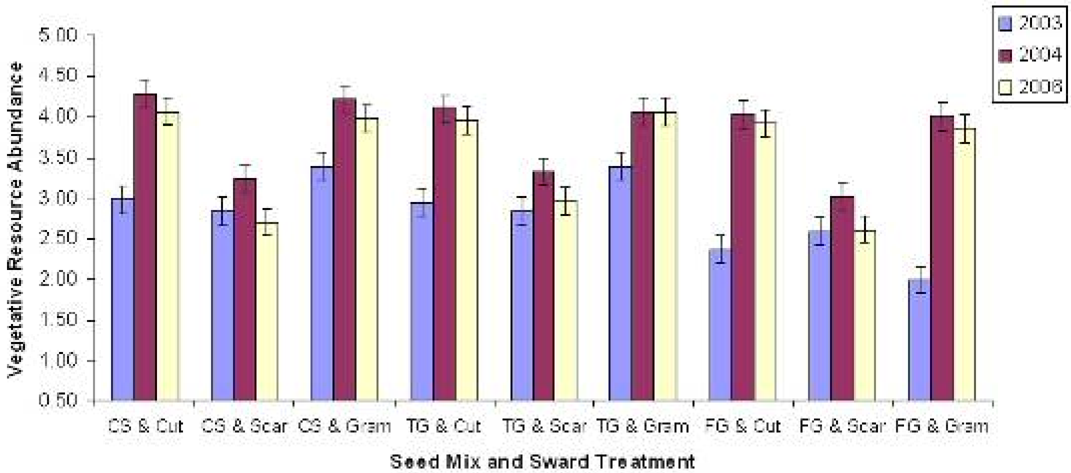


Figure 6.147. Sown grass vegetative resource values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was found for the abundance of flowering shoots of the sown grasses ($F_{4,269.5}$ = 3.1, P < 0.05). The TG mix was associated with the greatest abundance, and regardless of seed mix, values in 2004 were generally lower (Figure 6.148).

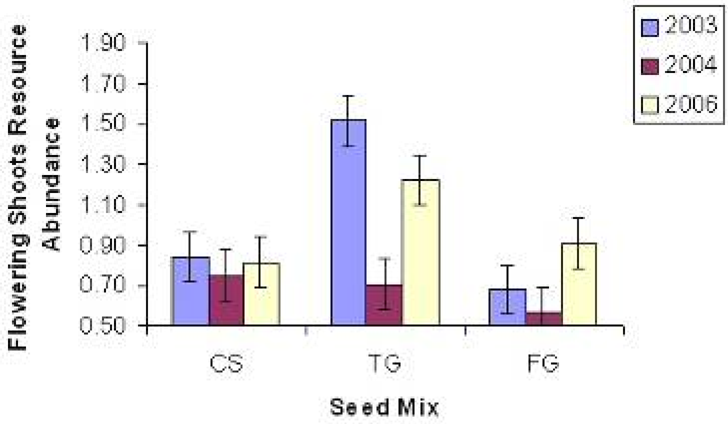


Figure 6.148. Sown grass flowering shoot abundance (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant effect of sward treatment was also found ($F_{2,157.4} = 5.6$, $P < 0.01$). Values were significantly greater in association with cutting compared with graminicide ($P < 0.05$), but no difference was found between cutting and scarification, or scarification and graminicide (Figure 6.149).

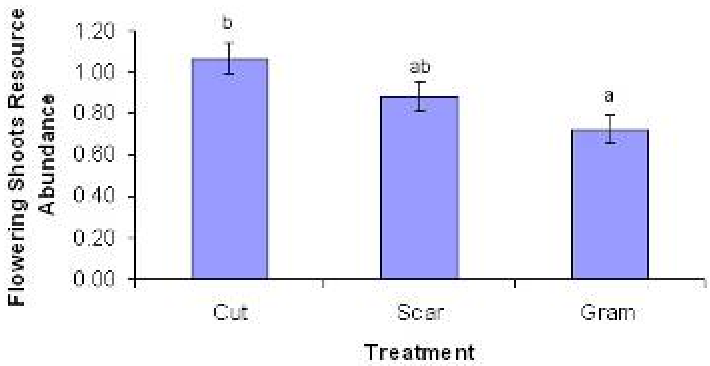


Figure 6.149. Sown grass flowering shoot abundance (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A marginal interaction between seed mix and year was determined for the effect on sown grass flower abundance ($F_{4,261.3} = 2.4$, $P = 0.051$). In contrast, a highly significant effect of year was determined ($F_{2,261.3} = 59.9$, $P = 0.001$). A significantly greater abundance of sown grass flowers was found in 2003 compared with subsequent years ($P < 0.05$) (Figure 6.150).

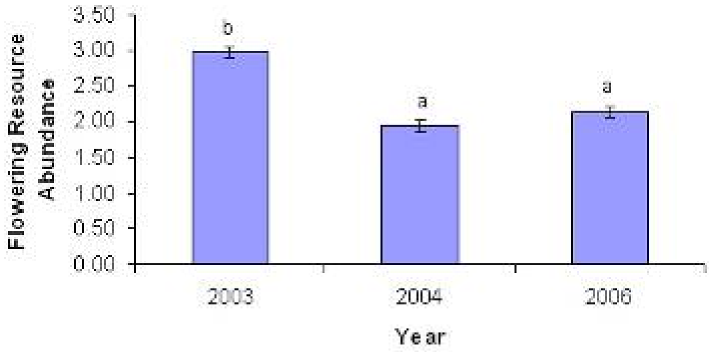


Figure 6.150. Sown grass flowering shoot abundance (± SE) across all sites according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between seed mix and sward treatment was found for values of sown grass flower abundance ($F_{4,125.6} = 4.7$, $P < 0.01$). Overall, values were greater in association with cutting and least with scarification (Figure 6.151). However, in association with graminicide, values were considerably lower in plots sown with the TG mix.

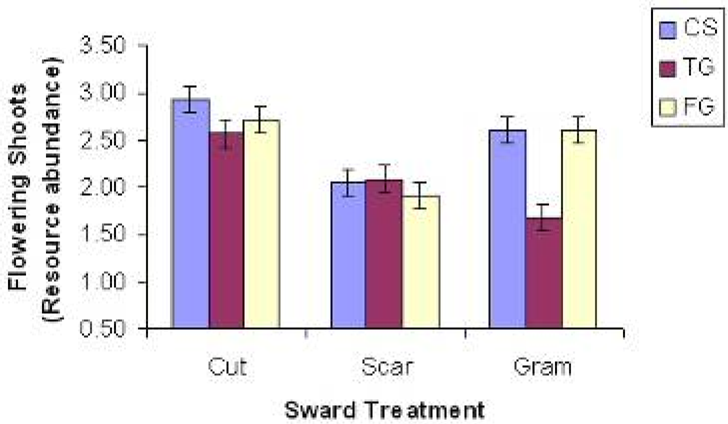


Figure 6.151. Sown grass flower abundance resource values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant seed mix effect was determined for values of sown grass seed abundance ($F_{2,180.6} = 13.0$, $P < 0.001$). Values were significantly lower in association with the TG mix compared with the CS and FG mixes (Figure 6.152). The interactions with seed mix and the other model parameters were not significant.

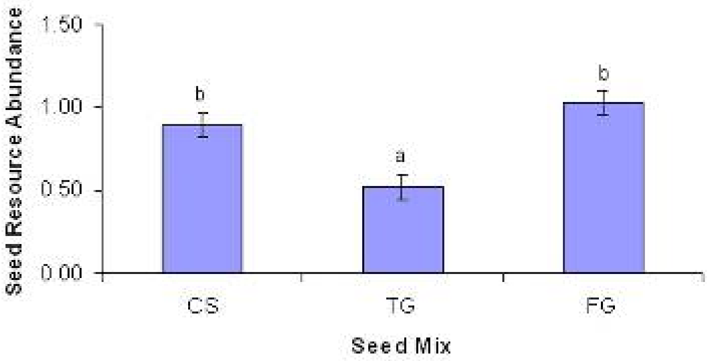


Figure 6.152. Sown grass seed abundance (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Seed mix treatments with the same letter do not differ significantly (*P* > 0.05).

The effect of sward treatment on values of sown grass seed abundance was also significant ($F_{2,180.6} = 3.4$, $P < 0.05$). Values were significantly lower in association with scarification ($P < 0.05$). Comparisons between cutting and graminicide were not significant (Figure 6.153). Interactions with sward treatment and other model parameters were not significant.

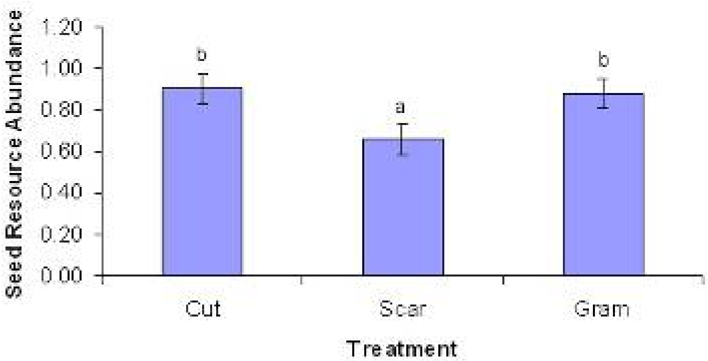


Figure 6.153. Sown grass seed abundance (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly (*P* > 0.05).

A significant effect of year was also determined ($F_{2,279.4} = 110.1$, $P < 0.001$). Values decreased significantly between years (Figure 6.154).

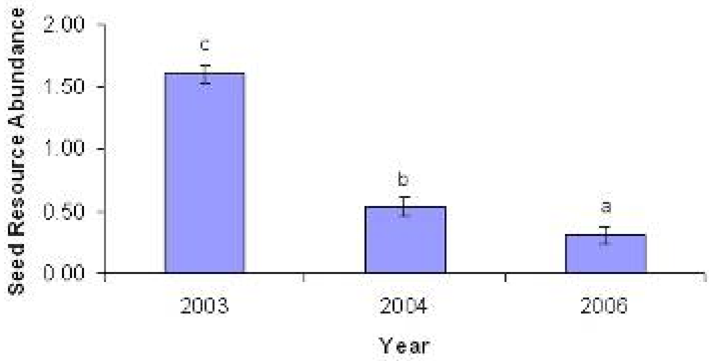


Figure 6.154. Sown grass seed abundance (± SE) across all sites according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Sown Forbs

A significant interaction between seed mix and year was found for values of sown forb vegetative resource abundance ($F_{2,226.6} = 7.5$, $P < 0.001$). Forbs were not sown in the CS mix and consequently made a negligible contribution to the sward. In association with the TG and FG mixes, values tended to increase between years, although they were observed to peak in 2004 in plots sown with the TG mix (Figure 6.155).

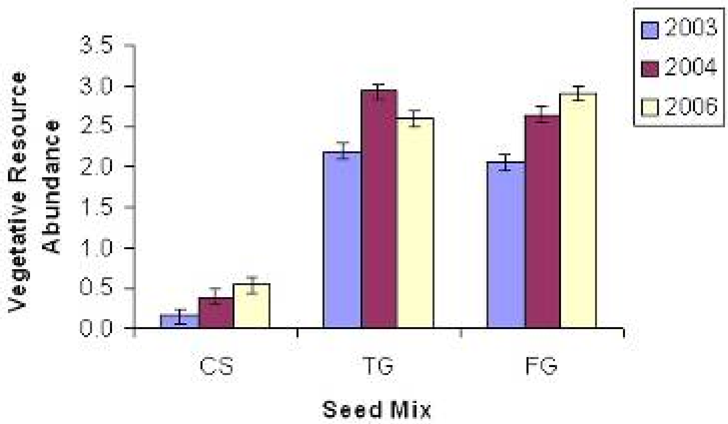


Figure 6.155. Sown forb vegetative resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined for values of sown forb vegetative resource ($F_{2,226.6} = 6.0$, $P < 0.001$). Values generally increased between years regardless of treatment, but peaked in 2004 with scarification (Figure 6.156).

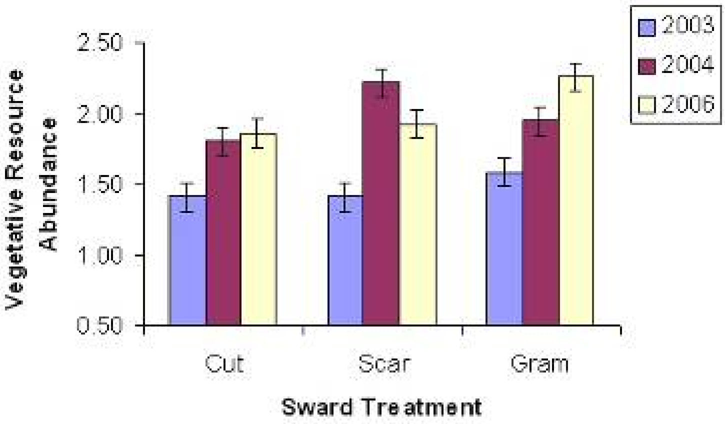


Figure 6.156. Sown forb vegetative resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix, sward treatment and year was determined for values of flowering shoot resource abundance of the sown forbs ($F_{12,214.7}$ = 2.4, P < 0.01). Values were generally greater in 2006 compared with preceding years and the treatment of graminicide was associated with a greater increase between years in plots sown with either the TG or FG mixes (Figure 6.157). Cutting of plots sown with the FG mix was also associated with a greater abundance of flowering shoots compared with scarification. Values were negligible in plots sown with the CS mix.

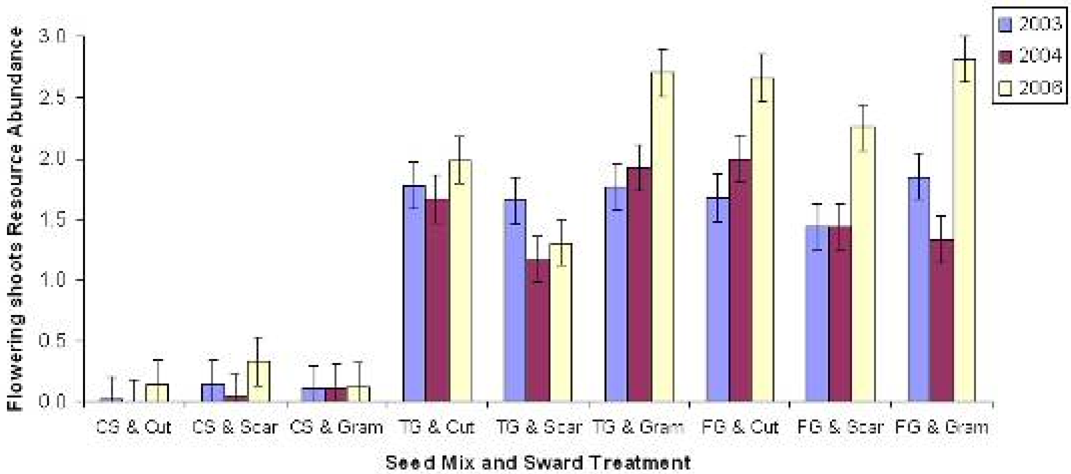


Figure 6.157. Sown forb flower shoot resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for values of sown forb flower abundance ($F_{4,253.9}$ = 10.6, P < 0.001). Values remained relatively constant between years in association with the FG mix, but were observed to decrease by 2006 in plots sown with the TG mix (Figure 6.158). Values remained constantly low in plots sown with the CS mix.

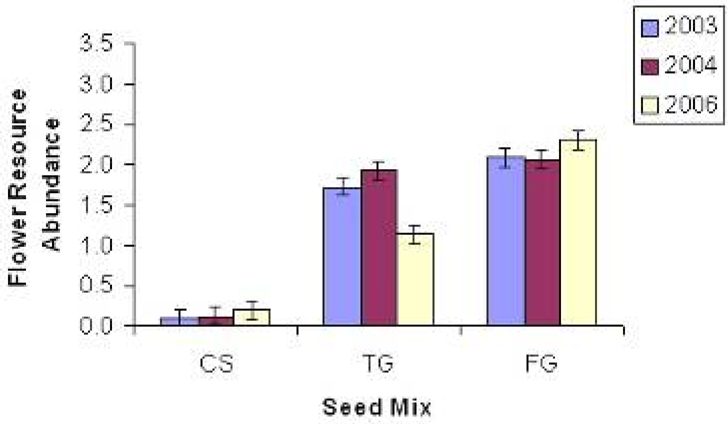


Figure 6.158. Sown forb flower resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined for values of sown forb flower abundance ($F_{4,253.9} = 3.9$, $P < 0.01$). Values of flower abundance were generally greater in plots treated with graminicide, especially compared with scarification, but were observed to decrease between 2004 and 2006 (Figure 6.159). In contrast, values remained relatively constant in association with cutting and scarification.

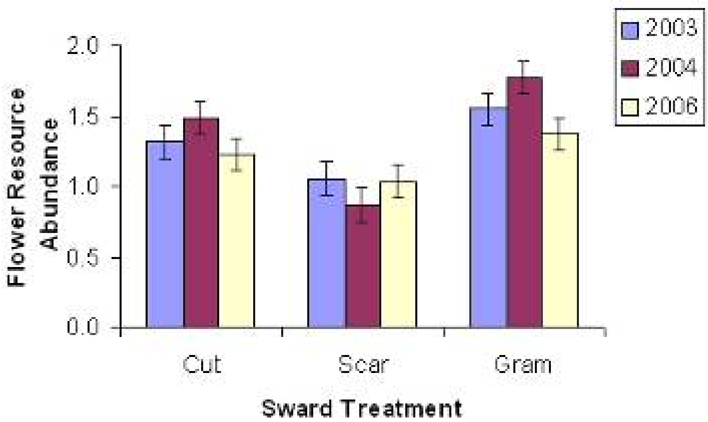


Figure 6.159. Sown forb flower resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

For values of abundance of seed that was forming, ripe or dehiscent, significant effects of seed mix ($F_{2,152.7} = 64.7$, $P < 0.001$), sward treatment ($F_{2,152.7} = 6.6$, $P < 0.01$) and year ($F_{2,265.2} = 3.1$, $P < 0.05$) were determined. However, all combinations of interactions between these parameters were not significant. Pairwise comparisons revealed that seed abundance was significantly greater in association with the FG mix ($P < 0.05$) (Figure 6.160) and significantly lower in association with scarification ($P < 0.05$) (Figure 6.161). Between years, seed abundance decreased and the significant year effect was owing to the significant difference between 2003 and 2006 (Figure 6.162).

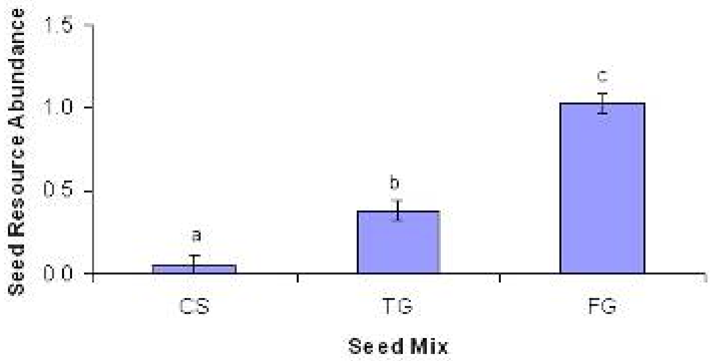


Figure 6.160. Sown forb seed resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

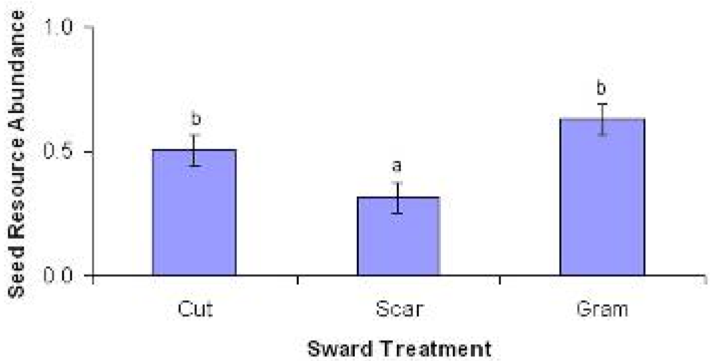


Figure 6.161. Sown forb seed resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

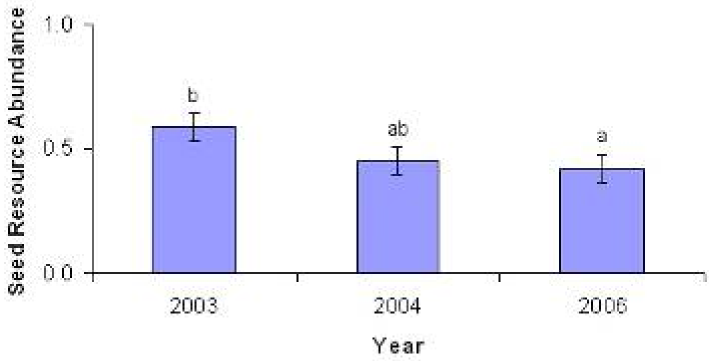


Figure 6.162. Sown forb seed abundance (± SE) across all sites according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Unsown Grasses

A significant effect of seed mix was found for values of unsown grass vegetative resource abundance ($F_{2,139.8} = 5.0$, $P < 0.01$). Values were significantly greater in association with the CS mix compared with the TG mix ($P < 0.05$) (Figure 6.163). No difference was found between the CS and the FG mixes, or between the TG and FG mixes. Interactions between seed mix and all other parameters were not significant.

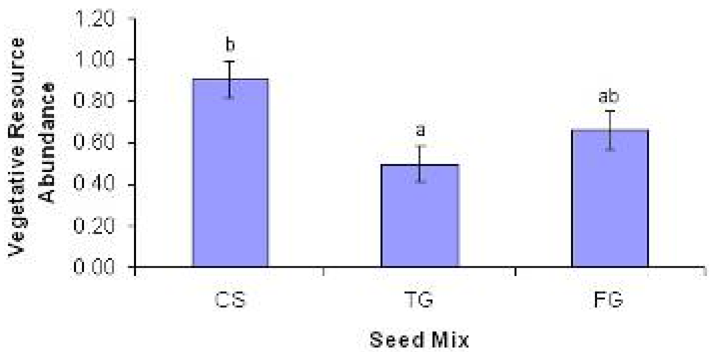


Figure 6.163. Unsown grass vegetative resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was determined ($F_{4,206.5} = 6.2$, $P < 0.001$). Values increased between years in association with scarification, but decreased with graminicide (Figure 6.164). The response to cutting was variable.

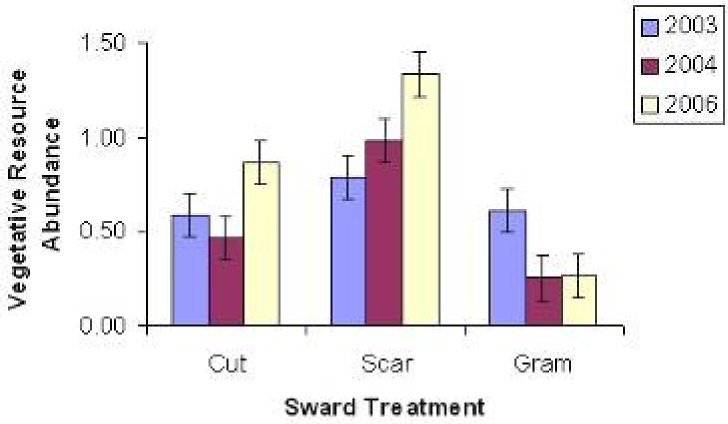


Figure 6.164. Unsown grass vegetative resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for values of unsown grass flowering shoot abundance ($F_{2,126.7}$ = 3.5, P < 0.05). Values were significantly lower in association with the TG mix compared with the CS and FG mixes (P < 0.05) (Figure 6.165). Interactions between seed mix and all other parameters were not significant.

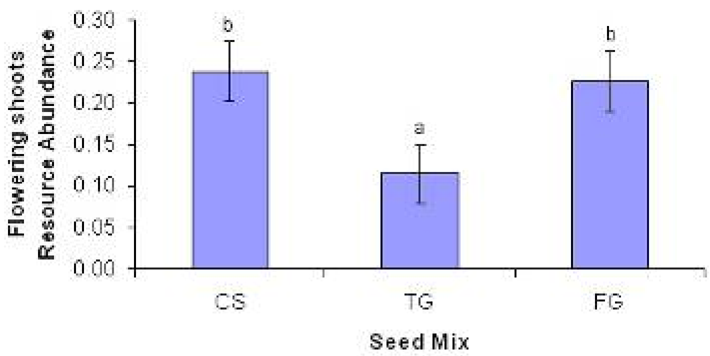


Figure 6.165. Unsown grass flowering shoot resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (P > 0.05).

A significant interaction between sward treatment and year was also determined ($F_{4,236.9}$ = 5.1, P = 0.001). In association with graminicide, values decreased after 2003. However, in association with cutting and scarification, overall, values increased between 2003 and 2006, despite decreasing in 2004 with cutting (Figure 6.166).

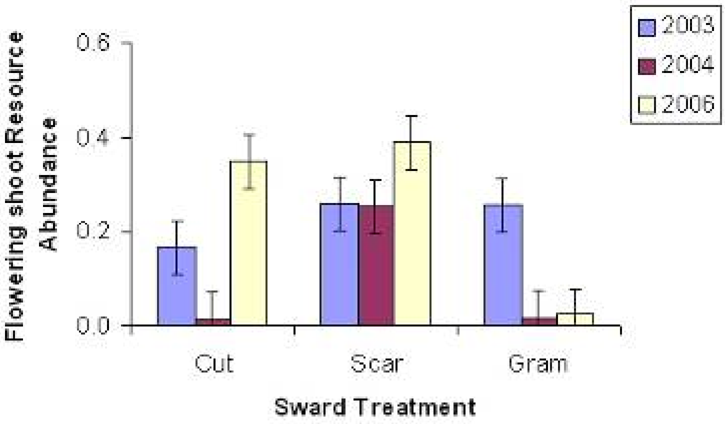


Figure 6.166. Unsown grass flowering shoot resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for values of flower resource abundance of the unsown grasses ($F_{2,136.6} = 6.6$, $P < 0.01$). A greater abundance of flowering unsown grasses was associated with the CS mix ($P < 0.05$) (Figure 6.167). No significant difference was found between the TG and FG mixes.

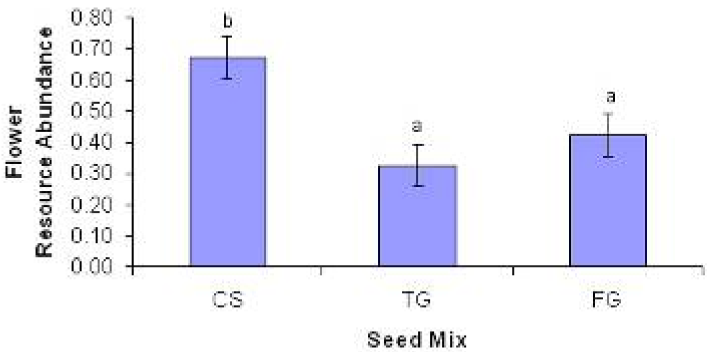


Figure 6.167. Unsown grass flower resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was determined for values of flower resource abundance produced by the unsown grasses ($F_{4,211.6} = 6.0$, $P < 0.001$). Values remained relatively constant in association with scarification, but were observed to decrease after 2003 in association with cutting and graminicide (Figure 6.168).

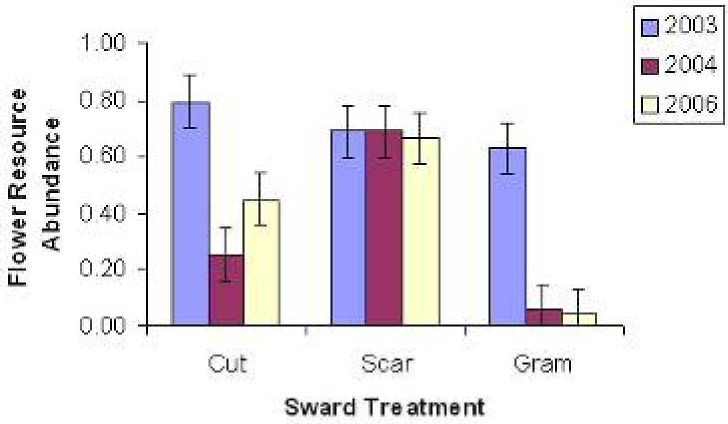


Figure 6.168. Unsown grass flower resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

No significant effects of seed mix or sward treatment were found for values of unsown grass seed resource abundance. However, a significant year effect was determined ($F_{2,235.2}$ = 71.7, P < 0.001). Values were significantly greater in 2003 compared with subsequent years (P < 0.05) (Figure 6.169).

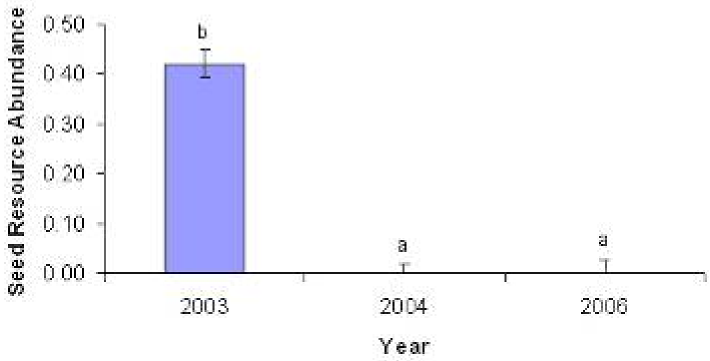


Figure 6.169. Unsown grass seed abundance (± SE) across all sites according to year. Treatments with the same letter do not differ significantly (P > 0.05).

Unsown forbs

A significant effect of seed mix was determined for values of unsown forb vegetative resource abundance ($F_{2,131.4}$ = 6.4, P < 0.01). Values were significantly greater in plots sown with the CS mix (P < 0.05) and no difference was found between the TG and FG mixes (Figure 6.170). Interactions between seed mix and all other parameters were not significant.

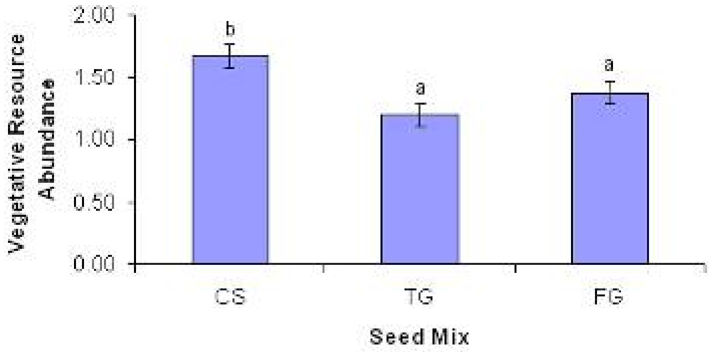


Figure 6.170. Unsown forb vegetative resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was also determined ($F_{4,184.3} = 4.8$, $P < 0.01$). Values remained relatively constant in association with cutting and graminicide during 2003 and 2004, but increased in 2006. The treatment of scarification was associated with the greatest values of vegetative resource and values increased between years (Figure 6.171).

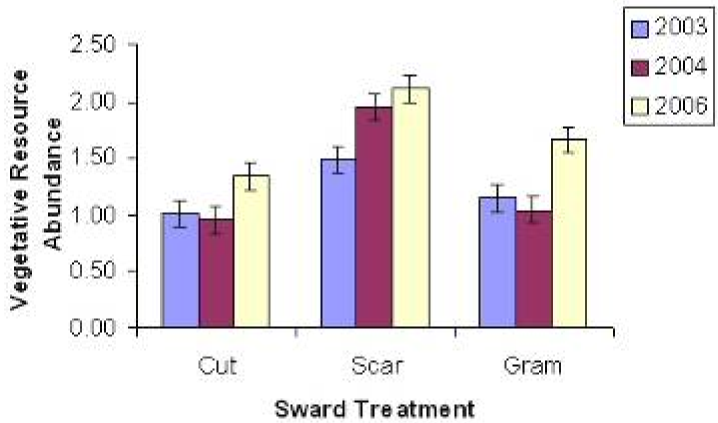


Figure 6.171. Unsown forb vegetative resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for values of unsown forbs flowering shoot resource abundance ($F_{2,132.2} = 4.8$, $P < 0.01$). Values were significantly greater in association with plots sown with the CS mix compared with the TG mix ($P < 0.05$). Differences between the TG and FG mixes and the FG and CS mixes were not significant (Figure 6.172).

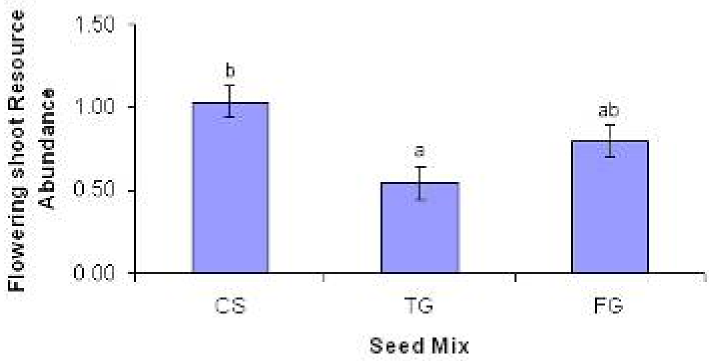


Figure 6.172. Unsown forb flowering shoot resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was determined for values of flowering shoot resource abundance ($F_{4,221.9} = 3.9$, $P < 0.01$). In association with cutting and graminicide, values were markedly lower in 2004 compared with 2003 and 2006. In contrast, values remained relatively constant in association with scarification (Figure 6.173).

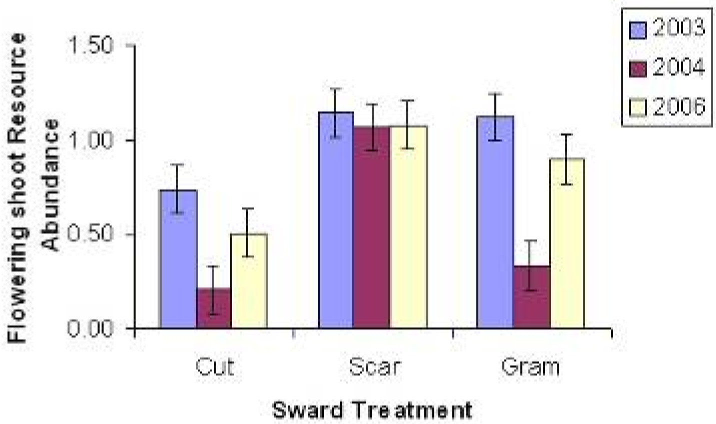


Figure 6.173. Unsown forb flowering shoot resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for values of unsown forb flower resource abundance ($F_{2,136.0} = 6.5$, $P < 0.01$). Values were significantly greater in association with plots sown with the CS mix ($P < 0.05$). No significant difference was found between the TG and FG mixes (Figure 6.174).

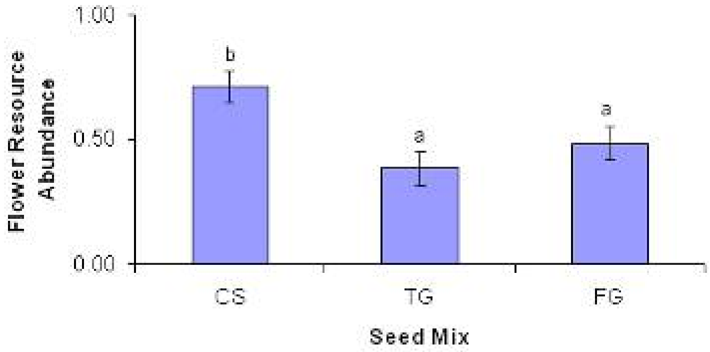


Figure 6.174. Unsown forb flower resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (*P* > 0.05).

A significant interaction between sward treatment and year was determined for unsown forb flower resource abundance ($F_{4,218.7}$ = 2.5, P < 0.05). Values were constantly greater in association with scarification, especially in 2004 (Figure 6.175).

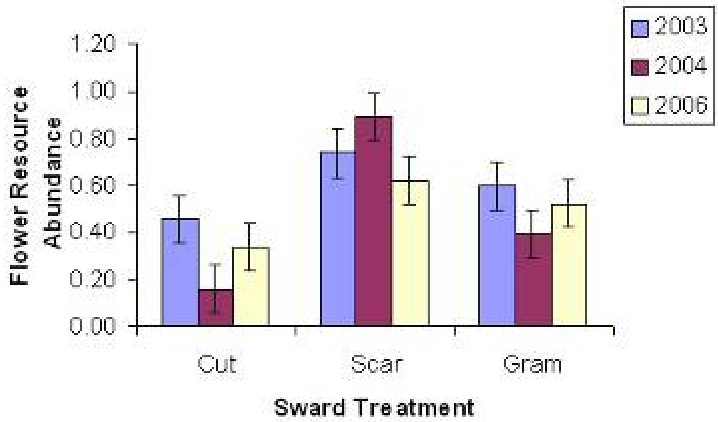


Figure 6.175. Unsown forb flower resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Abundance values for seed that was forming, ripe or dehiscent were not influenced significantly by seed mix. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,235.3}$ = 4.0, P < 0.01). Overall, responses were variable, but for all treatments, values were lower in 2006 than in 2003(Figure 6.176).

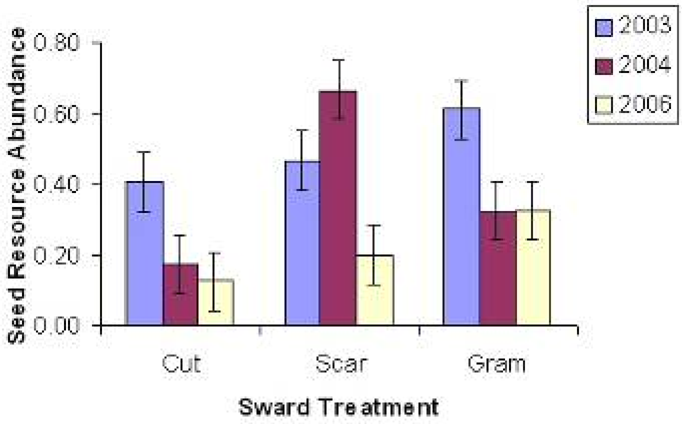


Figure 6.176. Unsown forb seed resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Total Resources

A significant interaction between seed mix and year was determined for values of total vegetative resource abundance ($F_{4,203.5} = 4.1$, $P < 0.01$). Values were observed to be greater in 2004 and 2006 compared with 2003 (Figure 6.177).

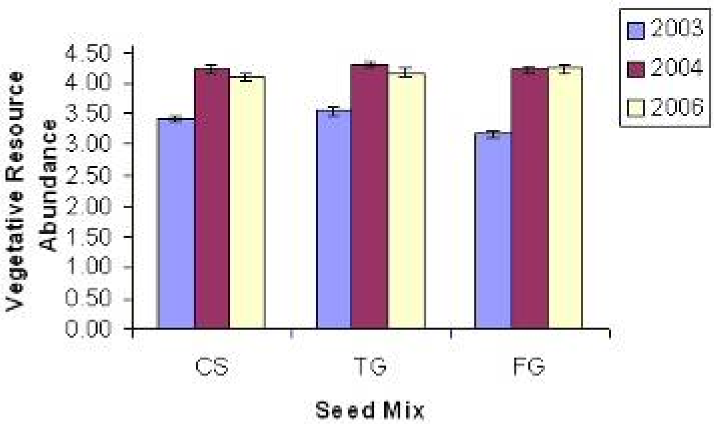


Figure 6.177. Total vegetative resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined for total values of vegetative resource abundance ($F_{4,203.5} = 6.7$, $P < 0.001$). In association with cutting, values were generally lower than with scarification and graminicide, but increased between years. In the scarified and graminicide-treated plots, values were observed to be lower in 2004 compared with 2003 and 2006 (Figure 6.178).

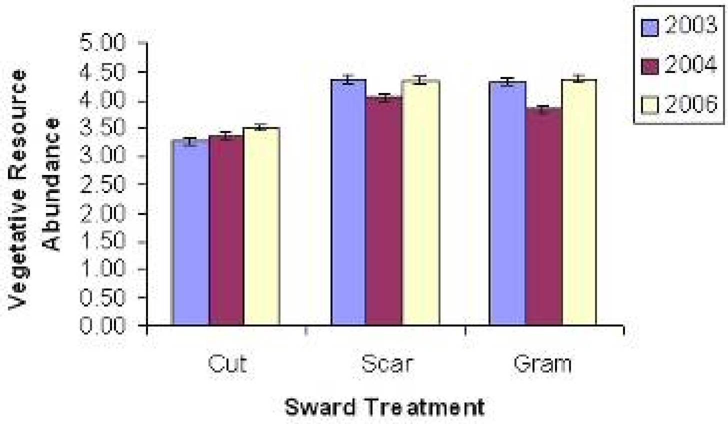


Figure 6.178. Total vegetative resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for total values of flowering shoot resource abundance ($F_{4,204.6}$ = 4.1, P < 0.01). Values were generally lower in plots sown with the CS mix (Figure 6.179). Sward treatment had no significant effect on values of total flowering shoot resource abundance.

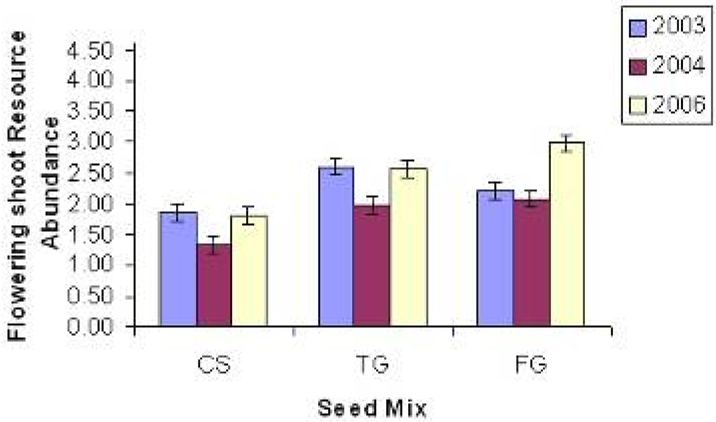


Figure 6.179. Total flowering shoot resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant effect of seed mix was determined for total values of flower resource abundance ($F_{2,130.3}$ = 15.9, P < 0.001). Values were significantly greater in association with plots sown with the FG mix (P < 0.05). No significant difference was found between the CS and TG mixes (Figure 6.180). Interactions between seed mix and all other parameters were not significant.

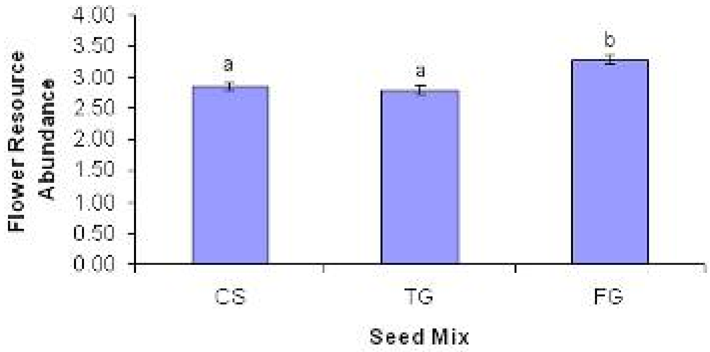


Figure 6.180. Total flower resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (*P* > 0.05).

A significant effect of sward treatment was also determined for total values of flower resource abundance ($F_{2,130.3}$ = 16.4, $P < 0.001$). Values were significantly lower in scarified plots ($P < 0.05$) and no difference was found between cutting and graminicide (Figure 6.181). Interactions between sward treatment and all other parameters were not significant.

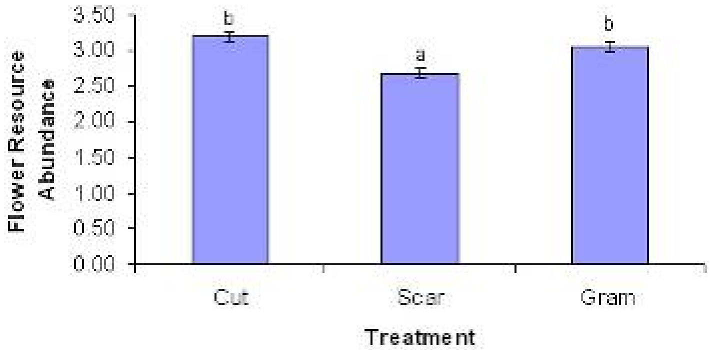


Figure 6.181. Total flower resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly (*P* > 0.05).

Year was also found to have a significant effect on total values of flower resource abundance ($F_{2,247.5}$ = 38.4, $P < 0.001$). Values were significantly greater in 2003 compared with subsequent years ($P < 0.05$). No difference was determined between 2004 and 2006 (Figure 6.182).

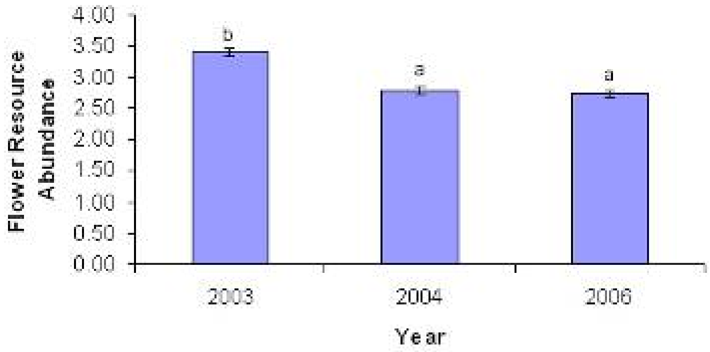


Figure 6.182. Total flower resource abundance values (± SE) across all sites according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant effect of seed mix was determined for total resource abundance values for seed that was forming, ripe or dehiscent ($F_{2,163.9} = 31.1$, $P < 0.001$). Values differed significantly between treatments ($P < 0.05$), with a greater abundance in plots sown with the FG mix. The TG plots had the lowest values of seed resource abundance (Figure 6.183). Interactions between seed mix and all other parameters were not significant.

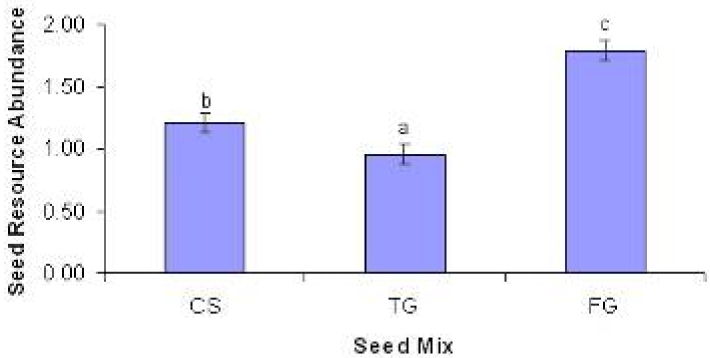


Figure 6.183. Total seed resource abundance values (± SE) across all sites according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant effect of sward treatment was also determined ($F_{2,163.9} = 6.0$, $P < 0.01$). Values of seed resource abundance were significantly lower in association with scarification compared with plots treated with graminicide ($P < 0.05$). No difference was found between scarification and cutting or cutting and graminicide (Figure 6.184). Interactions between sward treatment and all other parameters were not significant.

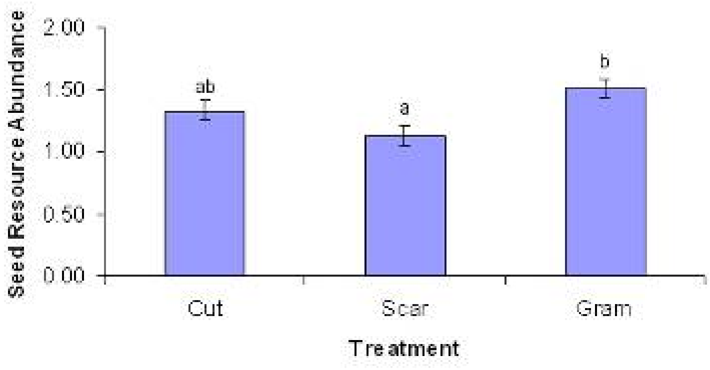


Figure 6.184. Total seed resource abundance values (± SE) across all sites according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant year effect was also determined for values of total seed resource abundance ($F_{2,272.0} = 94.7$, $P < 0.01$), with values decreasing significantly between years ($P < 0.05$) (Figure 6.185).

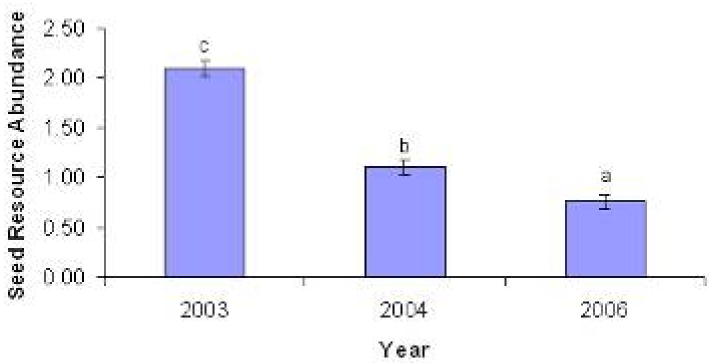


Figure 6.185. Total seed resource abundance values (± SE) across all sites according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Individual site responses

Boxworth

Sown Grasses

A significant interaction between seed mix, sward treatment and year was determined for values of sown grass vegetative resource abundance ($F_{16,52.6} = 1.9$, $P < 0.05$). Responses were highly variable, but in general, values were lower in association with scarification (Figure 6.186).

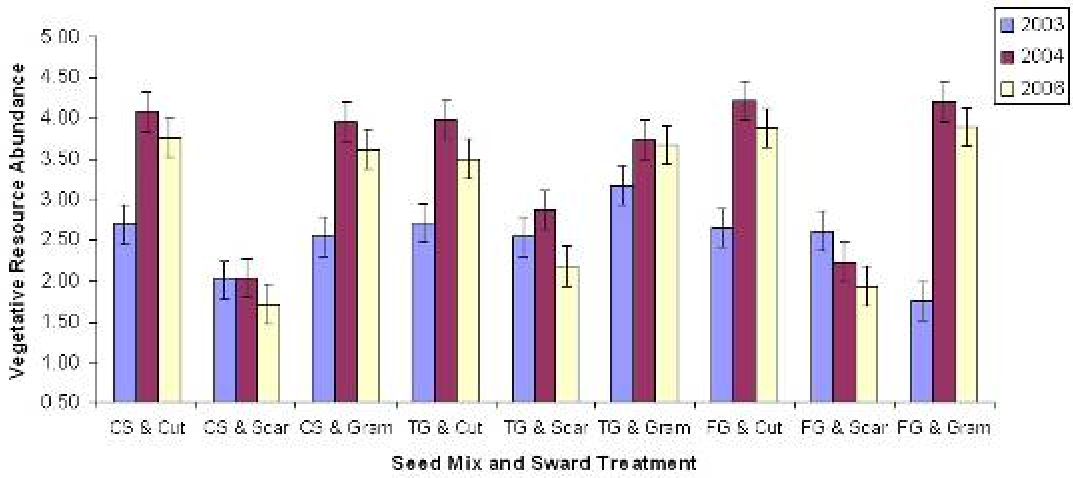


Figure 6.186. Sown grass vegetative resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and sward treatment was determined for values of sown grass flowering shoot resource abundance ($F_{4,42.6} = 3.0$, $P < 0.05$). In association with scarification, values were greater in plots sown with the TG seed mix and least with the CS mix. Cutting was associated with a reduced flowering shoot resource in plots sown with the FG mix, whilst CS and TG plots treated with graminicide had greater values relative to the FG plots (Figure 6.187).

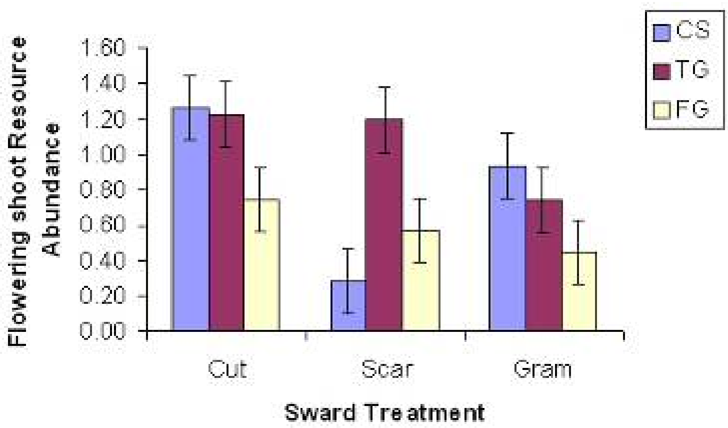


Figure 6.187. Sown grass flowering shoot resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant interaction between seed mix and year was determined for values of sown grass flowering shoot resource abundance at Boxworth ($F_{4,83.0} = 2.7$, $P < 0.05$).

In 2003, values were greater in plots sown with the TG mix. However, in 2004 values were relatively constant across seed mixes, while in 2006 values were lower in association with plots sown with the FG mix (Figure 6.188).

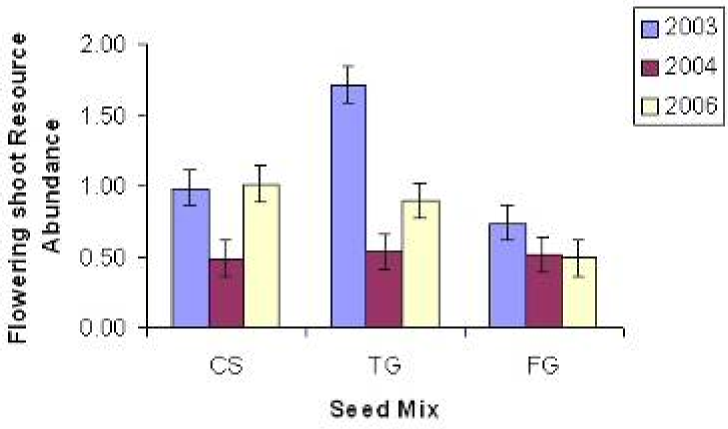


Figure 6.188. Sown grass flowering shoot resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Seed mix had no significant effect on values of sown grass flower resource abundance. In contrast, a significant effect of sward treatment was determined ($F_{2,53.8} = 15.5$, $P < 0.001$). Values were found to differ significantly between treatments ($P < 0.05$), with scarification being associated with the lowest values and cutting the greatest (Figure 6.189). Interactions between sward treatment and all other parameters were not significant.

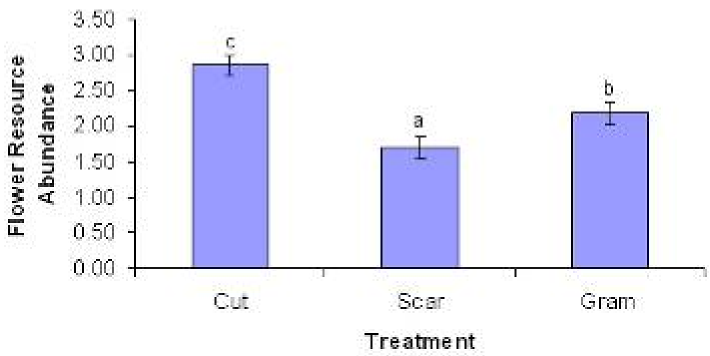


Figure 6.189. Sown grass flower resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant year effect was also determined ($F_{2,93.0} = 16.4$, $P < 0.001$). Values were significantly greater in 2003 compared with subsequent years ($P < 0.05$) (Figure 6.190). No difference was found between years 2004 and 2006.

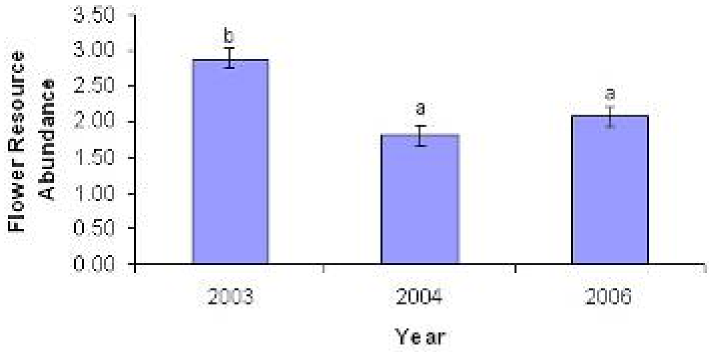


Figure 6.190. Sown grass flower resource abundance values (± SE) at Boxworth according to year. Treatments with the same letter do not differ significantly (*P* > 0.05).

No significant effects of seed mix and sward treatment were found for sown grass resource abundance values for seed that was forming, ripe or dehiscent. However, a significant year effect was determined ($F_{2,80.3}$ = 144.4, *P* < 0.001). Values were significantly greater in 2003 compared with subsequent years (*P* < 0.05) and no difference was found between 2004 and 2006. (Figure 6.191).

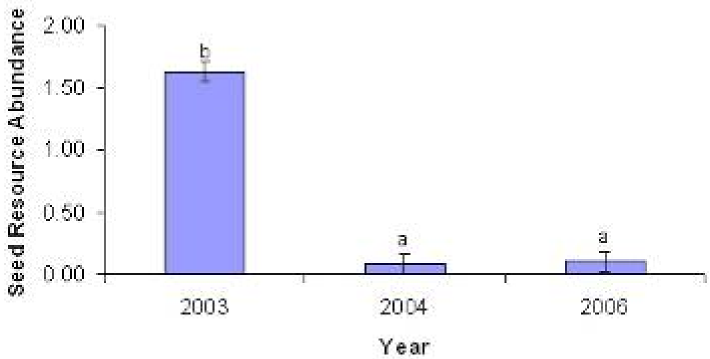


Figure 6.191. Sown grass seed resource abundance values (± SE) at Boxworth according to year. Treatments with the same letter do not differ significantly (*P* > 0.05).

Sown Forbs

A significant effect of seed mix was determined for values of sown forb vegetative resource abundance ($F_{2,39.7}$ = 51.2, *P* < 0.001). Values were significantly lower in association with the CS mix (*P* < 0.05) and there was no difference between the TG and FG mixes (Figure 6.192). Interactions between seed mix and all other parameters were not significant.

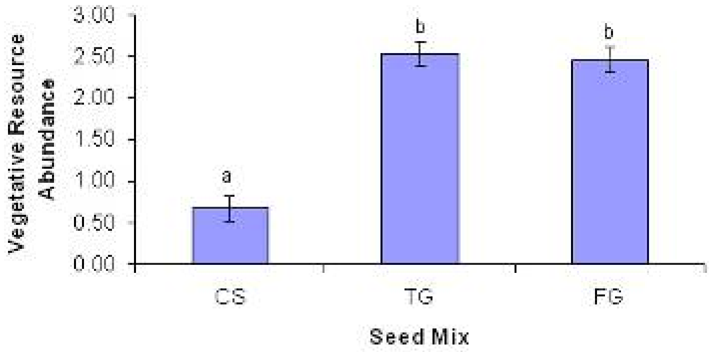


Figure 6.192. Sown forb vegetative resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was also determined ($F_{4,39.7} = 81.5$, $P < 0.05$). Values increased between years and to a greater extent in association with scarification (Figure 6.193). Interactions between sward treatment and all other parameters were not significant.

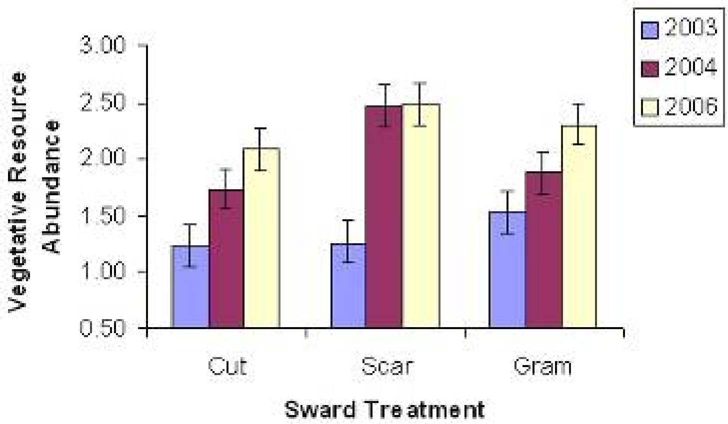


Figure 6.193. Sown forb vegetative resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was found for values of sown forb flowering shoot resource abundance ($F_{2,39.9} = 42.3$, $P < 0.001$). Values were significantly greater in association with the TG and FG mixes, compared with CS mix ($P < 0.05$) (Figure 6.194). Interactions between seed mix and all other parameters were not significant. No significant effect of sward treatment was determined.

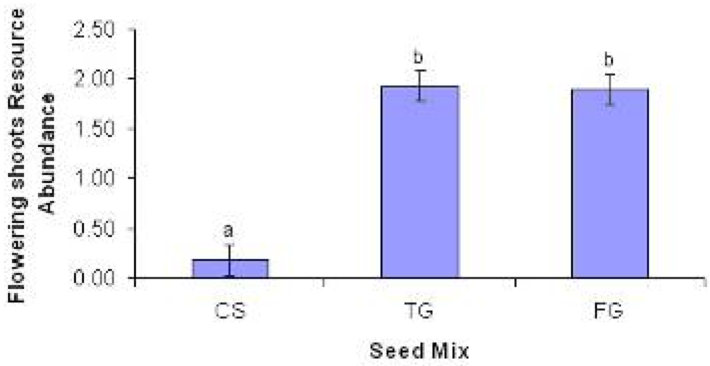


Figure 6.194. Sown forb flowering shoot resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (*P* > 0.05).

There was a significant effect of year on values of flowering shoot abundance ($F_{2,88.0}$ = 19.6, $P < 0.001$). Values were greatest in 2006 ($P < 0.05$) and lowest in 2004 (Figure 6.195).

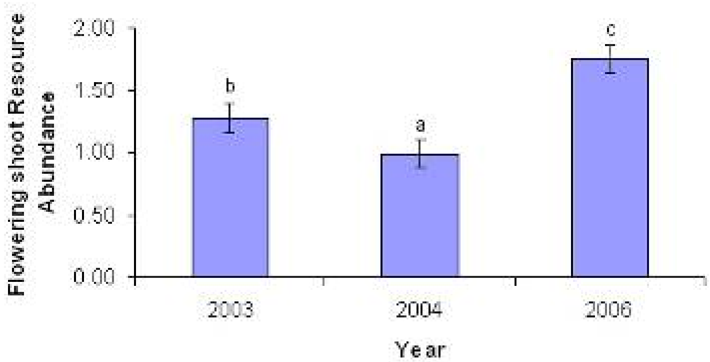


Figure 6.195. Sown forb flowering shoot resource abundance values (± SE) at Boxworth according to year. Treatments with the same letter do not differ significantly (*P* > 0.05).

A significant interaction between seed mix and year was determined for values of sown forb flower resource abundance ($F_{4,54.3}$ = 2.7, $P < 0.05$). Values were observed to be substantially lower in plots sown with the CS mix. Plots sown with the TG mix had an increased flower abundance in 2004 compared with 2003, while values in plots sown with the FG mix were constant for the first two years and increased in 2006 (Figure 6.196).

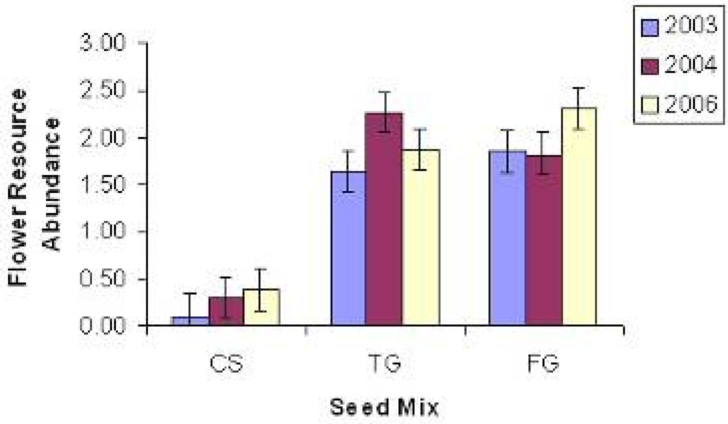


Figure 6.196. Sown forb flower resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined with respect to values of sown forb flower abundance ($F_{4,54.3}$ = 4.4, P < 0.01). Greater values of flower abundance were initially achieved with the cutting and graminicide treatments. However, in 2006, values were similar regardless of treatment (Figure 6.197).

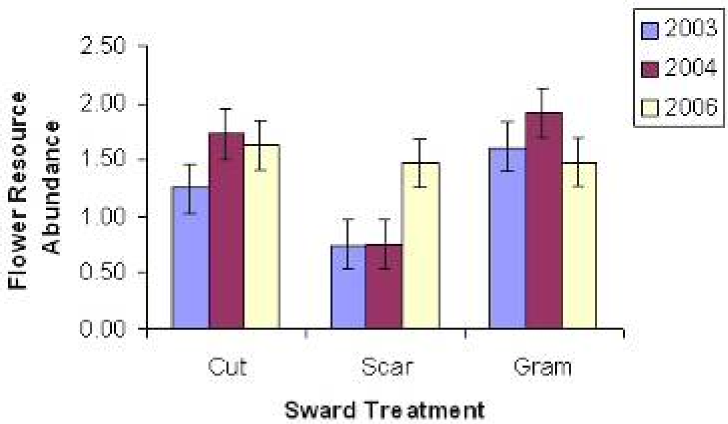


Figure 6.197. Sown forb flower resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for sown forb resource abundance values for seed that was forming, ripe or dehiscent ($F_{2,163.9}$ = 31.1, P < 0.001). Values of seed resource abundance were low in 2004 regardless of seed mix. The greatest value of seed resource abundance was found in 2006 in plots sown with the FG mix (Figure 6.198). Sward treatment had no significant effect on values of sown forb seed abundance.

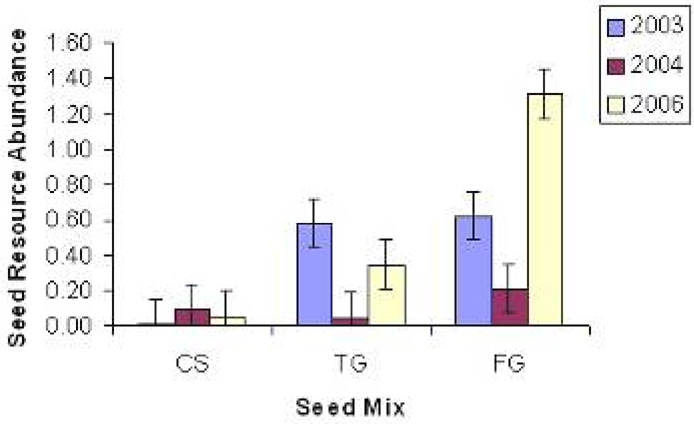


Figure 6.198. Sown forb seed resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Unsown Grasses

A significant effect of seed mix was found for values of unsown grass vegetative resource abundance ($F_{2,37.9} = 4.8$, $P < 0.05$). (Figure 6.199). Values were significantly greater in association with the CS mix ($P < 0.05$) and no difference was found between the TG and FG mixes. Interactions between seed mix and all other parameters were not significant.

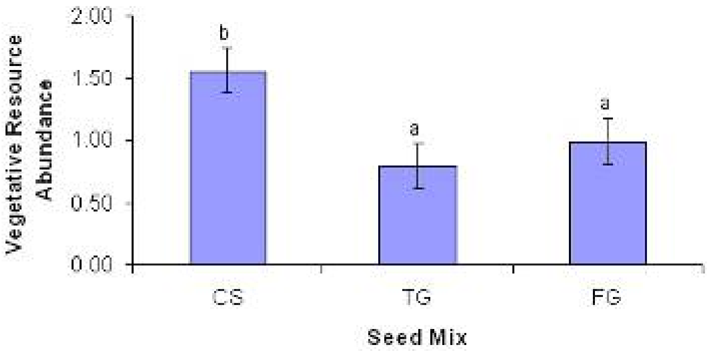


Figure 6.199. Unsown grass vegetative resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was also determined ($F_{4,64.2} = 14.5$, $P < 0.001$). Values increased between years in plots treated with cutting and scarification. In contrast, values decreased in association with graminicide. Values were substantially greater in association with scarification in 2004 and 2006 (Figure 6.200).

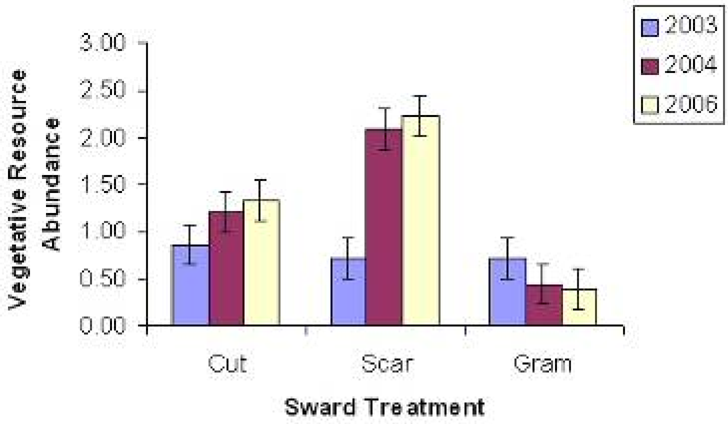


Figure 6.200. Unsown grass vegetative resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

No significant effect of seed mix on values of unsown grass flowering shoot abundance was found. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,77.2} = 4.0$, $P < 0.01$). Values increased between years in scarified plots, but decreased in plots treated with graminicide (Figure 6.201).

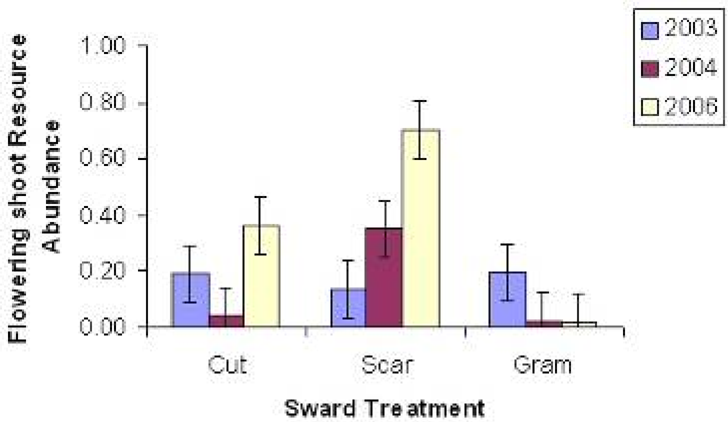


Figure 6.201. Unsown grass flowering shoot resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for values of unsown grass flower resource abundance ($F_{2,40.8} = 13.8$, $P < 0.001$). Values were significantly greater in association with the CS mix and no significant difference was found between the TG and FG mixes ($P < 0.05$) (Figure 6.202). Interactions between seed mix and all other parameters were not significant.

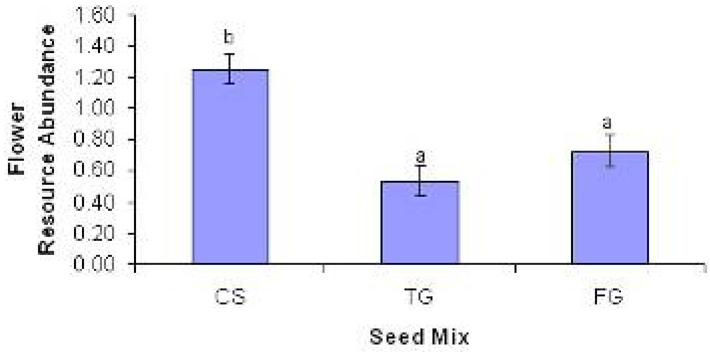


Figure 6.202. Unsown grass flower resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was also determined for values of unsown grass flower abundance ($F_{4,73.5} = 18.4$, $P < 0.001$). In 2003, values were greater in association with cutting, but by 2004 values were greater in plots that were scarified. Values for the graminicide treatment decreased between years (Figure 6.203).

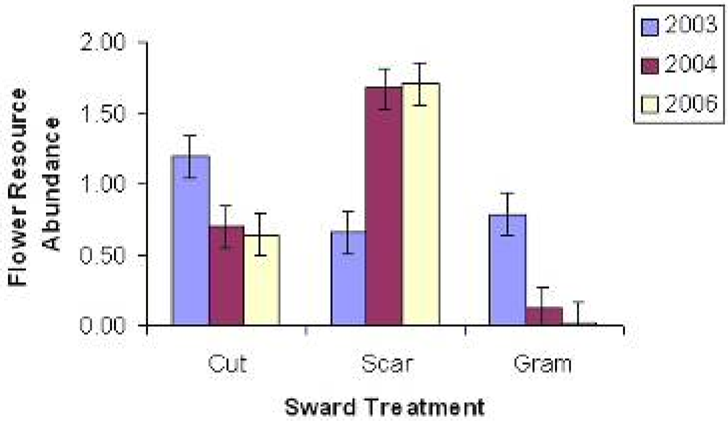


Figure 6.203. Unsown grass flower resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for abundance values of seed that was forming, ripe or dehiscent ($F_{4,65.9} = 4.9$, $P < 0.01$). In 2003, values were greater in plots sown with the CS mix. In subsequent years, values of seed resource abundance were negligible (Figure 6.204). The effect of sward treatment on values was not significant.

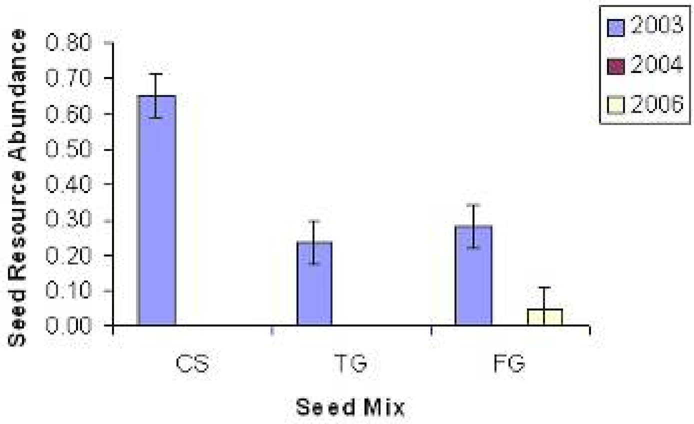


Figure 6.204. Unsown grass seed resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Unsown Forbs

A significant effect of seed mix was determined for values of unsown forb vegetative resource abundance ($F_{2,41.3} = 12.6$, $P < 0.001$). Values differed significantly between seed mixes ($P < 0.05$), being lower in plots sown with the TG mix and greatest with the CS mix (Figure 6.205). Interactions between seed mix and all other parameters were not significant.

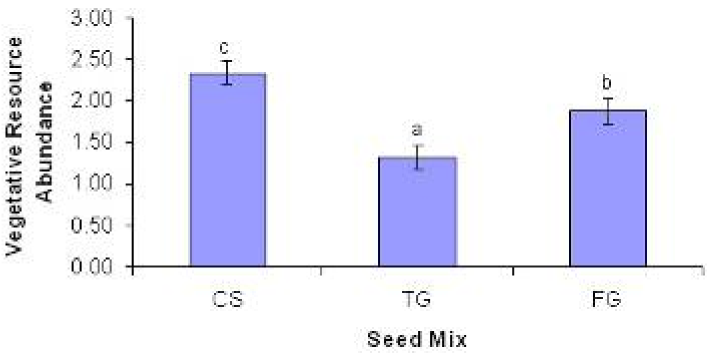


Figure 6.205. Unsown forb vegetative resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was determined for values of unsown forb vegetative resource abundance ($F_{4,80.4} = 7.7$, $P < 0.001$). Values increased between years with all sward treatments, but to a greater extent with scarification (Figure 6.206).

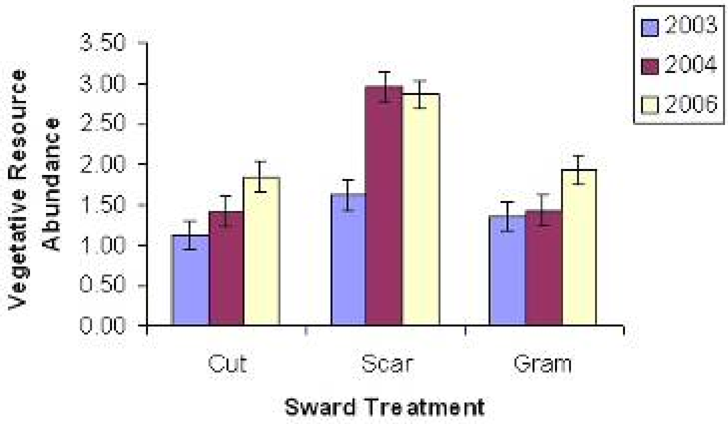


Figure 6.206. Unsown forb vegetative resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Seed mix had a significant effect on values of flowering shoot resource abundance values ($F_{2,43.6} = 7.0$, $P < 0.01$). The significant difference was owing to a greater abundance in plots sown with the CS mix compared with the TG mix (Figure 6.207). Interactions between seed mix and all other parameters were not significant. No significant effect of sward treatment was determined.

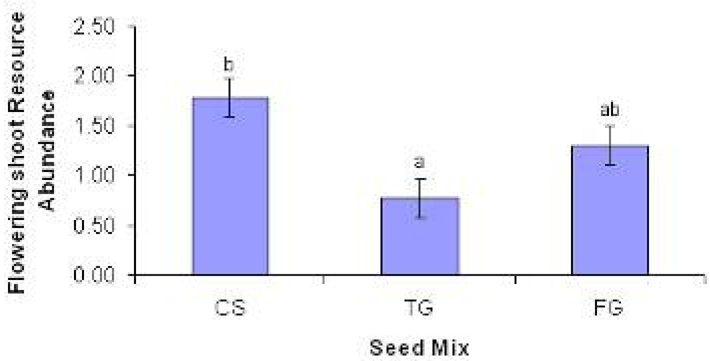


Figure 6.207. Unsown forb flowering shoot resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

There was a significant effect of year on unsown forb flowering shoot resource ($F_{2,86.4} = 13.3$, $P < 0.001$), values being significantly lower in 2004 ($P < 0.05$) (Figure 6.208).

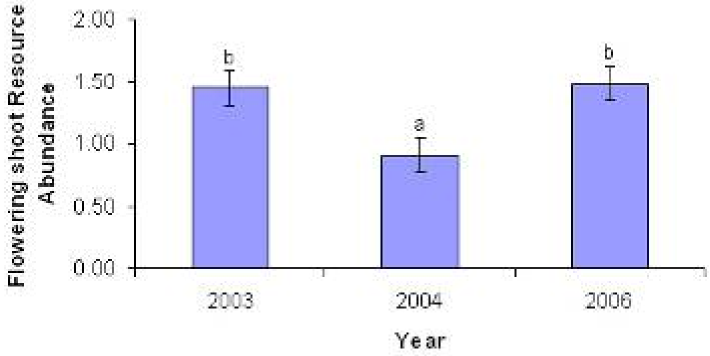


Figure 6.208. Unsown forb flowering shoot resource abundance values (± SE) at Boxworth according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant effect of seed mix was determined for values of flower resource abundance ($F_{2,41.9} = 6.3$, $P < 0.01$). Values were significantly greater in plots sown with the CS mix compared with the TG and FG mixes ($P < 0.05$) (Figure 6.209).

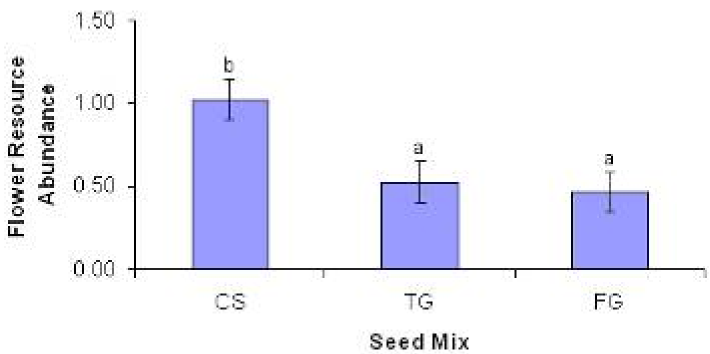


Figure 6.209. Unsown forb flower resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was also determined ($F_{4,72.1} = 2.8$, $P < 0.05$). Overall, values were greater in association with scarification, having increased between years (Figure 6.210).

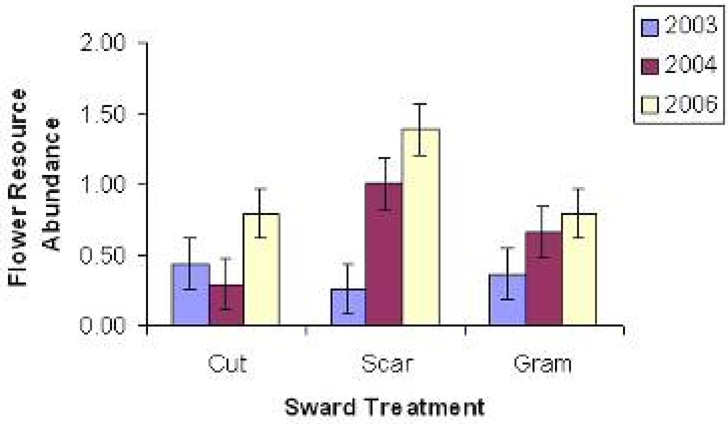


Figure 6.210. Unsown forb flower resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Seed mix, sward and year had no significant effects on resource abundance values for seed that was forming, ripe or dehiscent.

Total Resources

No significant effects of seed mix and sward treatment were determined for total values of vegetative resource abundance. However, a significant year effect was determined ($F_{2,72.1} = 2.8$, $P < 0.05$). Values were significantly lower in 2003 compared with subsequent years ($P < 0.05$) (Figure 6.211).

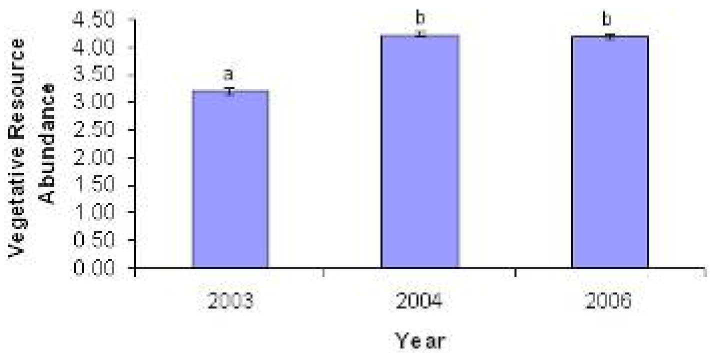


Figure 6.211. Total vegetative resource abundance values (± SE) at Boxworth according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Seed mix and sward treatment were also found not have a significant effect on total values of flowering shoot resource abundance. The year effect was significant ($F_{2,145.0} = 19.5$, $P < 0.001$), with significantly lower values in 2004 ($P < 0.05$) (Figure 6.212).

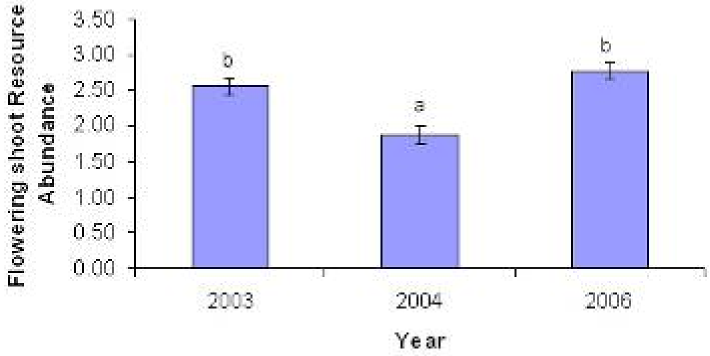


Figure 6.212. Total vegetative resource abundance values (± SE) at Boxworth according to year. Treatments with the same letter do not differ significantly (*P* > 0.05).

A significant interaction between seed mix and year was determined for total values of flower resource abundance ($F_{4,79.8}$ = 4.0, $P < 0.01$), indicating a variable response in plots sown with the different seed mixes according to year (Figure 6.213).

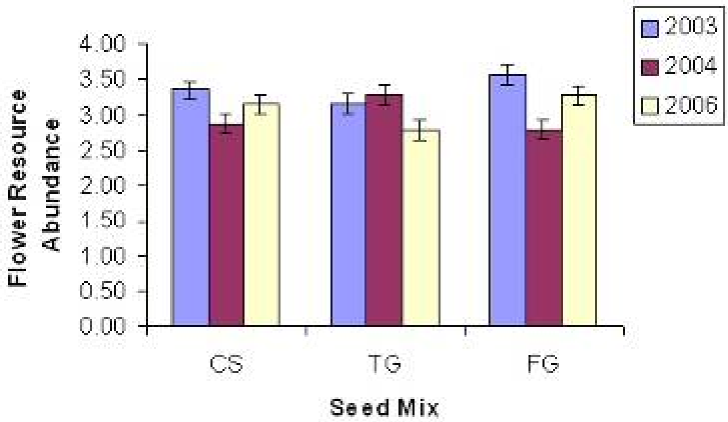


Figure 6.213. Total flower resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant sward treatment by year interaction was also determined ($F_{4,79.8}$ = 10.0, $P < 0.001$). In years 2003 and 2004 values were lower in association with scarification, but in 2006 values increased with scarification relative to 2004, while values in plots that were treated with graminicide decreased (Figure 6.214).

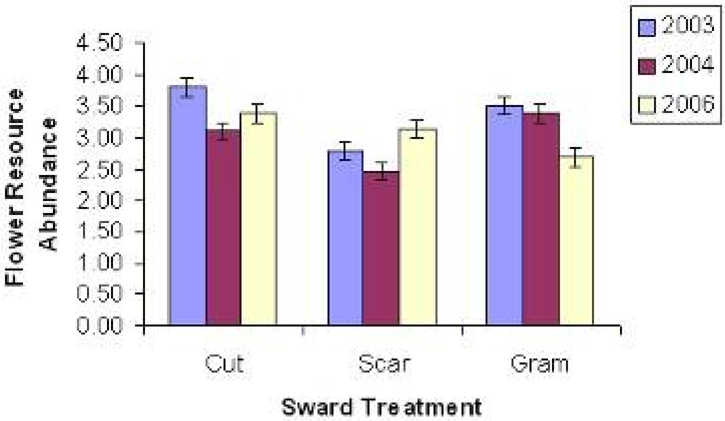


Figure 6.214. Total flower resource abundance values (± SE) at Boxworth according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for values of seed that was forming, ripe or dehiscent ($F_{4,79.8} = 3.6$, $P < 0.01$). In general, values were greater in 2003 irrespective of seed mix. In 2006 values in FG sown plots were substantially greater than with the CS and TG mixes (Figure 6.215). Sward treatment had no significant effect on values of seed resource abundance.

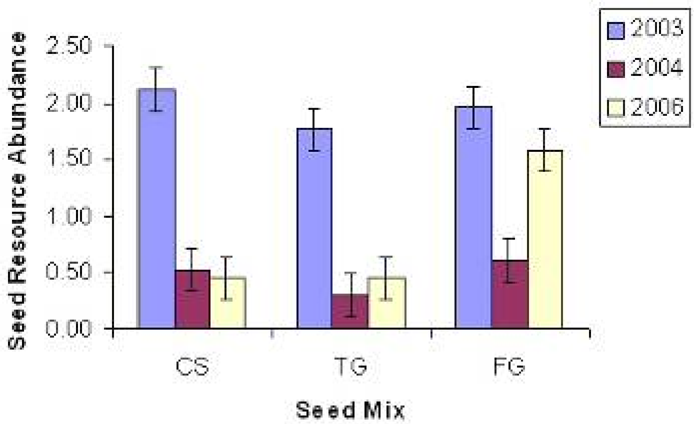


Figure 6.215. Total seed resource abundance values (± SE) at Boxworth according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Gleadthorpe

Sown Grasses

A significant interaction between seed mix and year was determined for values of vegetative resource abundance ($F_{4,74.9} = 3.4$, $P < 0.05$). In 2003, values were lower in plots sown with the FG mix. However, in 2006 values were similar regardless of seed mix (Figure 6.216).

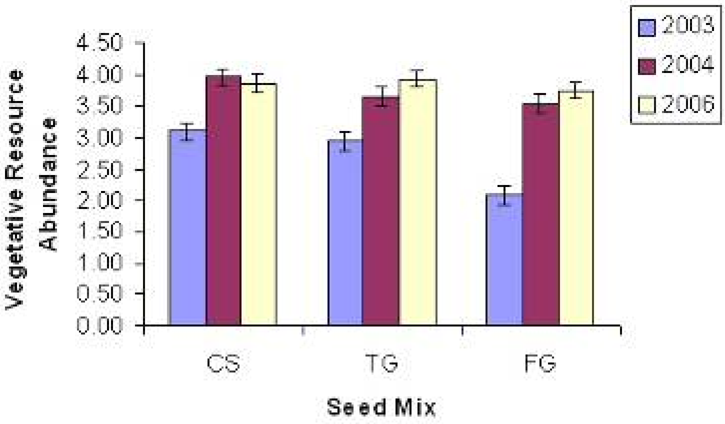


Figure 6.216. Sown grass vegetative resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Sward treatment also had a significant effect on values of vegetative resource abundance ($F_{2,39.5} = 5.0$, $P < 0.05$). Values were significantly lower in association with scarification ($P < 0.05$), while no difference was found between the treatments of cutting and graminicide (Figure 6.217). Interactions between sward treatment and all other parameters were not significant.

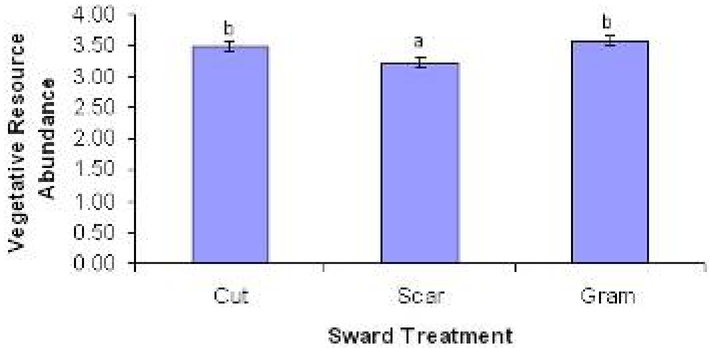


Figure 6.217. Sown grass vegetative resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between seed mix and year was determined for values of sown grass flowering shoot resource abundance ($F_{4,80.4} = 3.3$, $P < 0.05$). In plots sown with the TG and FG mixes values increased between years. However, in association with the CS mix, values peaked in 2004 (Figure 6.218). Sward treatment had no significant effect on values of flowering shoot resource abundance.

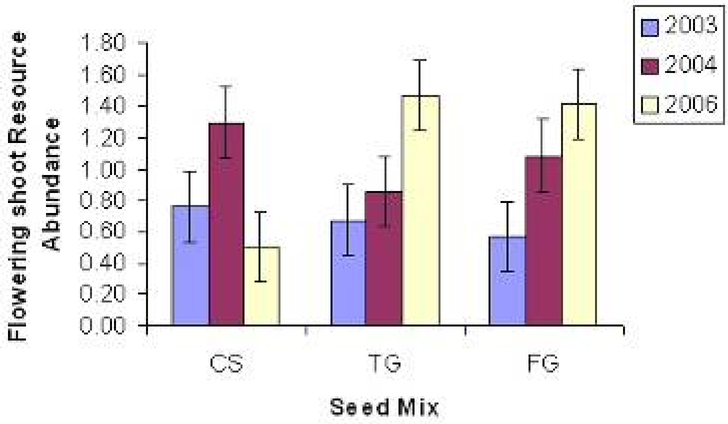


Figure 6.218. Sown grass flowering shoot resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Values of sown grass flower resource abundance were not influenced significantly by seed mix. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,79.1}$ = 2.6, P < 0.05). Values remained relatively constant in plots treated with graminicide, but in association with scarification were substantially lower in 2004 (Figure 6.219).

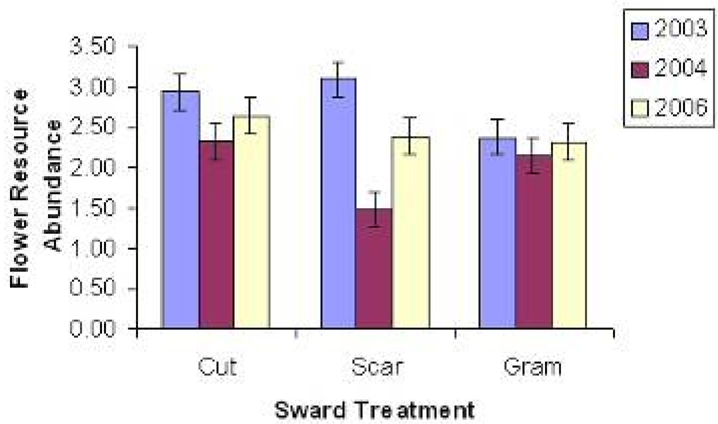


Figure 6.219. Sown grass flower resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant seed mix effect was determined for sown grass values of seed that was forming, ripe or dehiscent ($F_{2,31.8}$ = 5.0, P < 0.05). Values were significantly lower in plots sown with the TG mix. No difference was found between the CS and FG mixes (Figure 6.220).

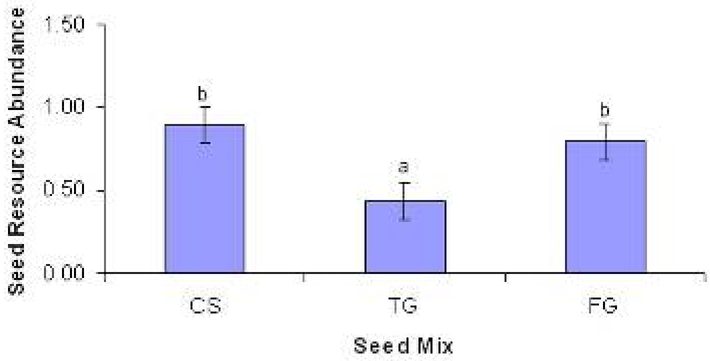


Figure 6.220. Sown grass seed resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between sward treatment and year was determined with respect to values of sown grass seed resource abundance ($F_{4,82.4} = 4.4$, $P < 0.01$). In 2003 values of sown grass seed resource abundance were greater in plots treated with cutting and scarification. However, in 2004, values decreased under all treatments, especially cutting and scarification (Figure 6.221).

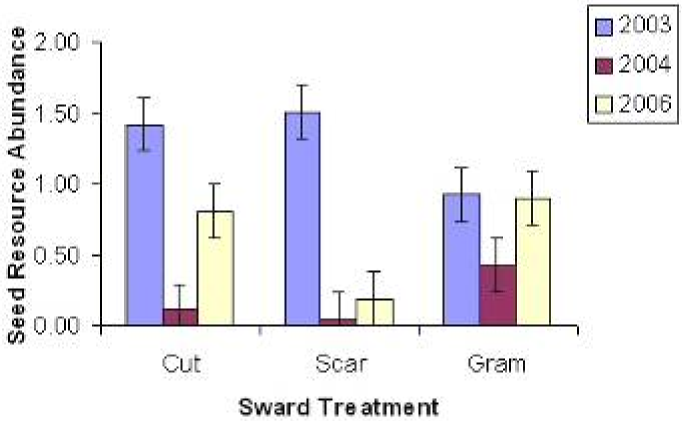


Figure 6.221. Sown grass seed resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Sown Forbs

A significant interaction was determined between seed mix and year for values of sown forb vegetative resource abundance ($F_{4,77.3} = 4.1$, $P < 0.01$). Values were consistently greater in plots sown with the TG and FG seed mixes compared with the CS mix. Values were lowest in 2003, and this effect was greater for the TG and FG mixes, compared with the CS mix (Figure 6.222). Sward treatment had no significant effect on values.

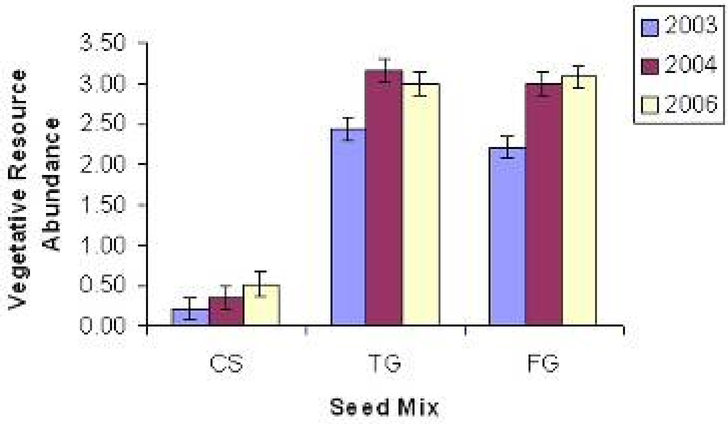


Figure 6.222. Sown forb vegetative resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between seed mix and year was also determined for values of sown forb flowering shoot resource abundance ($F_{4,63.4}$ = 11.3, P < 0.001). Values were substantially lower with the CS mix. In association with the FG mix, values increased between years and by 2006 were greater than with the TG mix. Values in the TG mix peaked in 2004 (Figure 6.223). The effect of sward treatment was not significant.

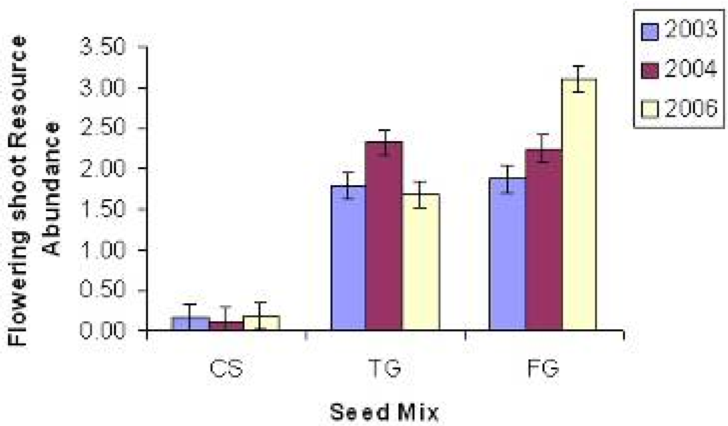


Figure 6.223. Sown forb flowering shoot resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between seed mix and year was determined for values of sown forb flower resource abundance ($F_{4,83.2}$ = 5.0, P = 0.001). Values were consistently greater in plots sown with the FG mix and lowest with the CS mix. Values increased in the TG plots in 2004 relative to 2003, but decreased in 2006. In contrast, values in the FG plots were similar during 2003 and 2004, but increased in 2006 (Figure 6.224).

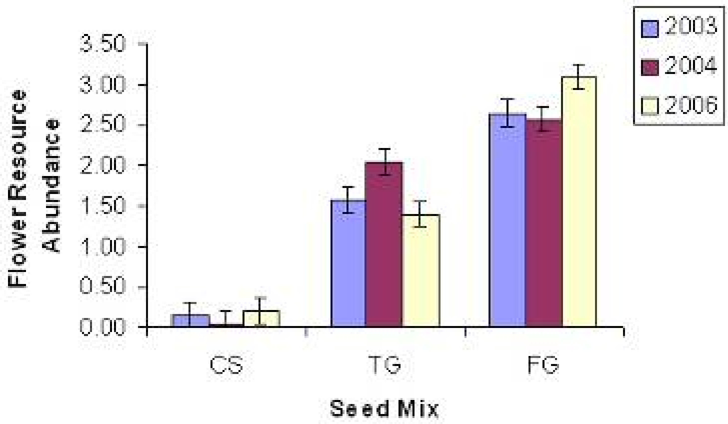


Figure 6.224. Sown forb flower resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant sward treatment effect was also found for values of sown forb flower abundance ($F_{2,46.5}$ = 3.8, $P < 0.05$). Values were significantly greater in plots treated with graminicide ($P < 0.05$). No difference was found between cutting and scarification (Figure 6.225). Interactions between sward treatment and all other parameters were not significant.

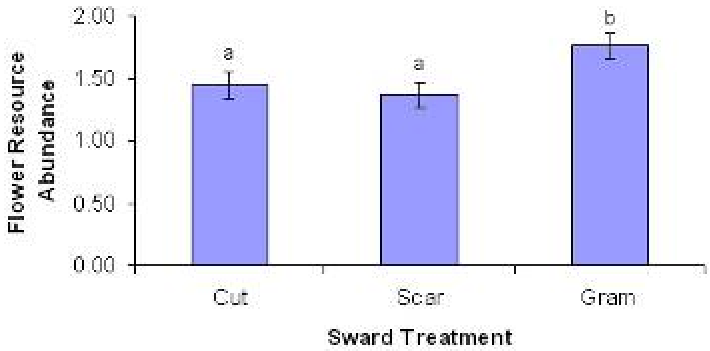


Figure 6.225. Sown forb flower resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant interaction between seed mix and year was determined for values of sown forb seed that was forming, ripe or dehiscent ($F_{4,77.3}$ = 3.1, $P < 0.05$). Values were negligible in plots sown with the CS mix and substantially greater in plots sown with the FG mix. In plots sown with the TG and FG mixes, values were observed to decrease after 2003 (Figure 6.226). The effect of sward treatment was not significant.

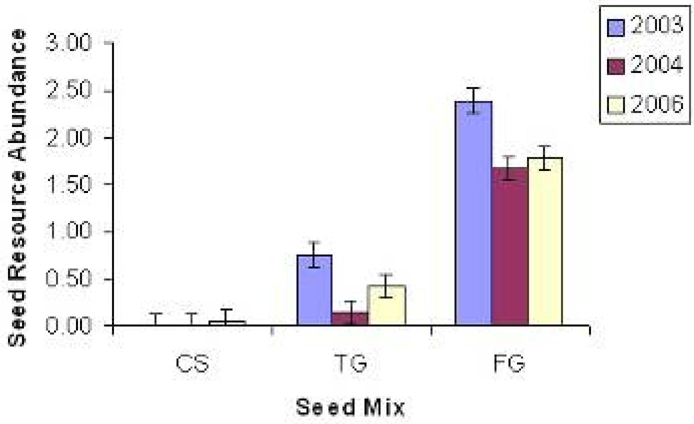


Figure 6.226. Sown forb seed resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

Unsown Grasses

Seed mix and sward treatment had no significant effects on values of unsown grass vegetative resource abundance. In contrast, year was observed to have a significant effect ($F_{2,76.4}$ = 13.3, P < 0.001) (Figure 6.227).

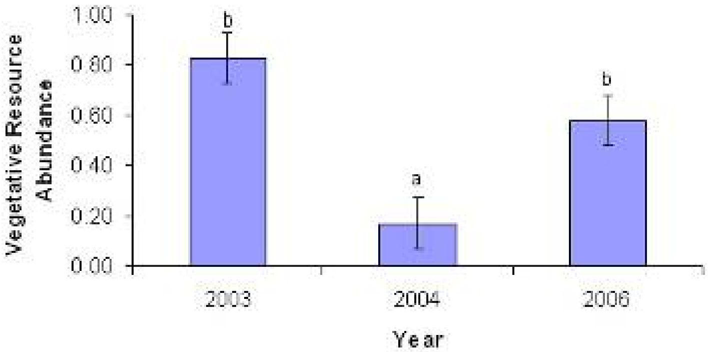


Figure 6.227. Unsown grass vegetative resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly (P > 0.05).

Seed mix had no significant effect on values of unsown grass flowering shoot resource abundance. However, a significant interaction between sward treatment and year was determined ($F_{4,68.7}$ = 2.6, P < 0.05). Values decreased after 2003 in plots treated with scarification or graminicide, but increased in association with cutting between 2003 and 2006 (Figure 6.228).

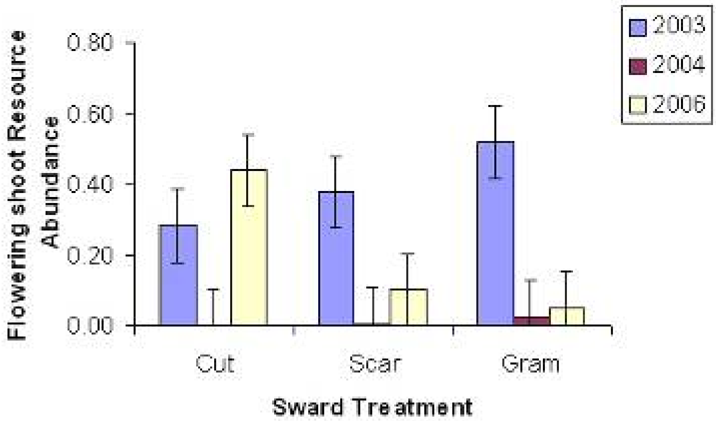


Figure 6.228. Unsown grass flowering shoot resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Seed mix and sward treatment had no significant effects on values of unsown grass flower resource abundance. However, year was observed to have a significant effect ($F_{2,72.9}$ = 73.7, P < 0.001). Values were significantly greater in 2003 compared with subsequent years (P < 0.05). No difference was determined between years 2004 and 2006 (Figure 6.229).

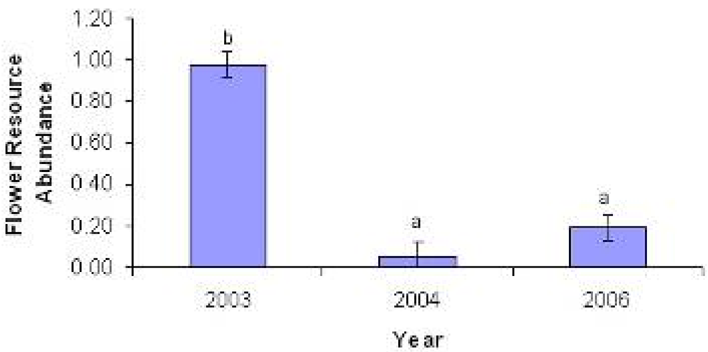


Figure 6.229. Unsown grass flower resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly (P > 0.05).

Seed mix and sward treatment had no significant effects on values of unsown grass seed that was forming, ripe or dehiscent. However, year was observed to have a significant effect ($F_{2,68.9}$ = 47.3, P < 0.001). Values were significantly greater in 2003 compared with 2004 and 2006 (P < 0.05). No difference was found between 2004 and 2006 values (Figure 6.230).

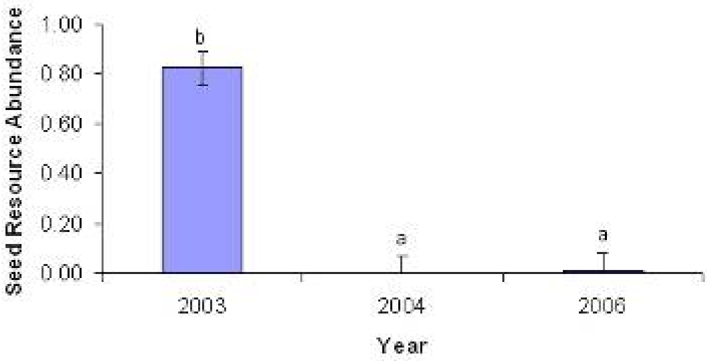


Figure 6.230. Unsown grass seed resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Unsown Forbs

Seed mix had no significant effect on values of unsown forb vegetative resource abundance values. A significant sward treatment effect was determined ($F_{2,39.9} = 3.5$, $P < 0.05$). Values were significantly lower in association with cutting ($P < 0.05$). No difference was found between the treatments of scarification and graminicide (Figure 6.231).

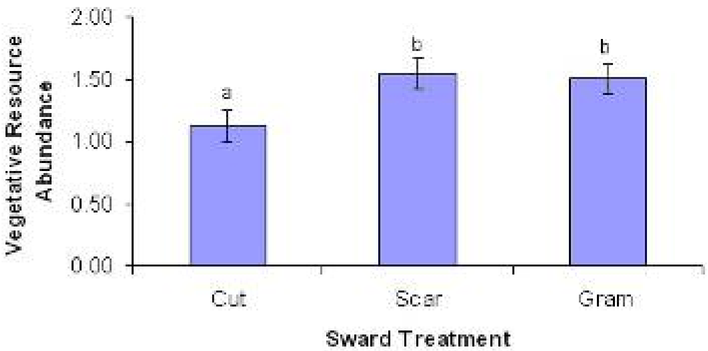


Figure 6.231. Unsown forb vegetative resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant year effect was also determined ($F_{2,69.6} = 23.6$, $P < 0.001$). Values differed significantly between years ($P < 0.05$), decreasing from 2003 to 2004, but increasing from 2004 to 2006 (Figure 6.232).

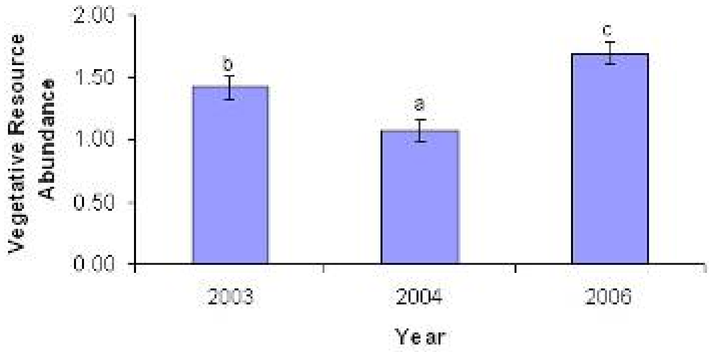


Figure 6.232. Unsown forb vegetative resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

A marginal effect of seed mix was found for values of unsown forb flowering shoot resource abundance ($F_{2,37.0} = 3.2$, $P = 0.051$). Values were greatest in the CS plots and lowest in association with the TG mix. A significant interaction between sward treatment and year was determined ($F_{4,76.7} = 3.7$, $P < 0.01$). Values were markedly lower during 2004 compared with 2003 and 2006. In 2003, graminicide was associated with the greatest flowering shoot resource abundance, while in 2006 similar values were obtained under treatments of graminicide and scarification (Figure 6.233).

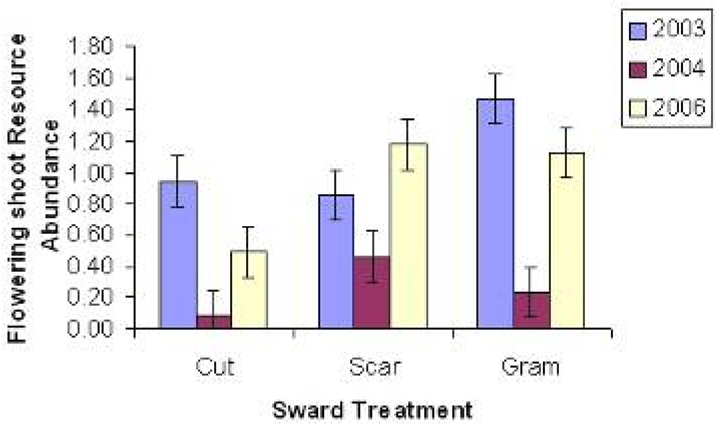


Figure 6.233. Unsown forb flowering shoot resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Seed mix had no significant effect on values of unsown forb flower resource abundance. The effect of sward treatment was marginally significant ($F_{2,42.5} = 3.1$, $P = 0.054$). A significant effect of year was determined ($F_{2,83.5} = 38.8$, $P < 0.001$). Values were significantly greater in 2003 compared with subsequent years ($P < 0.05$). No difference was found between years 2004 and 2006 (Figure 6.234).

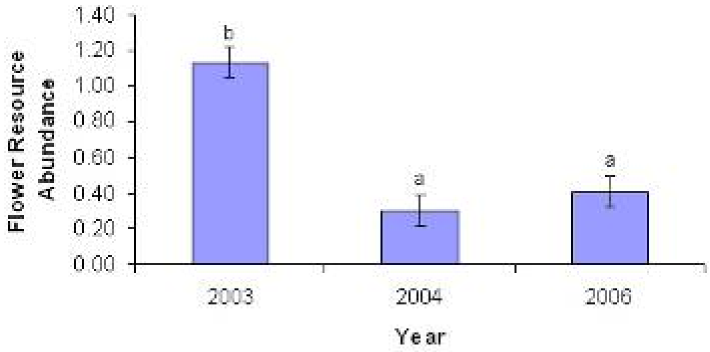


Figure 6.234. Unsown forb flower resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Seed mix and sward treatment had no significant effect on values of unsown forb seed that was forming, ripe or dehiscent. A significant year effect was determined ($F_{2,77.7} = 26.6$, $P < 0.001$). As with measures of flower resource abundance, values were significantly greater in 2003 compared with subsequent years ($P < 0.05$), and no difference was found between years 2004 and 2006 (Figure 6.235).

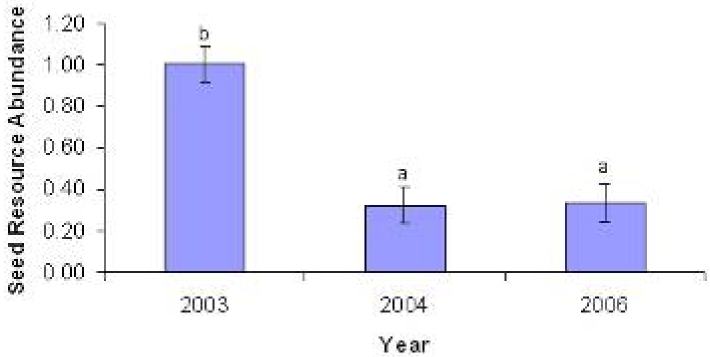


Figure 6.235. Unsown forb seed resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Total Resource Abundance Values

No significant effect of seed mix on values of total vegetative resource abundance was determined. In contrast, sward treatment had a significant effect ($F_{2,46.2} = 3.6$, $P < 0.05$). Values were significantly greater in plots treated with graminicide compared with scarification ($P < 0.05$). No difference was found between scarification and cutting or between cutting and graminicide (Figure 6.236).

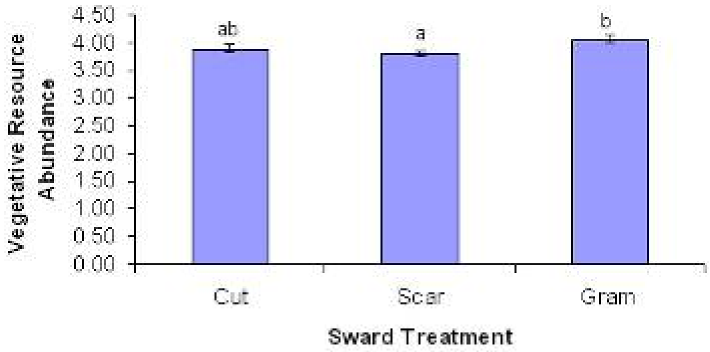


Figure 6.236. Total vegetative resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly ($P > 0.05$).

Year also had a significant effect on values of total vegetative resource abundance ($F_{2,86.2} = 71.3$, $P < 0.001$). Values were observed to increase significantly between years ($P < 0.05$) (Figure 6.237).

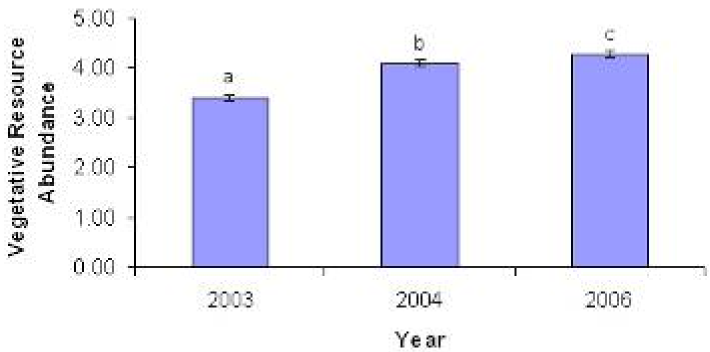


Figure 6.237. Total vegetative resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant interaction between seed mix and year was determined for total values of flowering shoot resource abundance ($F_{4,72.8} = 5.5$, $P = 0.001$). Values were generally lower in association with the CS mix. In 2006, values increased in plots sown with the FG mix relative to the other seed mixes (Figure 6.238). The effect of sward treatment on values of flowering shoot resource abundance was not significant.

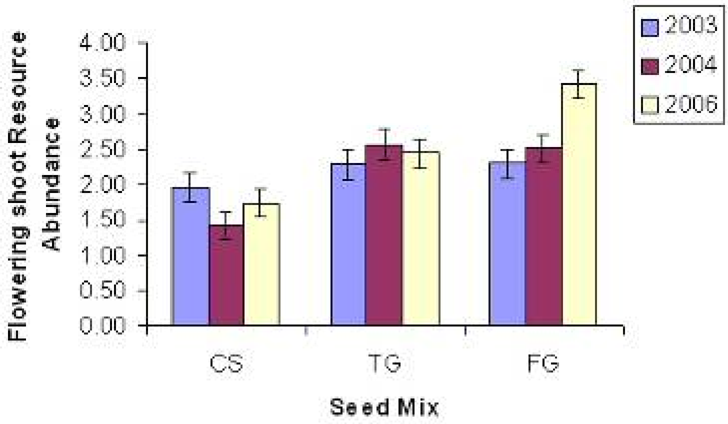


Figure 6.238. Total flowering shoot resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant effect of seed mix was determined for total values of flower resource abundance ($F_{2,36.9}$ = 16.2, P < 0.001); values were significantly greater in 2006 (P < 0.05). No difference was found between values obtained in 2003 and 2004 (Figure 6.239). Interactions between seed mix and all other parameters were not significant.

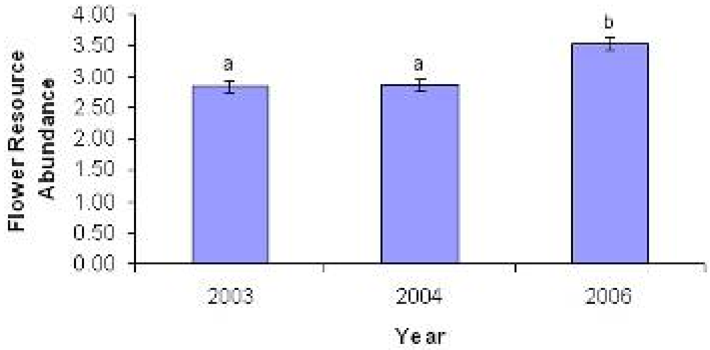


Figure 6.239. Total flower resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly (P > 0.05).

With respect to total flower resource abundance, the interaction between sward treatment and year was significant ($F_{4,65.1}$ = 5.3, P = 0.001). Values remained relatively constant in association with graminicide. In contrast, values decreased after 2003 in association with cutting and scarification.Values for 2004 were substantially lower than for 2003 in plots that were scarified, but then increased between 2004 and 2006 (Figure 6.240).

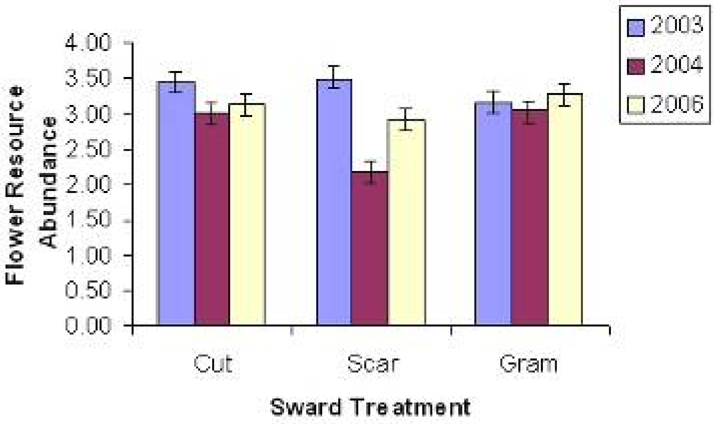


Figure 6.240. Total flower resource abundance values (± SE) at Gleadthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant effect of seed mix was determined for total values of seed that was forming, ripe or dehiscent ($F_{2,39.8}$ = 19.8, *P* < 0.001). A greater seed resource abundance was observed in plots sown with the FG mix (*P* < 0.05). No significant difference was found between plots sown with the CS and TG mixes (Figure 6.241). Interactions between seed mix and all other parameters were not significant.

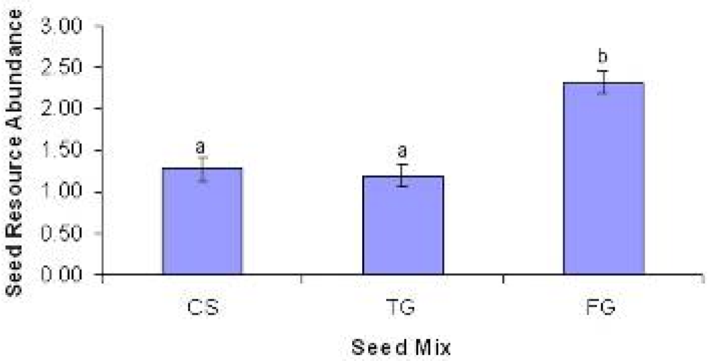


Figure 6.241. Total seed resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (*P* > 0.05).

There was also a significant effect of sward treatment on total values of seed resource abundance ($F_{2,39.8}$ = 5.6, *P* < 0.01). Values were significantly greater in graminicide treated plots compared with scarification (*P* < 0.05). No differences were found between graminicide and cutting, or cutting and graminicide (Figure 6.242). Interactions between sward treatment and all other parameters were not significant.

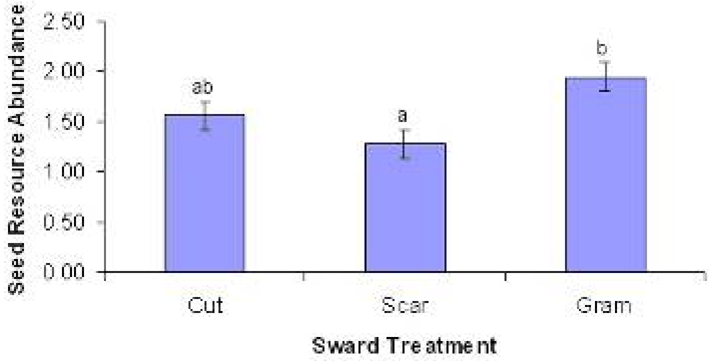


Figure 6.242. Total seed resource abundance values (± SE) at Gleadthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix). Treatments with the same letter do not differ significantly (*P* > 0.05).

A significant year effect was also determined ($F_{2,83.2}$ = 43.2, *P* < 0.001). Values were significantly greater in 2003 compared with subsequent years (*P* < 0.05). No difference was found between 2004 and 2006 (Figure 6.243).

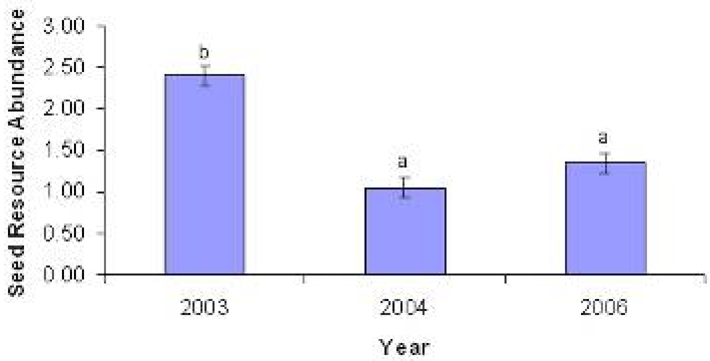


Figure 6.243. Total seed resource abundance values (± SE) at Gleadthorpe according to year. Treatments with the same letter do not differ significantly (*P* > 0.05).

High Mowthorpe

Sown Grasses

A significant interaction between seed mix, sward treatment and year was determined for values of sown grass vegetative resource abundance ($F_{12,46.1}$ = 2.2, *P* < 0.05). The lowest values were observed in 2003 in plots sown with the FG mix that were either cut or treated with graminicide (Figure 6.244).

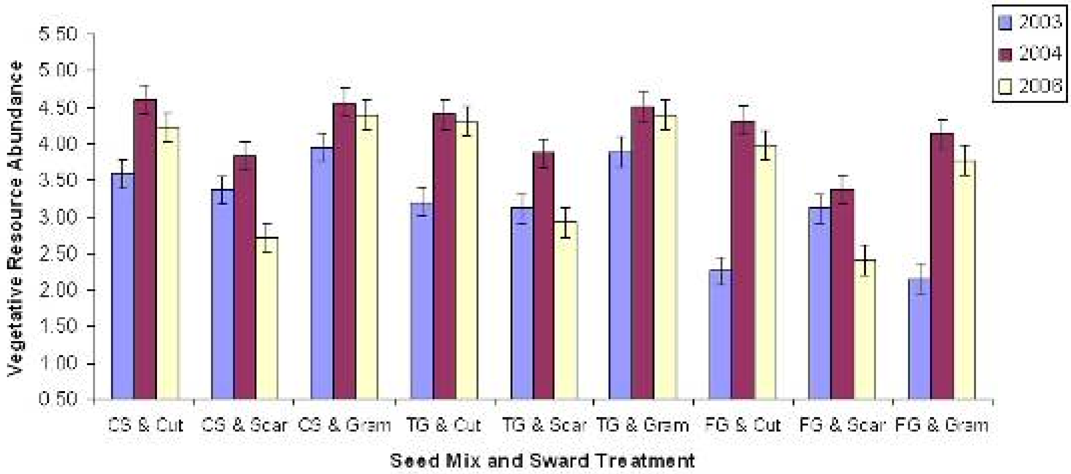


Figure 6.244. Sown grass vegetative resource values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for values of flowering shoot resource abundance ($F_{4,82.0}$ = 2.9, P < 0.05). In 2003, values were substantially greater in plots sown with the TG mix and regardless of seed mix, values were lower in 2004 compared with 2003 and 2006 (Figure 6.245). No significant effect of sward treatment was determined.

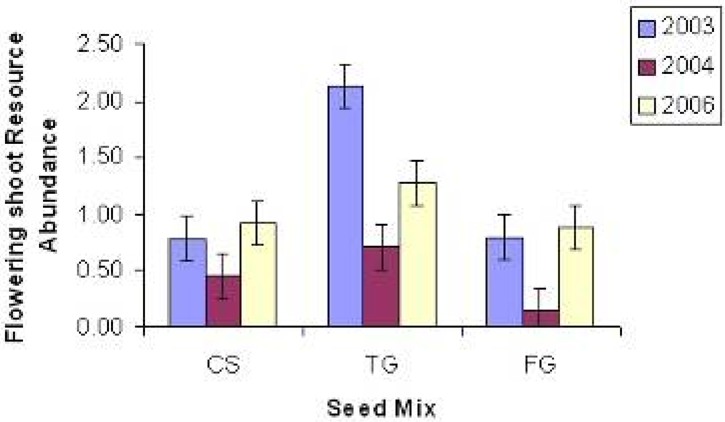


Figure 6.245. Sown grass flowering shoot resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between seed mix and year was determined for values of sown grass flower resource abundance ($F_{4,78.6}$ = 7.0, P < 0.001). In association with the CS and TG mixes, values decreased between years. In contrast, in plots sown with the FG mix, values decreased between 2003 and 2004, but had increased by 2006 (Figure 6.246).

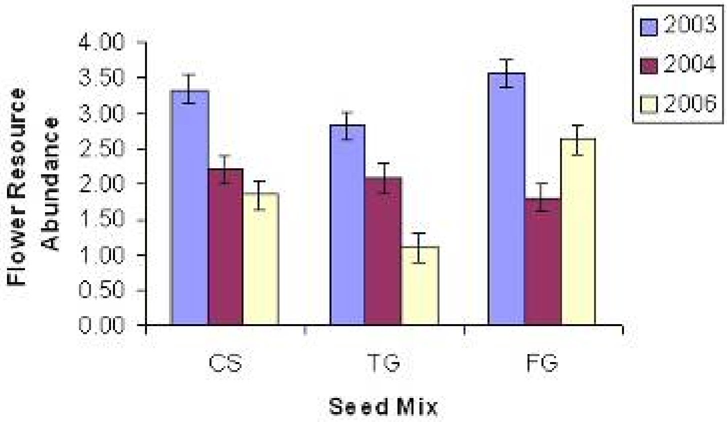


Figure 6.246. Sown grass flower shoot resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined ($F_{4,78.6}$ = 8.6, P < 0.001). Values were greater in 2003, especially in association with cutting. During 2004 and 2006 values remained relatively constant in plots that were cut or treated with graminicide, but decreased to markedly lower values with scarification (Figure 6.247).

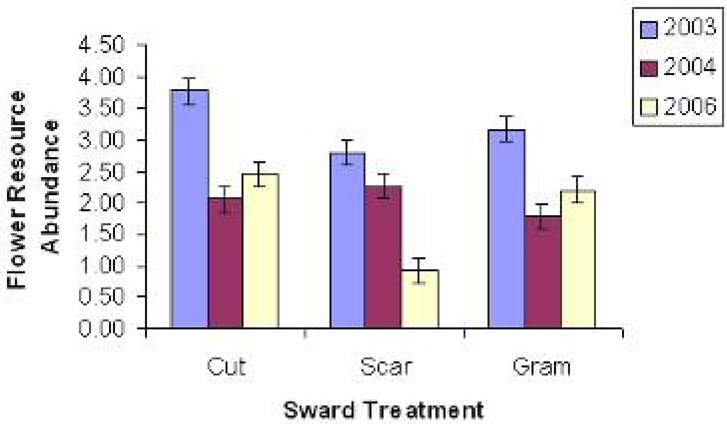


Figure 6.247. Sown grass flower resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix, sward treatment and year was determined for values of sown grass seed that was forming, ripe or dehiscent ($F_{16,71.5}$ = 2.0, P < 0.05). Overall, values were generally lower in plots sown with the TG mix and w ere substantially low er in 2006 irrespective of seed mix and sw ard treatment (Figure 6.248).

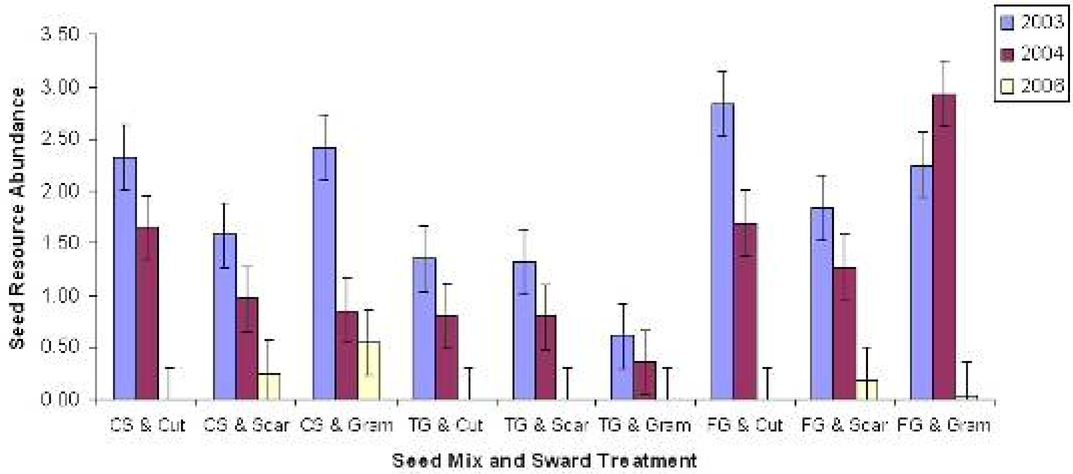


Figure 6.248. Sow n grass seed resource values (± SE) at High Mow thorpe according to seed mix (CS = Countryside Stew ardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sw ard treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Sow n Forbs

A significant interaction betw een seed mix and year w as determined for values of sow n forb vegetative resource abundance ($F_{4,59.0} = 9.6$, $P < 0.001$). Values remained relatively low in plots sown with the CS mix, but increased w ith time in the FG plots. In contrast, in association w ith the TG mix, values peaked in 2004 (Figure 6.249).

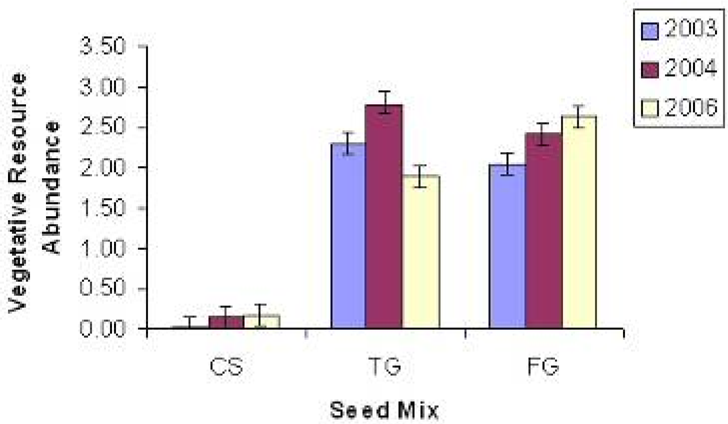


Figure 6.249. Sow n forb vegetative resource abundance values (± SE) at High Mow thorpe according to seed mix (CS = Countryside Stew ardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sw ard treatment and year w as also determined ($F_{4,59.0} = 7.9$, $P < 0.001$). In association w ith cutting values remained constant over the study period. In contrast, in plots that were scarified, values of sown forb vegetative resource abundance peaked in 2004, while with graminicide, values increased with time (Figure 6.250).

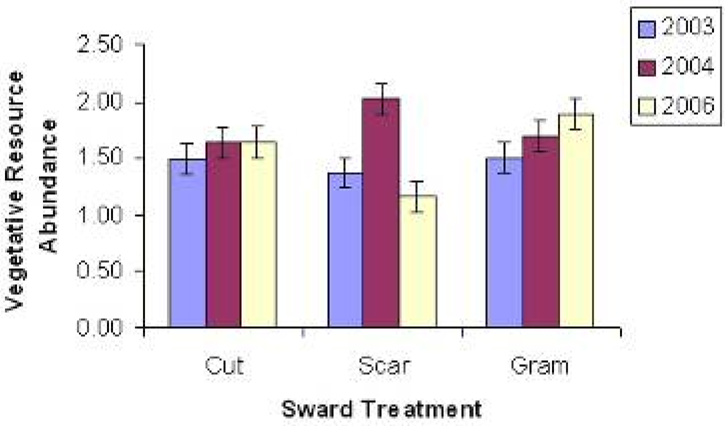


Figure 6.250. Sown forb vegetative resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix, sward treatment and year was determined for values of sown forb, flowering shoot resource abundance ($F_{8,64.5} = 3.1$, $P < 0.01$). In all years, values were negligible in plots sown with the CS mix. In 2003, values were similar in plots sown with the TG and FG mixes, regardless of sward treatment. However, in 2004 and 2006, values were lower in association in plots sown with the TG mix that were also scarified. Overall, values were greatest in 2006 in plots sown with the TG mix and treated with graminicide (Figure 6.251).

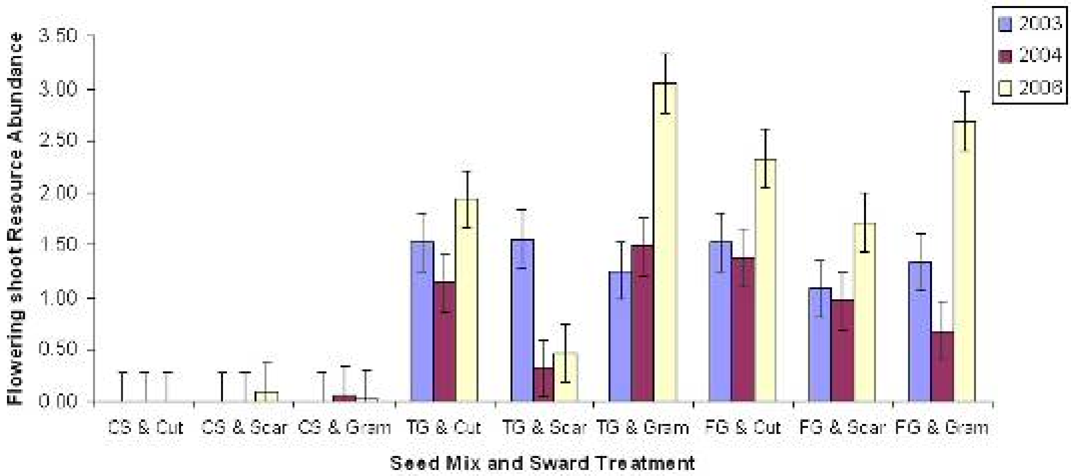


Figure 6.251. Sown forb flowering shoot resource values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix), sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and sward treatment was determined for values of sown forb flower resource abundance ($F_{4,48.5} = 3.9$, $P < 0.01$). Values were negligible in plots sown with the CS mix and were generally greater in plots sown with the FG mix under all sward treatment regimes (Figure 6.252).

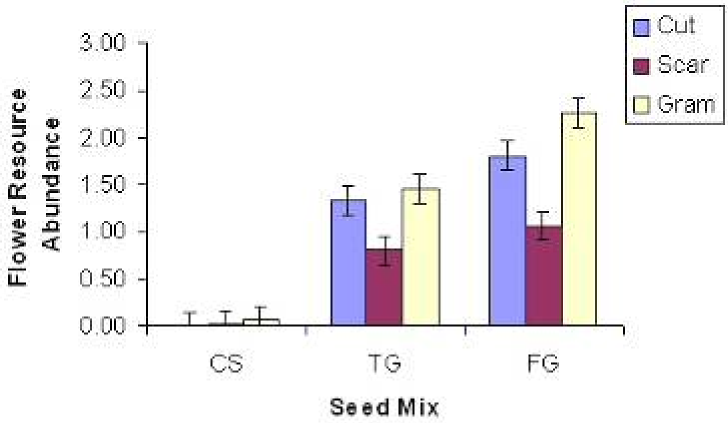


Figure 6.252. Sown forb flower resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant interaction between seed mix and year was also determined ($F_{4,87.7} = 14.0$, $P < 0.001$). Values were negligible in the CS plots and were observed to decrease substantially in plots sown with the TG mix by 2006. In contrast, values remained relatively constant in plots sown with the FG mix (Figure 6.253).

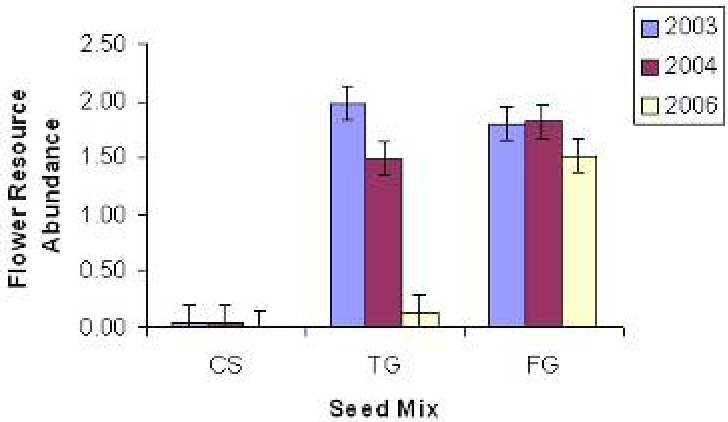


Figure 6.253. Sown forb flower resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between seed mix and year was determined for values of sown forb seed that was forming, ripe or dehiscent ($F_{4,69.5} = 7.9$, $P < 0.001$). As with the other measures of resource abundance, sown forb seed abundance in plots sown with the CS plots was negligible. In plots sown with the TG and FG mixes, values were similar in 2003, but were substantially greater in the FG plots in 2004 (Figure 6.254). However, in 2006, values were low for all seed mixes.

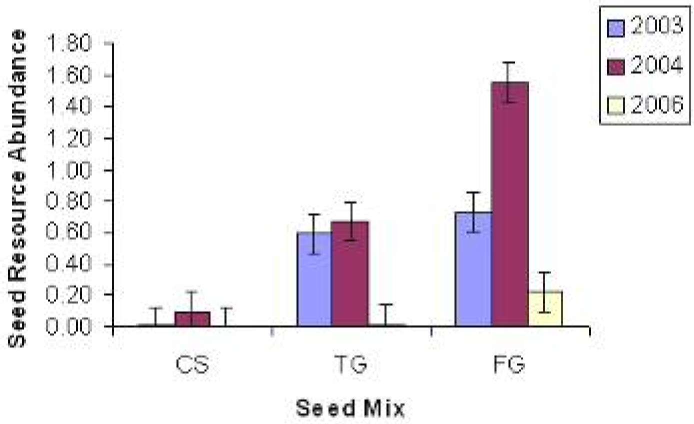


Figure 6.254. Sown forb seed resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined ($F_{4,69.5} = 3.0$, $P < 0.05$). In plots that were cut or treated with graminicide, values were greatest in 2004. Scarification was associated with the lowest values of seed resource abundance (Figure 6.255).

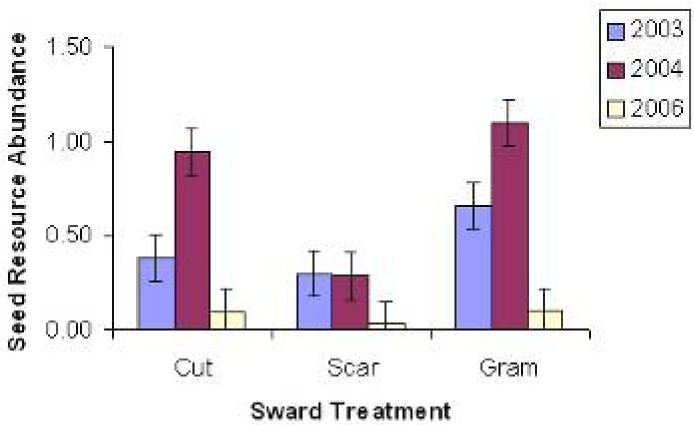


Figure 6.255. Sown forb seed resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Unsown Grasses

Seed mix had no significant effect on values of unsown grass vegetative resource abundance. In contrast, a significant effect of sward treatment was found ($F_{2,38.8}$ = 15.2, $P < 0.001$). Scarification was associated with a significantly greater abundance of unsown grass vegetative resource ($P < 0.05$) and no difference was found between the cut and graminicide treatments (Figure 6.256). Interactions between sward treatment and all other parameters were not significant.

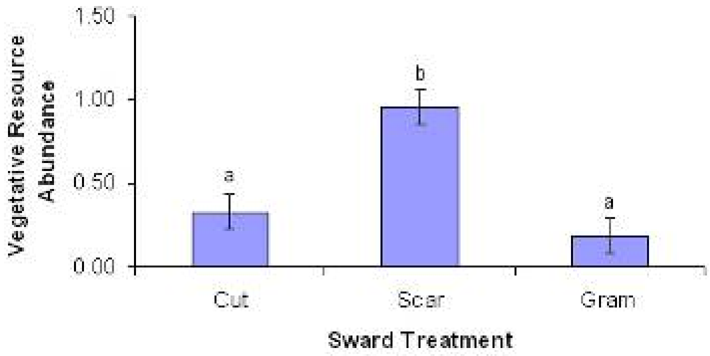


Figure 6.256. Unsown grass vegetative resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant year effect was found ($F_{2,69.9}$ = 6.0, $P < 0.01$). Values were significantly greater in 2006 compared with 2004 ($P < 0.05$). However, no difference was found between 2003 and 2004 and 2003 and 2006 (Figure 6.257).

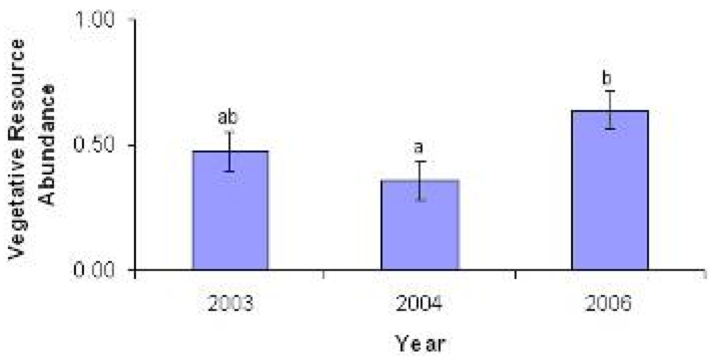


Figure 6.257. Unsown grass vegetative resource abundance values (± SE) at High Mowthorpe according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Seed mix and year had no significant effects on values of unsown grass flowering shoot resource abundance. In contrast, a significant effect of sward treatment was determined ($F_{2,45.4}$ = 12.5, $P < 0.001$). Values were significantly greater in plots that were scarified ($P < 0.05$) and no difference was found between treatments of cutting or graminicide (Figure 6.258). Interactions between sward treatment and all other parameters were not significant.

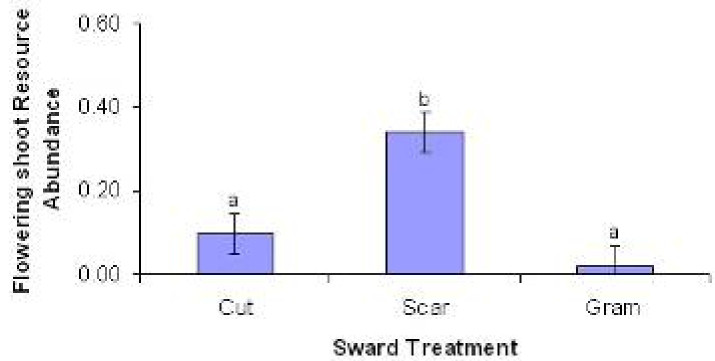


Figure 6.258. Unsown grass flowering shoot resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

Seed mix had no significant effect on values of unsown grass, flower resource abundance. In contrast, a significant interaction between sward treatment and year was determined ($F_{4,70.1} = 4.6$, $P < 0.01$). By 2004, values were negligible in association with graminicide treated plots (Figure 6.259).

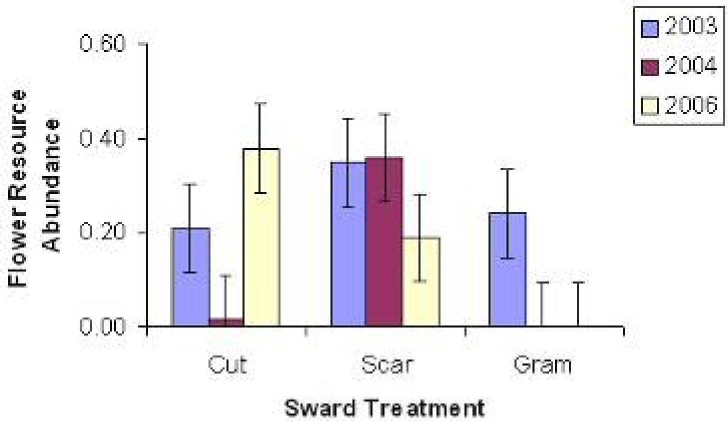


Figure 6.259. Unsown grass flower resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

For values of unsown grass seed that was ripe, forming or dehiscent, no significant effects of seed mix or sward treatment were determined. However, a significant year effect was determined ($F_{2,77.2} = 12.4$, $P < 0.001$). Regardless of year, values of seed resource abundance were low. However, values were significantly greater in 2003 compared with subsequent years ($P < 0.05$). No difference was found between 2004 and 2006 (Figure 6.260).

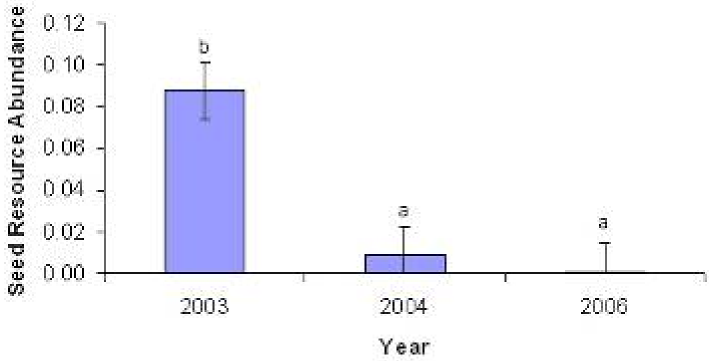


Figure 6.260. Unsown grass seed resource abundance values (± SE) at High Mowthorpe according to year. Treatments with the same letter do not differ significantly ($P > 0.05$).

Unsown Forbs

Seed mix had no significant effect on values of unsown forb, vegetative resource abundance. In contrast, the effect of sward treatment was significant ($F_{2,39.5} = 12.6$, $P < 0.001$). Values were significantly greater in plots that were scarified ($P < 0.05$) and no difference was found between cutting and graminicide (Figure 6.261). Interactions between sward treatment and all other parameters were not significant.

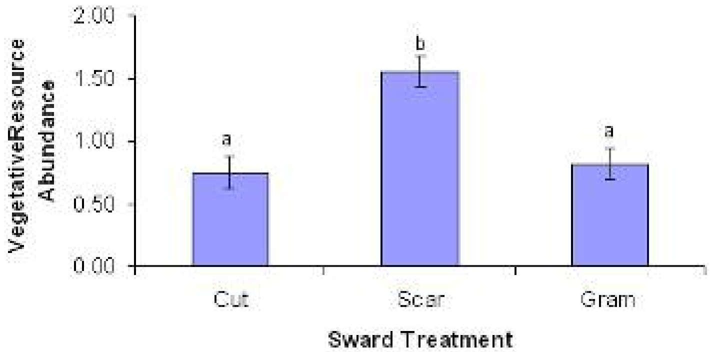


Figure 6.261. Unsown forb vegetative resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide). Treatments with the same letter do not differ significantly ($P > 0.05$).

A significant year effect was also determined ($F_{2,72.0} = 4.8$, $P < 0.05$) and values were significantly greater in 2006 compared with previous years ($P < 0.05$). No difference was found between 2003 and 2004 (Figure 6.262).

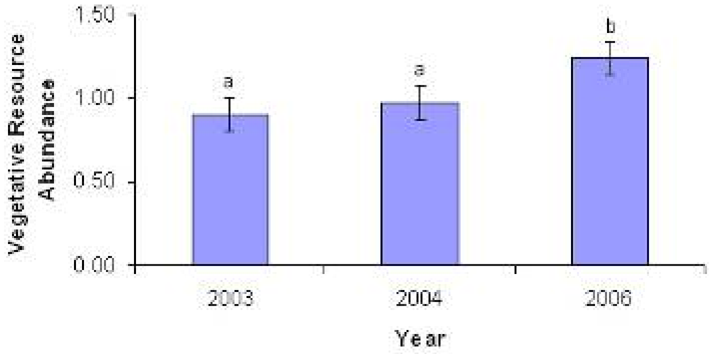


Figure 6.262. Unsown forb vegetative resource abundance values (± SE) at High Mowthorpe according to year. Treatments with the same letter do not differ significantly (*P* > 0.05).

No significant effect of seed mix was found for values of unsown forb, flowering shoot resource abundance. However, a significant interaction between sward treatment and year was determined ($F_{4,73.4}$ = 20.1, *P* < 0.001). Values were greater with scarification in 2003 and 2004, but in 2006, values were negligible across all treatments (Figure 6.263).

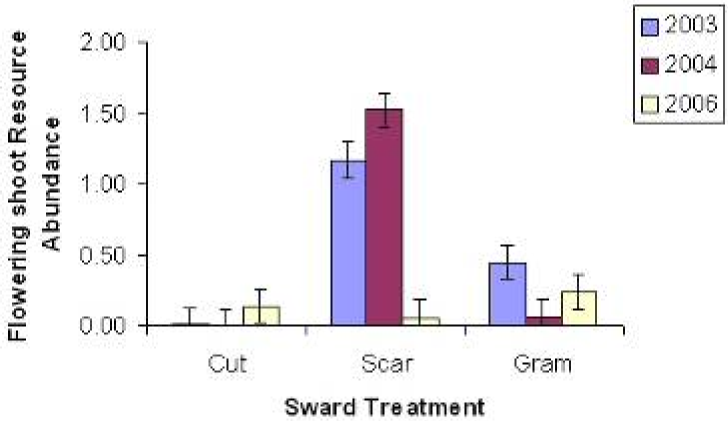


Figure 6.263. Unsown forb flowering shoot resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Seed mix also had no significant effect on values of flower resource abundance, but there was a significant interaction between sward treatment and year ($F_{4,83.6}$ = 16.8, *P* < 0.001). Values were greater in plots treated with scarification during 2003 and 2004, but were negligible under all treatments in 2006 (Figure 6.264).

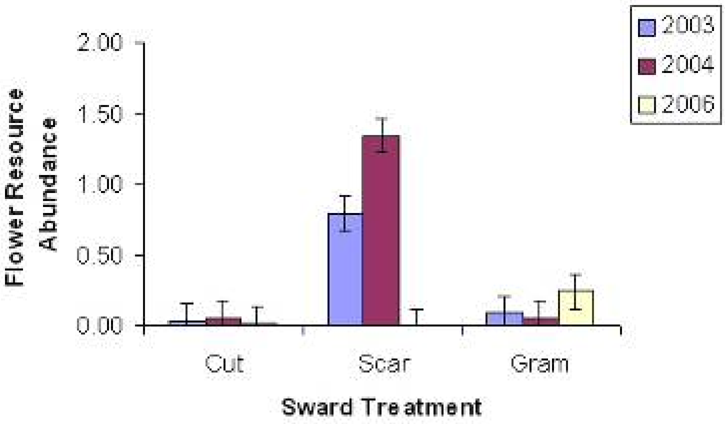


Figure 6.264. Unsown forb flower resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

No significant effect of seed mix was found for values of unsown forb seed that was ripe, forming or dehiscent. In contrast, a significant sward treatment by year interaction was determined ($F_{4,75.6}$ = 11.6, P < 0.001). Values were greater in plots treated with scarification during 2003 and 2004, but were negligible under all treatments in 2006 (Figure 6.265).

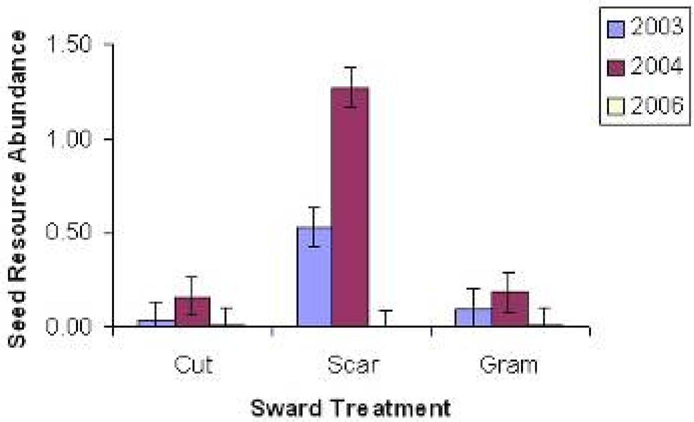


Figure 6.265. Unsown forb seed resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

Total Resource Abundance Values

For values of total vegetative resource abundance, significant interactions between seed mix and sward treatment ($F_{4,33.6}$ = 3.3, P < 0.05), seed mix and year ($F_{4,70.5}$ =

4.3, P < 0.01), and sward treatment and year ($F_{4,70.5}$ = 16.6, P < 0.001) were determined.

The interaction between seed mix and sward treatment was associated with lower values in plots sown with the CS or TG mix that were also scarified. Values in plots sown with the FG mix were similar under all treatments (Figure 6.266).

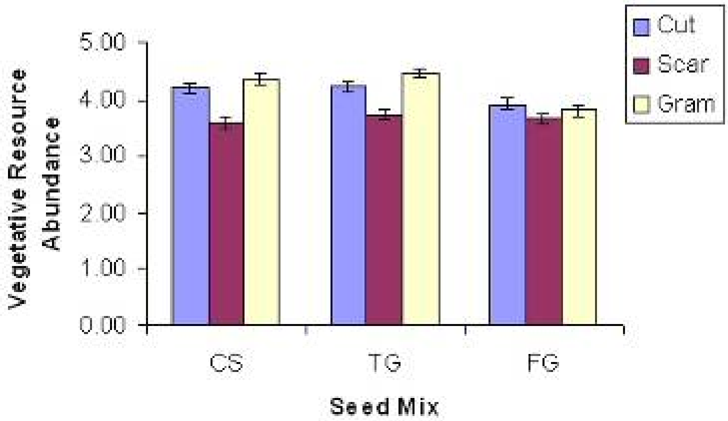


Figure 6.266. Total vegetative resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

The significant interaction between seed mix and year revealed that values increased in 2004 relative to values obtained in 2003. However, in 2006, values decreased and were lower for all seed mixes (Figure 6.267).

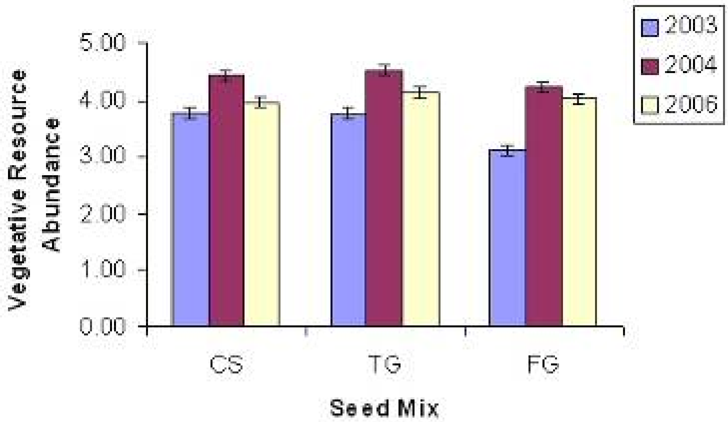


Figure 6.267. Total vegetative resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

The significant interaction betw een sward treatment and year indicated that values in 2003 w ere similar across all treatments, but in 2004 and 2006, values w ere low est in plots treated w ith scarification (Figure 6.268).

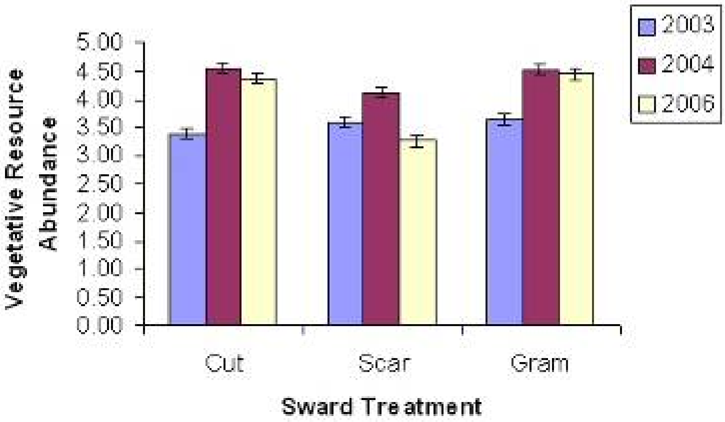


Figure 6.268. Total vegetative resource abundance values (± SE) at High Mow thorpe according to sw ard treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction betw een seed mix and sw ard treatment w as determined for values of total flow ering shoot resource abundance ($F_{4,41.8} = 2.7$, $P < 0.05$). Values were substantially low er in plots sown with the CS mix that w ere also treated with cutting or graminicide. In plots sow n w ith the TG or FG mixes, values w ere similar across all treatments (Figure 6.269).

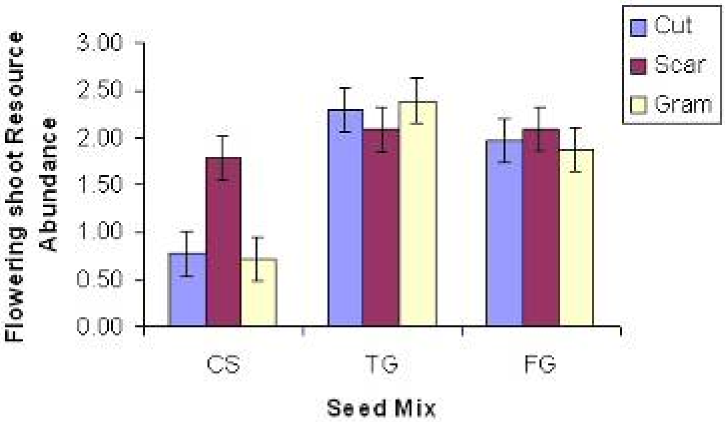


Figure 6.269. Total flow ering shoot resource abundance values (± SE) at High Mow thorpe according to seed mix (CS = Countryside Stew ardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and sw ard treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide).

A significant seed mix by year interaction was also determined for values of total flowering shoot resource abundance ($F_{4,78.4}$ = 3.7, P < 0.01). Values were lower across all years in plots sown with the CS mix. For the TG mix, values were lower in 2004 than in 2003 or 2006, but for the FG mix, values were lower in 2003 and 2004, than in 2006 (Figure 6.270).

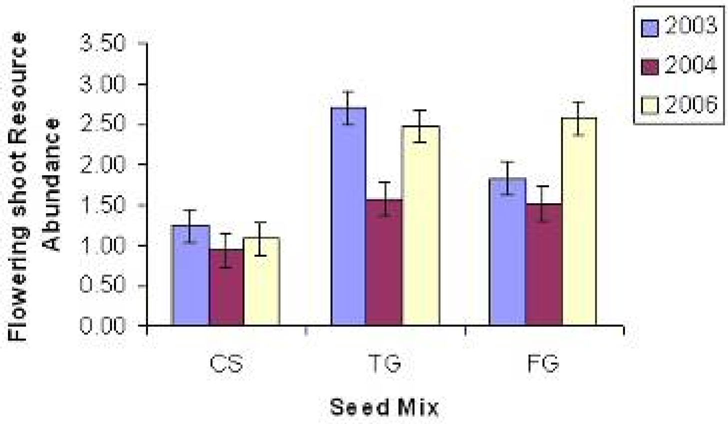


Figure 6.270. Total flowering shoot resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was also determined ($F_{4,78.4}$ = 4.1, P < 0.01). Values decreased under all treatments between 2003 and 2004. However, in 2006, values increased with cutting and graminicide, whilst values in scarified plots, values were similar to 2004 (Figure 6.271).

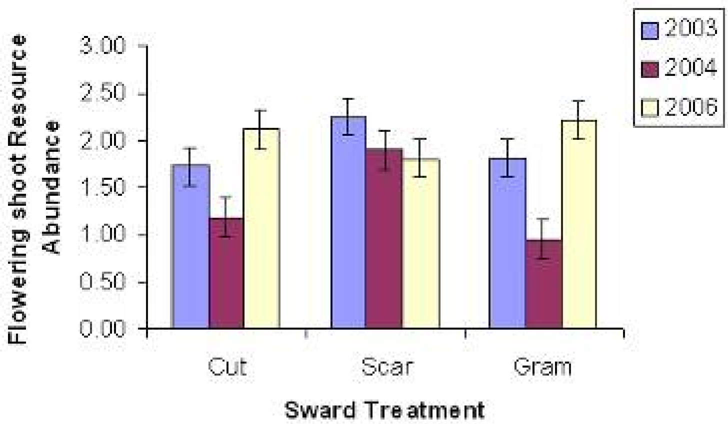


Figure 6.271. Total flowering shoot resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant seed mix by year interaction was determined for values of total flower resource abundance ($F_{4,64.5} = 8.5$, $P < 0.001$). Values were greater in 2003 for all seed mixes, but decreased between years in plots sown with the CS and TG mixes (Figure 6.272).

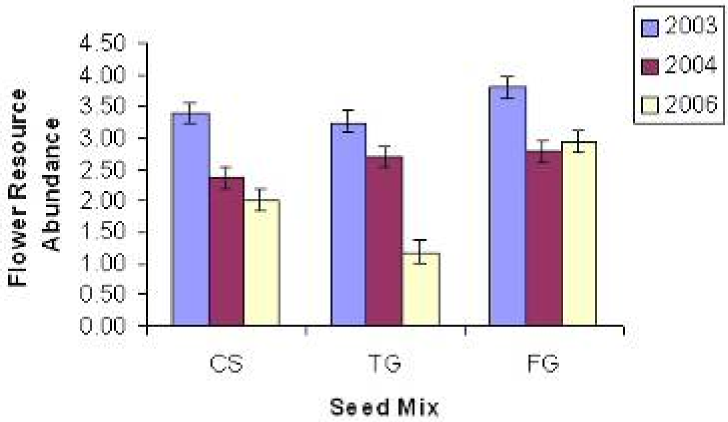


Figure 6.272. Total flower resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

A significant interaction between sward treatment and year was determined for values of total flower resource abundance ($F_{4,64.5} = 8.7$, $P < 0.001$). Values were greatest in 2003 under all treatments and were lowest in association with scarification by 2006 (Figure 6.273).

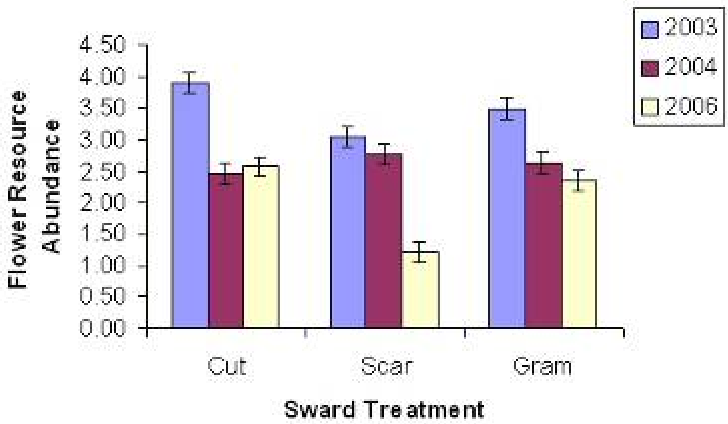


Figure 6.273. Total flower resource abundance values (± SE) at High Mowthorpe according to sward treatment (Cut = spring cut, Scar = spring scarification, Gram = spring application of graminicide) and year.

A significant interaction between seed mix and year was determined for values of total seed that was forming, ripe or dehiscent ($F_{4,57.0} = 4.6$, $P < 0.01$). In 2006, values were substantially lower with all seed mixes. In 2003 and 2004, values were greatest in plots sown with the FG mix and lowest with the TG mix (Figure 6.274). Sward treatment had no significant effect on values of seed resource abundance.

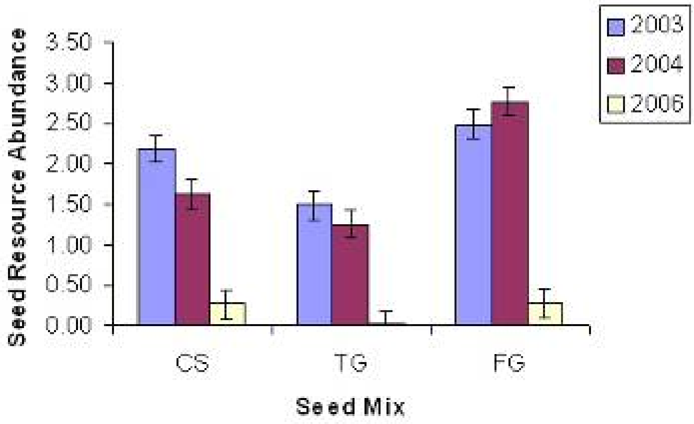


Figure 6.274. Total seed resource abundance values (± SE) at High Mowthorpe according to seed mix (CS = Countryside Stewardship, TG = Tussock grass and forb mix; FG = Fine grass and forb mix) and year.

6.3.3 Invertebrates (except bees and butterflies)

The following analyses of invertebrate abundance and species richness responses to site and all interactions between year, seed mix and management, are based on a temporal split-plot ANOVA. Where significant treatment effects were found, *post hoc* comparisons of means were performed. Although site is effectively a random blocking effect, differences between sites will be discussed. However, without replication at the level of soil types (sand, clay and chalk) such site differences are unsuitable for making predictions about abundance and species richness supported on different soil types. To meet assumptions of normality all count data have been Log_e N+1 transformed, although the means and SEs presented in the tables below are back transformed. For all sampling methods that incorporated multiple sampling periods within a single year, all values were based on summed season values. All analyses used mean values across the five replicate within a particular site. As management was not applied until 2003, the establishment year (2002) has been excluded from the subsequent analyses. For this reason the following results for the non-pollinator invertebrates are based (unless otherwise indicated) on the sample years 2003, 2004 and 2006 only.

6.3.3.1 Beetles (Coleoptera)

Beetles were sampled using two different methods, intended to assess different temporal and functional components of the fauna. The first sampling method used pitfall trapping in May to collect epigeal ground beetles, the second used suction sampling to collect both ground and sward active beetles (ground beetles, leaf beetles, weevils and ladybirds) in June and September.

Ground beetles (pitfall trap samples)

Sample year was not found to have a significant interactive effect with seed mix, management or seed-mix*management, for ground beetle abundance or species number (Table 6.28 and Table 6.29). However, considered alone, year had a significant effect on both abundance and species number. For ground beetle abundance this was characterised by a dramatic reduction after initially high values in 2003. Although heavy rain in 2004 damaged pitfall trap samples, the general pattern of declining ground beetle abundance within the pitfall trap samples persisted until 2006. In the case of ground beetle species number only 2004 had significantly fewer species than 2003 or 2006. Again this is attributed to rain damage of pitfall trap samples in 2004. Significant between-site differences in beetle abundance and species number were also found, characterised by Boxworth supporting both higher abundances and species number than Gleadthorpe or High Mowthorpe. Both ground beetle abundance (Figure 6.275) and species number (Figure 6.276) responded significantly to field margin management, although not to seed mix or the interaction between these two factors. In both cases scarification supported higher beetle abundances and species number of ground beetles.

Table 6.28. Repeated measures ANOVA table for ground beetle abundance (pitfall traps only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log$_e$ N+1			All years	2003	2004	2006
Site	$F_{2,22}$=48.4***					
Seed	$F_{2,20}$=1.55 NS	CS	68.0	119.4	12.4	72.2
			(± 13.9)	(± 31.6)	(± 2.03)	(± 12.6)
		FG	53.2	98.2	13.6	47.8
			(± 10.1)	(± 21.4)	(± 2.05)	(± 9.26)
		TG	56.1	98.7	13.5	56.1
			(± 9.96)	(± 19.5)	(± 2.16)	(± 11.3)
Management	$F_{2,22}$= 11.1 ***	Cut	56.1	108.5	12.8	47.0
			(± 11.9)a	(± 26.8)	(± 1.92)	(± 8.90)
		Gram	53.9	106.8	12.2	42.6
			(± 12.8)a	(± 30.1)	(± 1.87)	(± 8.44)
		Scar	67.4	101.1	14.5	86.6
			(± 9.60)b	(± 15.4)	(± 2.35)	(± 10.7)
Seed × Management	$F_{4,16}$=1.68 NS					
Year	$F_{2,52}$=92.6***			105.5	13.2	58.7
				(± 13.8)	(± 1.15)	(± 58.8)
Seed ×Year	$F_{4,36}$=0.48					
Management ×Year	$F_{4,44}$=1.12 NS					
Seed × Man. ×Year	$F_{8,36}$=0.12 NS					

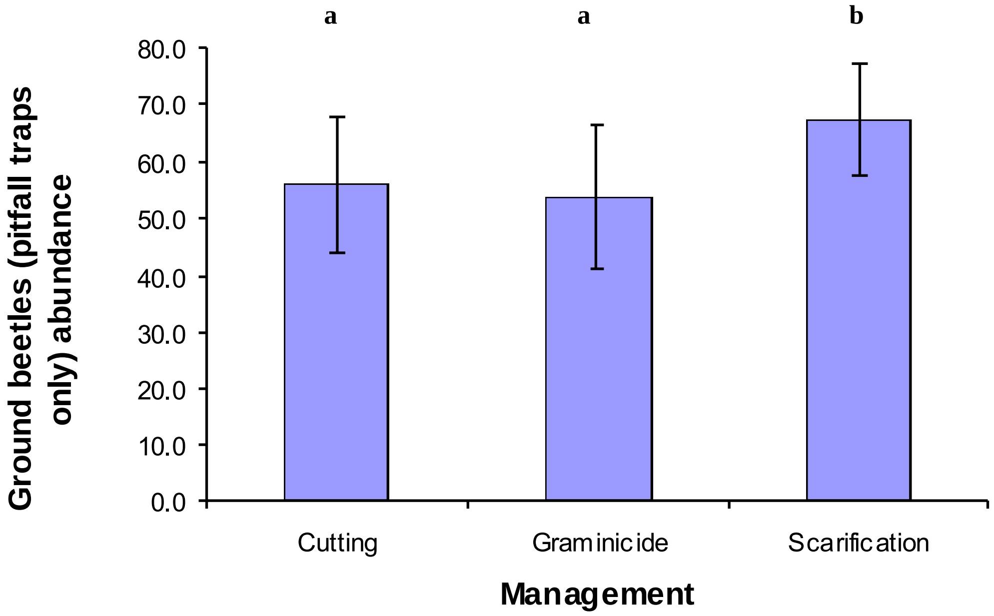


Figure 6.275. Response of ground beetle abundance (± SE) (pitfall trap samplesonly) to the three margin management practices. Based on post hocTukey's tests, treatment levels that share the same letter do not differ significantly (P> 0.05).

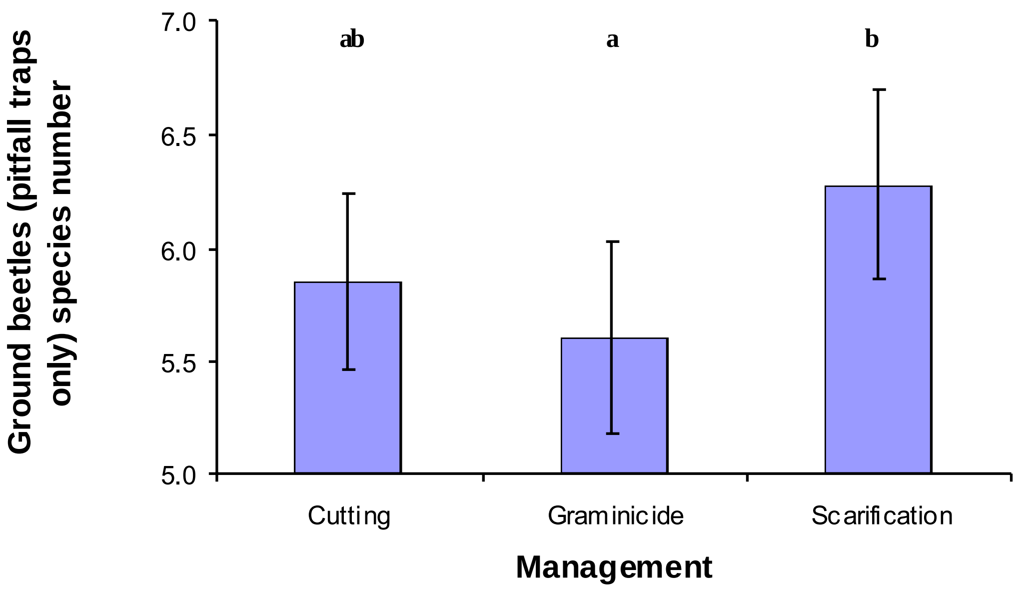


Figure 6.276. Response of ground beetle species number (± SE) (pitfall trap samples only) to the three margin management practices. Based on *post hoc* Tukey's tests, treatment levels that share the same letter do not differ significantly (P> 0.05).

Table 6.29. Repeated measures ANOVA table for ground beetle species number (pitfall traps only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter, they do not differ significantly (P> 0.05). * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed species number**			
Species number Log_e N+1			**All years**	**2003**	**2004**	**2006**
Site	$F_{2,22}$=76.5***					
Seed	$F_{2,20}$=0.54NS	CS	6.08	6.89	4.29	7.05
			(± 0.45)	(± 0.98)	(± 0.46)	(± 0.45)
		FG	5.7	6.38	4.74	5.98
			(± 0.35)	(± 0.71)	(± 0.55)	(± 0.43)
		TG	5.98	6.58	4.25	7.09
			(± 0.44)	(± 0.92)	(± 0.45)	(± 0.47)
Management	$F_{2,22}$=3.66*	Cut	5.86	6.72	4.52	6.34
			(±0.39)ab	(± 0.84)	(± 0.50)	(± 0.39)
		Gram	5.62	6.54	4.18	6.12
			(± 0.43)a	(± 0.97)	(± 0.44)	(± 0.48)
		Scar	6.29	6.6	4.58	7.67
			(± 0.42)b	(± 0.82)	(± 0.53)	(± 0.39)
Seed × Management	$F_{4,16}$=0.43 NS					
Year	$F_{2,52}$=22.3 ***			6.6	4.4	6.7
				(± 0.48)	(± 0.27)	(± 0.26)
Seed ×Year	$F_{4,48}$=0.70 NS					
Management ×Year	$F_{4,44}$=0.52 NS					
Seed × Man. ×Year	$F_{8,36}$=0.21 NS					

Beetles (suction samples only)

Between 2002 and 2006 a total of 25,835 individuals of Carabidae, Coccinellidae, Chrysomelidae and Curculionoidea were collected from all sites. The phytophagous weevil *Sitona lineatus* L. (Curculionidae) was the single most abundant species. Of the 248 species collected only 82 found at all sites, i.e. those on clay, sand and chalk soils. However, it was common for those species present at all sites to show large between site variations in their abundance. For example, the leaf beetle *Altica palustris* Weise (Chrysomelidae) was relatively abundant (> 50 individuals) at both

Boxworth and Gleadthorpe, although there were less than 5 individuals found at High Mowthorpe. Although Gleadthorpe supported the largest number of species (Species number (SR) =170) and High Mowthorpe the lowest (SR=132), this is at least in part explained by the north-south gradient of SAFFIE experiment 2 sites. For the chalk soil site the identification of the Staphylinidae added a further 62 species from 11,418 individuals. However, these were only included in the site-specific multivariate analysis below in the Trophic Linkages section (6.3.6).

There was no between-year interactions for either beetle abundance or species number, with seed mix, management or seed-mix*management (Table 6.30 and Table 6.31). However, significant between year variation in both beetle abundance and species number across all sites was found. Beetles abundance in 2003 was significantly lower than in 2004 and 2006, although across all years this had the appearance of a humpback response to time as 2004 supported the greater beetle abundance. This hump-backed pattern of the temporal relationship between beetle abundance and year was found for all three sites. In contrast to the relationship between beetle abundance and year, species number increased from its low point in 2003 and then plateaued from 2004 to 2006. Significant between site differences in beetle abundance and species number were found, and while abundance was significantly lower at Gleadthorpe than either Boxworth or High Mowthorpe, this pattern was reversed for beetle species number. Beetle abundance did not show a significant response to either management or the interaction between management and year, although seed mix alone did have a significant effect (Figure 6.2787). Both the fine grass and forbs, and tussock grass and forbs seed mixes were found to have higher beetle abundances than the conventional Countryside Stewardship seed mix, although neither (the mixes with forbs) differed significantly from the other. In contrast beetle species number was unaffected by seed mix or the interactions between seed mix and management, although management was found to have a significant effect (Figure 6.2798). The conventional margin management of cutting did not differ significantly from the use of the graminicide. However, scarification resulted in a significant increase in beetle species number relative to the other management treatments.

Table 6.30. Repeated measures ANOVA table for beetle abundance (suction samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log_e N+1			All years	2003	2004	2006
Site	$F_{2,22}$=5.08*					
Seed	$F_{2,22}$=7.65**	CS	37.7 (± 3.16)a	32.0 (± 4.31)	48.7 (± 6.98)	32.3 (± 2.68)
		FG	64.2 (± 7.48)b	42.5 (± 4.46)	76.5 (± 15.3)	73.6 (± 14.1)
		TG	50.3 (± 3.89)b	37.6 (± 2.51)	68.6 (± 7.92)	44.6 (± 3.46)
Management	$F_{2,20}$=0.55 NS	Cut	47.3 (± 15.7)	34.2 (± 6.61)	61.6 (± 20.7)	46.0 (± 30.1)
		Gram	53.4 (± 13.6)	39.7 (± 11.2)	64.4 (± 20.2)	56.0 (± 27.1)
		Scar	51.5 (± 11.6)	38.1 (± 7.19)	67.7 (± 21.2)	48.5 (± 22.5)
Seed × Management	$F_{4,16}$= 0.19 NS					
Year	$F_{2,52}$=13.8***			37.4 (± 2.33)	64.7 (± 6.39)	50.2 (± 5.81)
Seed ×Year	$F_{4,48}$=1.20 NS					
Management ×Year	$F_{4,44}$=0.12 NS					
Seed × Man. ×Year	$F_{8,36}$=0.13 NS					

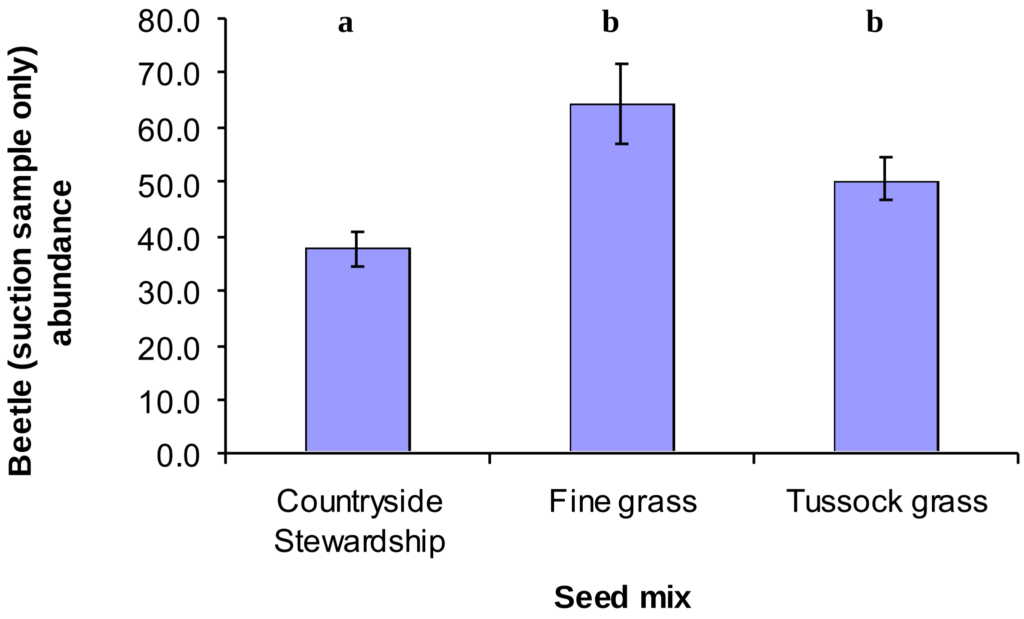


Figure 6.277. Response of beetle abundance (± SE) (suction samples only) to the three seed mixes used to establish the field margins. Based on *post hoc* Tukey's tests, treatment levels that share the same letter they do not differ significantly (P> 0.05).

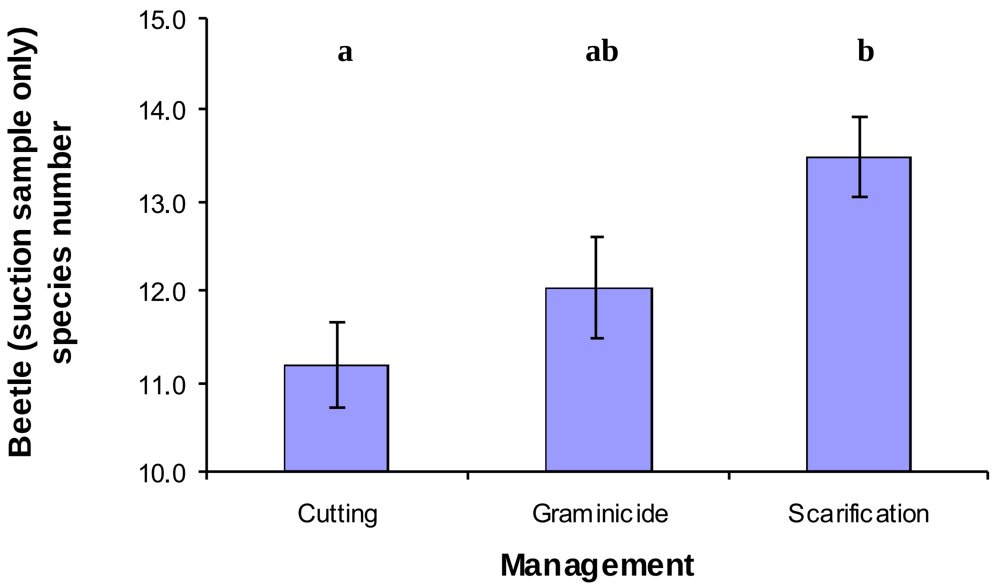


Figure 6.278. Response of beetle species number (± SE) (suction samples only) to the three margin management practices. Based on *post hoc* Tukey's tests, treatment levels that that share the same letter they do not differ significantly (P> 0.05).

Table 6.31. Repeated measures ANOVA table for beetle species number (suction samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

Species number Log_e N+1	Overall		Mean untransformed species number			
			All years	2003	2004	2006
Site	$F_{2,22}$=7.86**					
Seed	$F_{2,20}$=0.49 NS	CS	12.1 (± 0.45)	10.5 (± 0.70)	12.8 (± 0.84)	13.1 (± 0.55)
		FG	12.0 (± 0.64)	9.80 (± 1.16)	12.6 (± 0.97)	13.6 (± 0.83)
		TG	12.5 (± 0.44)	10.5 (± 0.79)	13.8 (± 0.46)	13.1 (± 0.55)
Management	$F_{2,22}$=5.44*	Cut	11.2 (± 0.46)a	9.29 (± 0.82)	12.1 (± 0.57)	12.1 (± 0.61)
		Gram	12.1 (± 0.55)a	10.5 (± 1.16)	12.4 (± 0.94)	13.1 (± 0.54)
		Scar	13.5 (± 0.44)b	11.0 (± 0.52)	14.7 (± 0.47)	14.6 (± 0.53)
Seed × Management	$F_{4,16}$=0.49 NS					
Year	$F_{2,52}$=30.1***			10.3 (± 0.50)	13.1 (± 0.44)	13.3 (± 0.36)
Seed ×Year	$F_{4,48}$=0.98 NS					
Management ×Year	$F_{4,44}$=0.55 NS					
Seed × Man. ×Year	$F_{8,36}$=0.22 NS					

6.3.3.2 Hemiptera

True bugs (Heteroptera)

A total of 19,519 individual Heteroptera (adults and nymphs) were collected at all three sites from 2002-2006. Adult bugs were identified to one of 98 species, and there were distinct differences in species diversity corresponding to site geographical location, with the more northerly sites having fewer species. There was no significant effect of seed mix on Heteroptera abundance, but scarification had a significant negative effect on abundance (Figure 6.28079). Management treatments however had no significant effect on species number, but seed mix did have a significant effect on species number, with CS and FG mix with high and low species number respectively (Figure 6.2810). For both abundance and species number, year had a significant effect, with abundance declining significantly from 2003-2006, but the trend was reversed for species number which increased from 2003-2006. Site had a significant effect on abundance but not species number, with significantly high abundance of true bugs at Gleadthorpe. None of the interactions between seed mix/ management/ year were significant for abundance or species number (Table 6.32 and Table 6.33). The overall trend of declining abundance over time is largely due to loss of early successional assemblages, including species such as the groundbug *Nysius ericae*, which was the single most numerous bug at Gleadthorpe in 2003, with 643 individuals. However, in 2004 none were sampled at Gleadthorpe, although 2 individuals were sampled at Boxworth in the same year. This does suggest that for Heteroptera at least the value of margins is greatest in the first 2 years in terms of abundance, and although diversity does increase over time as margin succession takes place, these later assemblages are different from the pioneer assemblages recorded during early plot succession, with a far greater diversity of grass feeding species such as Stenodeminae grass bugs. Of particular interest is the response of predatory Heteroptera such as the damsel bugs, which increased consistently at all sites from 2003-2006, suggesting that successionally mature margins will enhance natural predator abundance.

Table 6.32. Repeated measures ANOVA table for Hemiptera abundance (suction samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log$_e$ N+1			All years	2003	2004	2006
Site	$F_{2,22}$=24.5**					
Seed	$F_{2,20}$=0.63 NS	CS	34.6	29.1	47.3	27.3
			(± 3.34)	(± 4.08)	(± 6.15)	(± 4.83)
		FG	32.9	35.6	39.4	23.8
			(± 3.58)	(± 8.49)	(± 3.38)	(± 4.95)
		TG	34.5	34.0	44.8	24.6
			(± 3.70)	(± 5.82)	(± 8.15)	(± 2.74)
Management	$F_{2,22}$=5.20*	Cut	37.3	31.2	52.1	28.5
			(± 3.70)a	(± 4.76)	(± 6.69)	(± 4.95)
		Gram	36.1	33.9	49.7	24.6
			(± 3.59)a	(± 6.22)	(± 5.59)	(± 3.88)
		Scar	28.7	33.7	29.7	22.5
			(± 3.07)b	(± 7.98)	(± 2.45)	(± 3.79)
Seed × Management	$F_{4,16}$=0.93 NS					
Year	$F_{2,52}$=14.5***			83.0	43.9	25.2
				(± 3.59)	(± 3.51)	(± 2.40)
Seed ×Year	$F_{4,44}$=0.31 NS					
Management ×Year	$F_{4,48}$=1.35 NS					
Seed × Man. ×Year	$F_{8,36}$=0.25 NS					

Table 6.33. Repeated measures ANOVA table for Hemiptera species number (suction samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed species number**			
Species number Log_e N+1			All years	2003	2004	2006
Site	$F_{2,20}$=1.90 NS					
Seed	$F_{2,24}$=3.58*	CS	3.24 (± 0.06)a	3.06 (±0.13)	3.27 (± 0.05)	3.39 (± 0.09)
		FG	3.05 (± 0.08)b	2.64 (± 0.15)	3.17 (± 0.06)	3.32 (± 0.07)
		TG	3.21 (± 0.06)ab	2.97 (± 0.12)	3.28 (± 0.05)	3.38 (± 0.07)
Management	$F_{2,22}$=2.60 NS	Cut	3.25 (± 0.06)	3.04 (± 0.10)	3.26 (± 0.07)	3.45 (± 0.07)
		Gram	3.17 (± 0.06)	2.92 (± 0.12)	3.24 (± 0.06)	3.34 (± 0.08)
		Scar	3.08 (± 0.08)	2.71 (± 0.18)	3.22 (± 0.04)	3.31 (± 0.09)
Seed × Management	$F_{4,16}$=0.13 NS					
Year	$F_{2,52}$=18.8 ***			2.89 (± 0.08)	3.24 (± 0.03)	3.36 (± 0.04)
Seed ×Year	$F_{4,48}$=1.25 NS					
Management ×Year	$F_{4,44}$=0.83 NS					
Seed × Man. ×Year	$F_{8,36}$=0.65 NS					

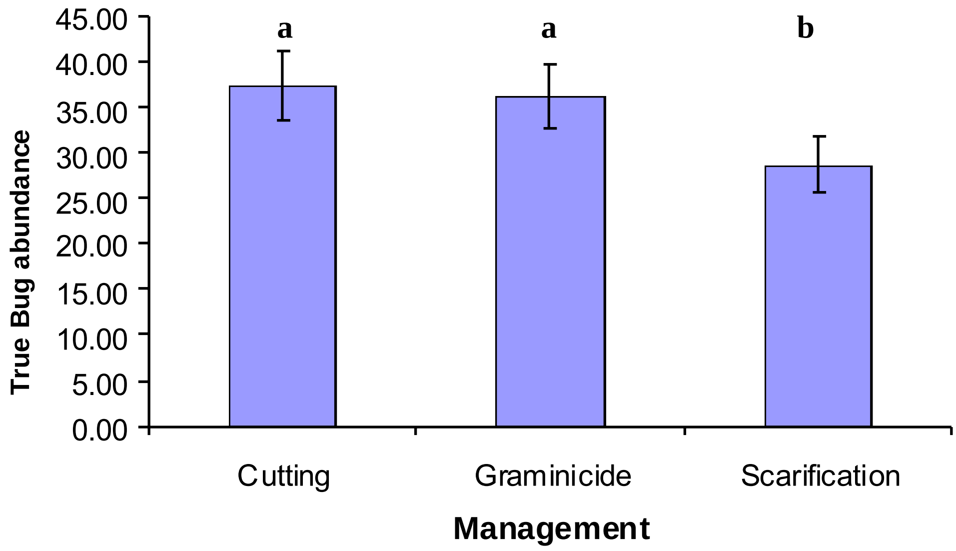


Figure 6.279. Response of true bug abundance (± SE) (suction samples only) to the three margin management practices. Based on *post hoc* Tukey's tests, treatment levels that that share the same letter do not differ significantly (P> 0.05).

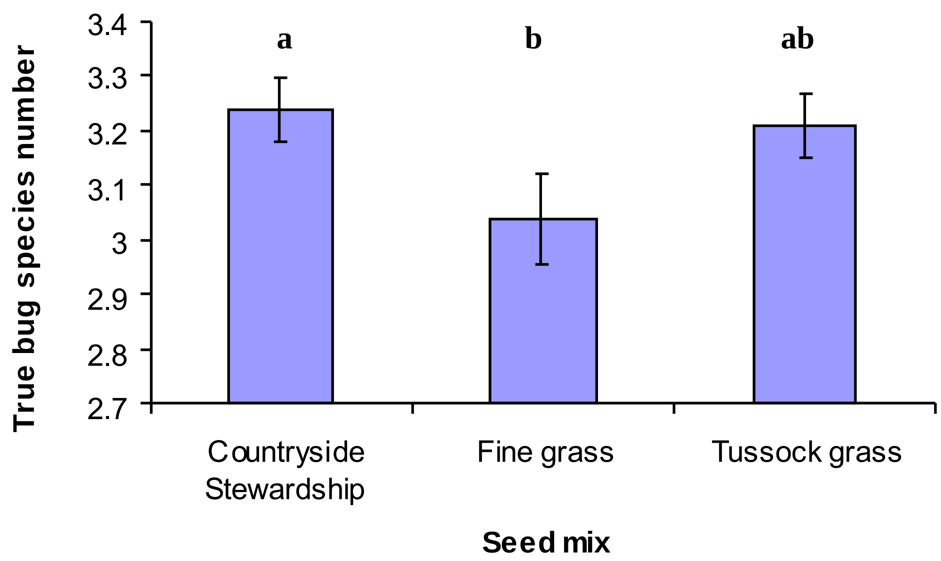


Figure 6.280. Response of true bug abundance (± SE) (suction samples only) to the three seed mixes used to establish the field margins. Based on *post hoc* Tukey's tests, treatment levels that that share the same letter do not differ significantly (P> 0.05).

Planthoppers (Auchenorrhyncha)

A total of 69,596 individuals (adults and nymphs) were collected at each of the three sites from 2002-2006. Seed mix had no significant effect on planthopper abundance or species number. There was a significant effect of management practice on planthopper abundance, with the scarified plots supporting the lowest overall abundances relative to either cutting or graminicide (Fig 6.281). None of the management treatment imposed had any significant effect on species number. None of the interactions between seed mix/ management/ year had a significant effect on abundance or species number, but year had a significant positive effect on both abundance and species number, with abundance and species number increasing from 2003-2006. Site had a significant effect on abundance, with Boxworth having significantly higher planthopper abundance than Gleadthorpe or High Mowthorpe, although this effect was not significant for species number (Table 6.34 and Table 6.35).

Table 6.34. Repeated measures ANOVA table for planthopper abundance (suction samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log_e N+1			All years	2003	2004	2006
Site	$F_{2,22}$=21.1**					
Seed	$F_{2,20}$=1.70 NS	CS	169.1 (± 21.76)	89.7 (± 19.21)	191.9 (± 47.29)	225.6 (± 27.57)
		FG	139.8 (± 15.82)	84.5 (± 16.01)	144.0 (± 28.29)	190.9 (± 29.53)
		TG	134.9 (± 15.66)	76.0 (± 10.48)	130.9 (± 27.24)	197.9 (± 24.67)
Management	$F_{2,22}$=16.3**	Cut	169.4 (±19.32)a	83.2 (± 14.79)	195.0 (± 38.49)	229.9 (± 21.69)
		Gram	178.0 (±18.76)a	101.2 (± 19.92)	191.0 (± 36.70)	241.4 (± 20.60)
		Scar	96.4 (±10.75)b	65.8 (± 7.32)	80.2 (± 11.90)	143.1 (± 22.56)
Seed × Management	$F_{4,16}$=0.26 NS					
Year	$F_{2,52}$=41.9 ***			83.5 (± 8.75)	155.6 (±20.35)	204.8 (± 14.76)
Seed ×Year	$F_{4,44}$=0.37 NS					
Management ×Year	$F_{4,48}$=1.95 NS					
Seed × Man. ×Year	$F_{8,36}$=0.59 NS					

Table 6.35. Repeated measures ANOVA table for planthopper species number (suction samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Species number Log$_e$ N+1			All years	2003	2004	2006
Site	$F_{2,22}$=0.61 NS					
Seed	$F_{2,22}$=0.85 NS	CS	3.08 (± 0.07)	2.98 (± 0.07)	2.98 (± 0.18)	3.26 (± 0.07)
		FG	3.13 (± 0.07)	3.00 (± 0.05)	3.15 (± 0.08)	3.24 (± 0.20)
		TG	3.18 (± 0.06)	2.97 (± 0.08)	3.23 (± 0.06)	3.34 (± 0.11)
Management	$F_{2,24}$=0.89 NS	Cut	3.07 (± 0.07)	2.91 (± 0.07)	3.03 (± 0.14)	3.26 (± 0.14)
		Gram	3.17 (± 0.07)	3.01 (± 0.07)	3.14 (± 0.14)	3.35 (± 0.12)
		Scar	3.15 (± 0.06)	3.04 (± 0.06)	3.18 (± 0.08)	3.22 (± 0.15)
Seed × Management	$F_{4,16}$=0.84 NS					
Year	$F_{2,52}$=4.08 *			3.0 (± 0.03)	3.1 (± 0.07)	3.3 (± 0.08)
Seed ×Year	$F_{4,48}$=0.49 NS					
Management ×Year	$F_{4,44}$=0.25 NS					
Seed × Man. ×Year	$F_{8,36}$=0.09 NS					

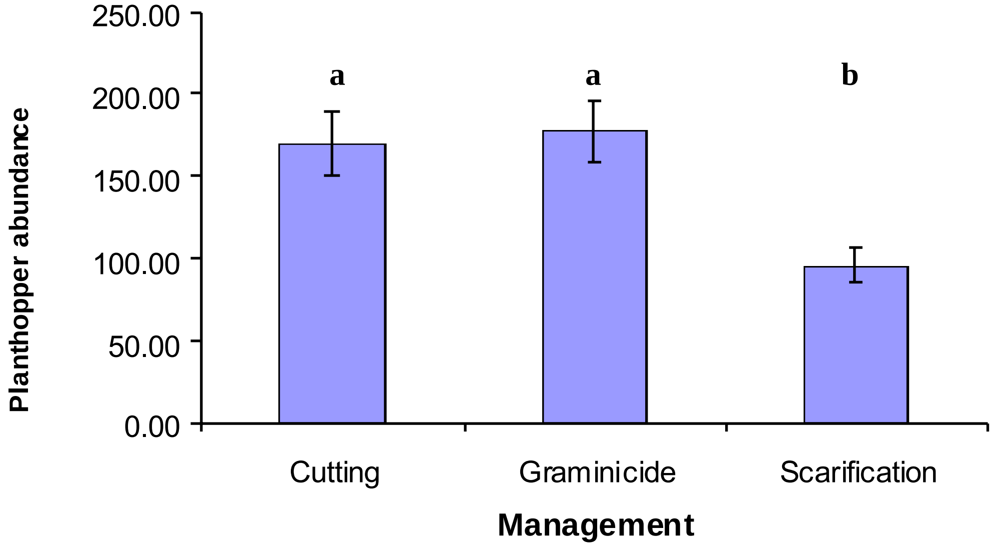


Figure 6.281. Response of planthopper abundance (± SE) (suction samples only) to the three margin management practices. Based on post hoc Tukey's tests, treatment levels that that share the same letter do not differ significantly (P> 0.05).

6.3.3.3 Spiders (Araneae)

Spiders were not identified to species and the following results refer to their abundance within the margin plots only. There was no significant interactions between year and spider abundance in response to seed mix, management or seed mix *management (Table 6.36). A significant site effect showed Boxworth to support the highest overall spider abundances. Significant between-year variation across all sites differed from the humpback relationship seen for the beetles, and instead there was a general trend of increasing spider abundance from 2003 to 2006. While the interactions between seed mix and management had no effect on spider abundance, both of these factors did individually have significant effects on the number of spider individuals. The tussock grass and forbs seed mix supported the highest abundances of spiders (Figure 6.2832). However, the conventional Countryside Stewardship seed mix did not differ significantly from the tussock grass and forbs seed mix. For margin management, applications of graminicide resulted in the highest spider abundances independent of seed mix (Figure 6.2843). In contrast to results for beetles, the scarification of the margin plots proved to have the greatest negative impact on spider abundance. There was no significant interaction between seed mix and management.

Table 6.36. Repeated measures ANOVA table for spider abundance (suction samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log_e N+1			All years	2003	2004	2006
Site	$F_{2,16}$=49.8***					
Seed	$F_{2,16}$=7.25**	CS	129.0	115.1	106.7	165.0
			(±7.53)ab	(± 6.83)a	(±6.39)ab	(± 14.7)a
		FG	119.5	113.5	93.5	151.5
			(± 7.33)a	(± 7.32)a	(± 7.49)a	(± 14.0)a
		TG	135.0	126.9	120.9	157.2
			(± 6.99)b	(± 7.69)a	(± 7.23)b	(± 16.4)a
Management	$F_{2,16}$=10.8***	Cut	126.8	112.1	104.4	164.0
			(± 7.96)a	(± 7.00)a	(± 7.14)a	(± 15.9)a
		Gram	137.8	133.4	113.8	166.1
			(± 6.30)b	(± 8.00)a	(± 6.60)a	(± 10.2)a
		Scar	118.9	110.0	102.9	143.6
			(± 7.36)a	(± 4.24)a	(± 9.64)a	(± 17.2)a
Seed × Management	$F_{4,16}$=5.29**					
Year	$F_{2,52}$=40.7***			118.6	107.1	158.0
				(± 4.20)	(± 4.85)	(± 8.45)
Seed ×Year	$F_{4,38}$=1.86 NS					
Management ×Year	$F_{4,44}$=0.75 NS					
Seed × Man. ×Year	$F_{8,36}$=0.47 NS					

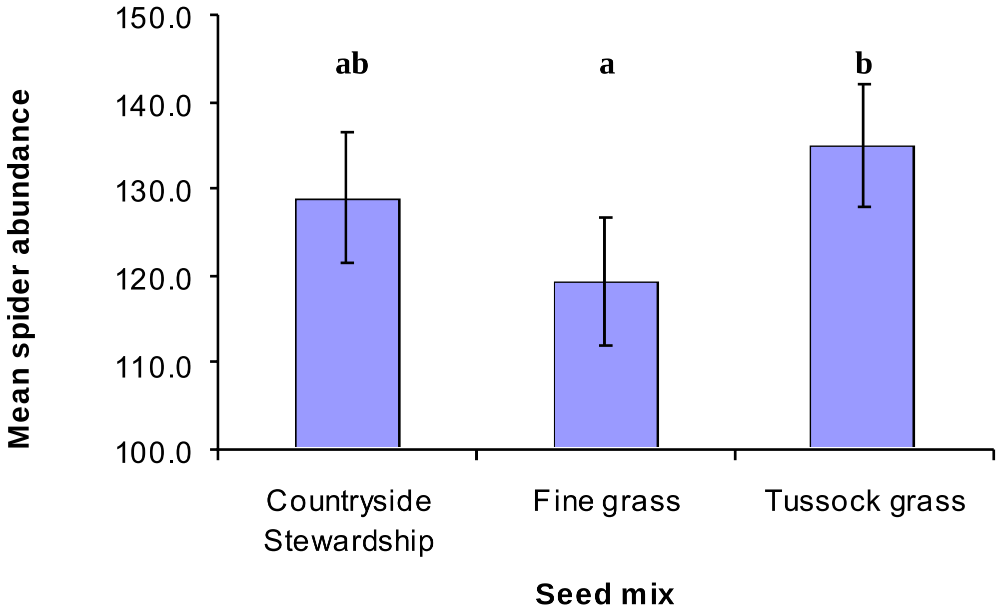


Figure 6.282. Response of spider abundance (± SE) (suction samples only) to the three seed mixes. Based on post hoc Tukey's tests, treatment levels that share the same letter do not differ significantly (P> 0.05).

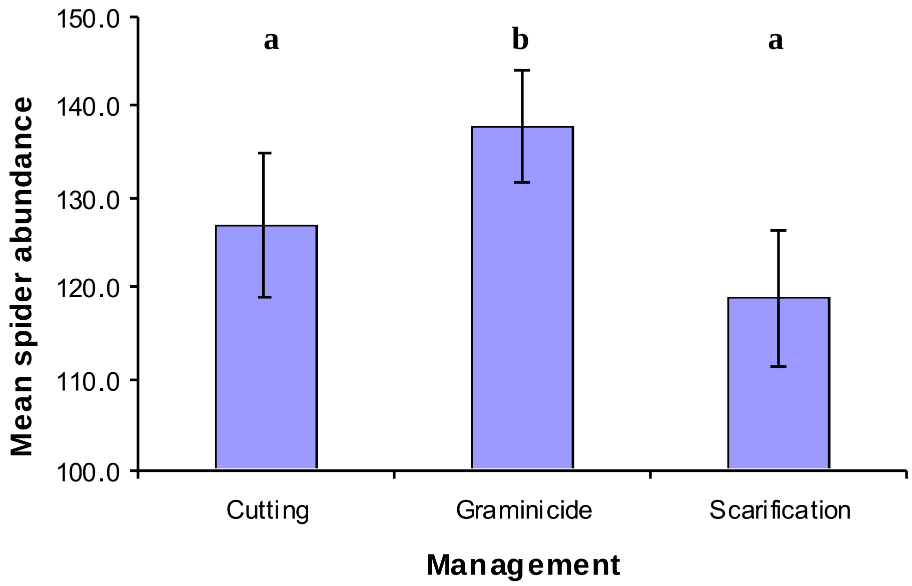


Figure 6.283. Response of spider abundance (± SE) (suction samples only) to the three margin management practices. Based on *post hoc* Tukey's tests treatment levels that share the same letter do not differ significantly (P> 0.05).

6.3.3.4 *Flies (Diptera)*

There were no significant effects of seed mix or management treatment on cranefly (Tipulidae: Table 6.37) or St Mark's fly abundance (Bibionidae: Table 6.38) in any year or at any site. There was a significant effect of year on abundance of craneflies and St Mark's flies, with lowest abundance recorded in 2006 for both fly families, and there was a distinct trend of declining abundance from 2003-2006 for craneflies. The effects of site were not significant for craneflies, but abundance was significantly affected by site for St Mark's flies, with significantly lower abundance at High Mowthorpe.

6.3.3.5 *Orthoptera*

A total of 96 individuals of eight species were recorded from 2003 to 2006. Highest Orthoptera abundance was recorded at Boxworth, the most southerly site, with the most abundant species being *Chorthippus albomarginatus* and *Metrioptera roeselii*. Both species are highly thermophilic and require dry grassland conditions. The hot dry summer of 2003 led to increased abundance of these two species in 2004. Most Orthoptera populations within farmland are dependent on historical management to maintain populations. However, *C. albomarginatus* and *M. roeselii* are very effective colonisers of new habitat such as field margins, suggesting that new margins will benefit these species in the long term. There were significant effects of site and year on Orthoptera abundance, with significantly greater Orthoptera abundance recorded in 2004. Boxworth had significantly higher abundance of Orthoptera than Gleadthorpe or High Mowthorpe.

Table 6.37. Repeated measures ANOVA table for cranefly abundance (sweep net only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log_e N+1			All years	2003	2004	2006
Site	$F_{2,20}$=0.56 NS					
Seed	$F_{2,22}$=1.68 NS	CS	0.07	0.14	0.05	0.00
			(± 0.02)	(± 0.06)	(± 0.03)	
		FG	0.17	0.43	0.07	0.00
			(± 0.05)	(± 0.11)	(± 0.05)	
		TG	0.2	0.27	0.32	0.00
			(± 0.10)	(± 0.15)	(± 0.24)	
Management	$F_{2,24}$=2.36 NS	Cut	0.1	0.25	0.05	0.00
			(± 0.03)	(± 0.06)	(± 0.03)	
		Gram	0.24	0.32	0.38	0.00
			(± 0.09)	(± 0.12)	(± 0.23)	
		Scar	0.09	0.27	0.00	0.00
			(± 0.06)	(± 0.17)		
Seed × Management	$F_{4,16}$=0.52 NS					
Year	$F_{2,52}$=7.59**			0.3	0.2	0.00
				(± 0.06)	(± 0.08)	
Seed ×Year	$F_{4,48}$=1.42 NS					
Management ×Year	$F_{4,44}$=1.13 NS					
Seed × Man. ×Year	$F_{8,36}$=1.68 NS					

Table 6.38. Repeated measures ANOVA table for St Marks fly abundance (sweep net only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

Abundance Log_e N+1	**Overall**		**Mean untransformed abundances**			
			All years	2003	2004	2006
Site	$F_{2,24}$=13.1***					
Seed	$F_{2,22}$=1.62 NS	CS	0.56	0.52	1.12	0.03
			(± 0.14)	(± 0.16)	(± 0.31)	(± 0.02)
		FG	0.37	0.25	0.78	0.07
			(± 0.08)	(± 0.08)	(± 0.17)	(± 0.03)
		TG	0.54	0.94	0.63	0.05
			(± 0.15)	(± 0.35)	(± 0.20)	(± 0.03)
Management	$F_{2,20}$=0.38 NS	Cut	0.49	0.6	0.8	0.05
			(± 0.11)	(± 0.17)	(± 0.24)	(± 0.03)
		Gram	0.44	0.32	0.94	0.05
			(± 0.11)	(± 0.09)	(± 0.26)	(± 0.03)
		Scar	0.54	0.78	0.78	0.05
			(± 0.16)	(± 0.36)	(± 0.24)	(± 0.03)
Seed × Management	$F_{4,16}$=0.54 NS					
Year	$F_{2,52}$=20.5***			0.6	0.8	0.1
				(± 0.14)	(± 0.14)	(± 0.02)
Seed ×Year	$F_{4,48}$=2.46 NS					
Management ×Year	$F_{4,44}$=0.75 NS					
Seed × Man. ×Year	$F_{8,36}$=0.48 NS					

Table 6.39. Repeated measures ANOVA table for Orthoptera abundance (sweep net only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log_e N+1			All years	2003	2004	2006
Site	$F_{2,24}$=76.8***					
Seed	$F_{2,22}$=0.59 NS	CS	0.45	0.05	1.12	0.16
			(± 0.22)	(± 0.03)	(± 0.62)	(± 0.10)
		FG	0.45	0.05	0.98	0.32
			(± 0.21)	(± 0.04)	(± 0.58)	(± 0.16)
		TG	0.27	0.05	0.45	0.29
			(± 0.11)	(± 0.03)	(± 0.28)	(± 0.17)
Management	$F_{2,20}$=0.23 NS	Cut	0.31	0.03	0.63	0.27
			(± 0.14)	(± 0.02)	(± 0.38)	(± 0.13)
		Gram	0.44	0.03	0.96	0.32
			(± 0.21)	(± 0.02)	(± 0.60)	(± 0.17)
		Scar	0.41	0.09	0.96	0.18
			(± 0.20)	(± 0.05)	(± 0.57)	(± 0.14)
Seed × Management	$F_{4,16}$=1.57 NS					
Year	$F_{2,52}$=8.92***			0.1	0.9	0.3
				(± 0.02)	(± 0.3)	(± 0.08)
Seed ×Year	$F_{4,48}$=0.49 NS					
Management ×Year	$F_{4,44}$=0.24 NS					
Seed × Man. ×Year	$F_{8,36}$=0.19 NS					

6.3.3.6 Symphyta and Lepidoptera larvae

The Symphyta and Lepidoptera larvae were considered together, although both abundance and wet mass were assessed from the sweep net samples.

There were no significant interactions between year and the response of larval abundance for seed mix, management or the interaction between seed mix and management (Table 6.40). This was not the case for larval mass, where there was a significant interaction between year and management (Table 6.41).

A significant year effect for larval abundance suggested a humpback temporal pattern, where margins peaked in the abundance of larvae they supported in 2004 before dropping again in 2006. There was however no significant between-year variations in larval mass.

Neither larval abundance nor mass showed significant between site differences.

Larval abundance was significantly affected by margin management, although this was not the case for either seed mix or the interaction between these two factors (Figure 6.2854). As for spiders, larval abundance was lowest where scarification was used as margin management, while the conventional management of cutting supported the highest larval abundance.

Larval mass showed a significant response to seed mix, although there was no significant interaction between seed mix and management. Although the fine grass and forbs seed mix supported the lowest overall mass of larvae, both seed mixes containing a component of tussock grasses (i.e. tussock grass and forbs and Countryside Stewardship seed mixes) supported similar levels of larval mass, (Figure 6.2865). Although there was a significant interaction bewteen year and management, this did not show any consistent trends. However, scarification again resulted in significantly lower larval mass across all seed mixes, relative to both cutting and graminicide (Figure 6.1286).

Table 6.40. Repeated measures ANOVA table for Symphyta and Lepidoptera larval abundance (sweep net only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant effects of seed mix or management was found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**			
Abundance Log$_e$ N+1			All years	2003	2004	2006
Site	$F_{2,22}$=1.53 NS					
Seed	$F_{2,20}$=0.80 NS	CS	1.56	1.32	2.47	0.89
			(± 0.21)	(± 0.30)	(± 0.35)	(± 0.19)
		FG	1.34	0.89	2.45	0.67
			(± 0.24)	(± 0.23)	(± 0.55)	(± 0.10)
		TG	1.62	1.34	2.8	0.72
			(± 0.30)	(± 0.30)	(± 0.70)	(± 0.16)
Management	$F_{2,24}$=4.56*	Cut	1.85	1.74	2.98	0.83
			(± 0.22)a	(± 0.30)	(± 0.27)	(± 0.14)
		Gram	1.43	0.72	2.63	0.92
			(± 0.25)ab	(± 0.18)	(± 0.55)	(± 0.18)
		Scar	1.25	1.09	2.12	0.54
			(± 0.27)b	(± 0.23)	(± 0.71)	(± 0.12)
Seed × Management	$F_{4,16}$=0.76 NS					
Year	$F_{2,52}$=20.8***			1.18	2.58	0.76
				(± 0.16)	(± 0.31)	(± 0.09)
Seed ×Year	$F_{4,44}$=0.20 NS					
Management ×Year	$F_{4,48}$=1.55 NS					
Seed × Man. ×Year	$F_{8,36}$=0.28 NS					

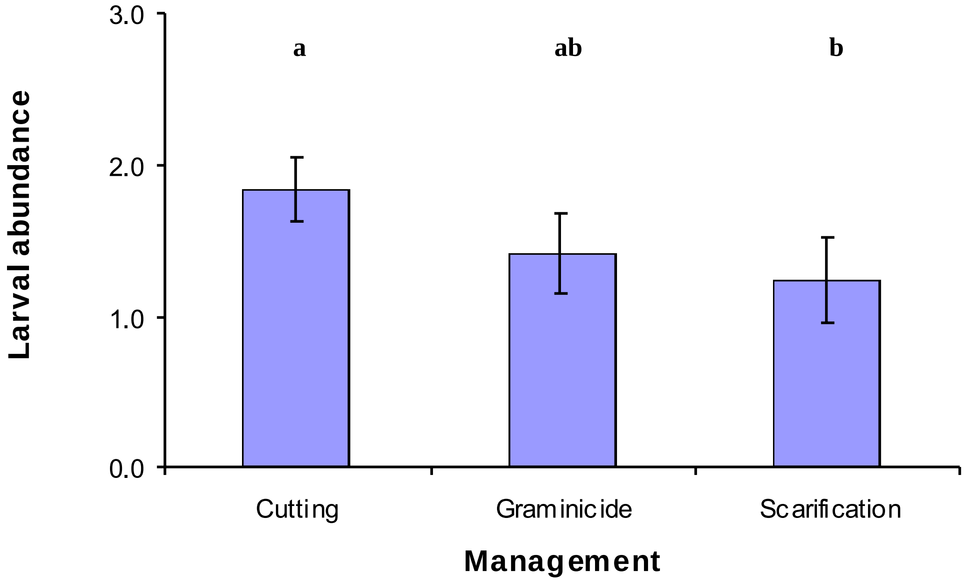


Figure 6.284. Response of Symphyta and Lepidoptera larval abundance (± SE) to the three margin management practices. Based on *post hoc* Tukey's tests, treatment levels that share the same letter do not differ significantly (P> 0.05).

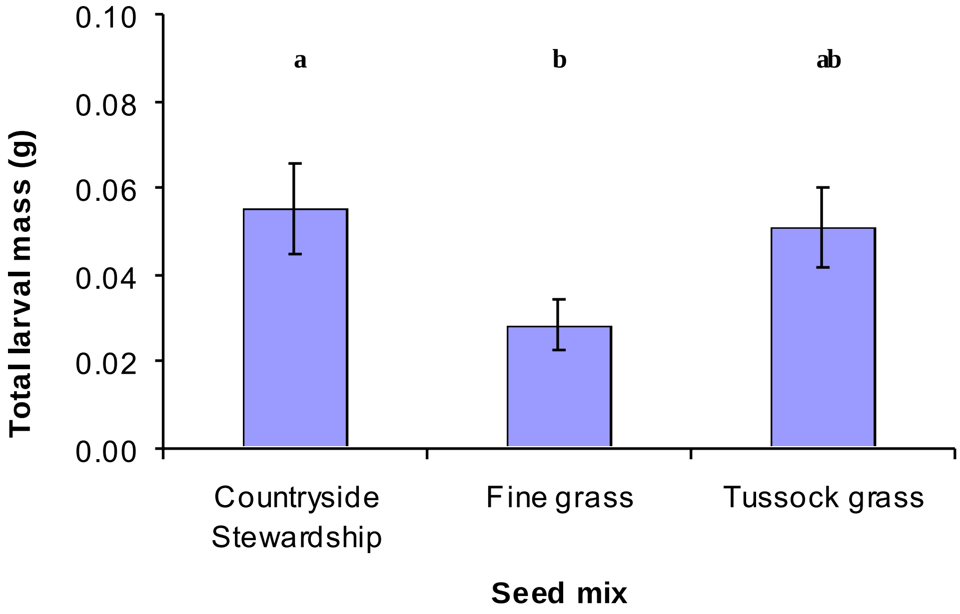


Figure 6.285. Response of Symphyta and Lepidoptera mass (g) (± SE) to the three seed mixes used to establish the field margins. Based on *post hoc* Tukey's tests, treatments that share the same letter do not differ significantly (P> 0.05).

Table 6.41. Repeated measures ANOVA table for Symphyta and Lepidoptera total mass (g) (sweep net only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Means untransformed mass (g)**			
Mass (g)			All years	2003	2004	2006
Site	$F_{2,20}$=1.18 NS					
Seed	$F_{2,22}$=3.40*	CS	0.06	0.09	0.04	0.05
			(±0.010)a	(± 0.026)	(± 0.005)	(± 0.013)
		FG	0.04	0.03	0.03	0.05
			(±0.006)b	(± 0.008)	(± 0.006)	(± 0.015)
		TG	0.06	0.05	0.05	0.07
			(±0.009)ab	(± 0.009)	(± 0.011)	(± 0.025)
Management	$F_{2,22}$=1.46 NS	Cut	0.06	0.08	0.04	0.05
			(±0.009)a	(± 0.023)	(± 0.006)	(± 0.011)
		Gram	0.06	0.03	0.04	0.09
			(±0.011)ab	(± 0.014)	(± 0.011)	(± 0.024)
		Scar	0.04	0.05	0.04	0.03
			(±0.006)b	(± 0.013)	(± 0.009)	(± 0.010)
Seed × Management	$F_{4,16}$=1.80 NS					
Year	$F_{2,48}$=0.83 NS			0.05	0.04	0.05
				(± 0.01)	(± 0.005)	(± 0.01)
Seed ×Year	$F_{4,44}$=1.08 NS					
Management ×Year	$F_{4,48}$=2.82*					
Seed × Man. ×Year	$F_{8,36}$=0.85 NS					

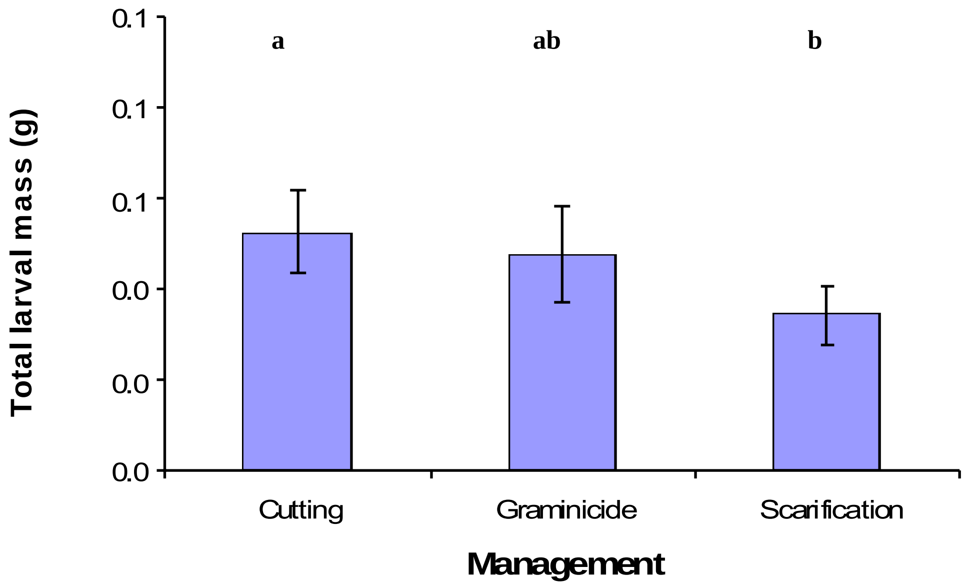


Figure 6.286. Response of Symphyta and Lepidoptera mass (g) (± SE) to margin management. Based on *post hoc* Tukey's tests, treatments that share the same letter do not differ significantly (P> 0.05).

6.3.3.7 Slugs

Slugs did not respond significantly to management or seed mix effects, and there were no significant effects of seed mix/ management/ year interactions. There was a significant response to year, with abundance declining overall from 2003 to 2006. Even in 2003, the first year following establishment, slug abundance was very low suggesting that margin establishment is unlikely to increase slug populations following establishment, and may even reduce pest problems by increasing local populations of slug predators such as ground beetles.

The effect of site was significant, with High Mowthorpe having significantly higher slug abundance than the other two sites.

Table 6.42. Repeated measures ANOVA table for slug abundance (pan trap samples only) showing effects of seed mix (Seed), margin management (Management), study site (Site) and sample year (Year). Back transformed mean values for each sample year for the fixed effects of seed mix (tussock grass + forbs = TG; fine grass + forbs = FG; countryside stewardship = CS) and margin management (scarification = Scar; graminicide = Gram; cutting = Cut) are shown (± SE). Where significant fixed effects of seed mix or management were found, subsequent *post hoc* Tukey's tests were performed. Where treatment levels of either seed mix or management within a column share the same letter they do not differ significantly (P> 0.05). Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05).

	Overall		**Mean untransformed abundances**		
Abundance Log$_e$ N+1			All years	2003	2006
Site	$F_{2,24}$=26.1***				
Seed	$F_{2,22}$=1.12 NS	CS	0.18	0.38	0.16
			(± 0.07)	(± 0.19)	(± 0.07)
		FG	0.12	0.34	
			(± 0.06)	(± 0.15)	0.00
		TG	0.12	0.29	0.05
			(± 0.05)	(± 0.13)	(± 0.03)
Management	$F_{2,20}$=1.14 NS	Cut	0.17	0.43	0.09
			(± 0.07)	(± 0.18)	(± 0.05)
		Gram	0.10	0.27	0.03
			(± 0.05)	(± 0.15)	(± 0.02)
		Scar	0.13	0.32	0.09
			(± 0.06)	(± 0.15)	(± 0.07)
Seed × Management	$F_{4,16}$=1.09 NS				
Year	$F_{1,26}$=11.1**			0.3	0.1
				(± 0.08)	(± 0.03)
Seed ×Year	$F_{2,24}$=0.17 NS				
Management ×Year	$F_{2,22}$=0.16 NS				
Seed × Man. ×Year	$F_{4,18}$=0.24 NS				

6.3.3.8 Below-ground macro-fauna

A total of 9872 individuals were collected, comprising 30 species. The Isopods (n=1662 individuals) and Chilopods (n=350) were the least diverse with 6 species each while the Lumbricidae (n=6949) and Diplopoda (n=911) had 9 species each.

Within the margins, the seed mix and management treatments had no significant effect on the abundances or species densities of the Lumbricidae, Chilopoda or Diplopoda. However, the abundance and species density of the Isopods showed a significant response to management with scarified plots containing fewer species than the graminicide or cut treatments. Seed mix had no significant effect on feeding group abundances or species densities, while litter-feeder species densities and abundances responded significantly to management, with fewer individuals and species in the scarified plots. Only soil-feeders responded significantly (P=0.03) to the interaction between seed mix and management with differences between the management types in the tussock grass treatments only.

Significant effects of season were found in all cases, except for soil-feeder species density, and there was a significant interaction between season and management for soil-feeder and litter-feeder abundances. This was due to low numbers of individuals or species in the scarified plots in the spring, which then increased to levels equal to, or greater than, the other management treatments in autumn (Figure 6.287).

RDA analysis indicated that soil invertebrate assemblages were not significantly different between the three seed mixes, with the canonical axes (Axis 1 & 2) accounting for only 4.9% of the variability in the species data (global Monte Carlo permutation test, F=1.188, P>0.05). However, the community was significantly correlated with the management treatments, with axes 1 and 2 explaining 16.9% and 1.6% of the species variance respectively (global Monte Carlo permutation test, F=4.505, P<0.001). The resulting ordination diagram indicates that the first axis divides the scarified treatment from the cut and graminicide treatments, whilst the second axis separates the cut and graminicide treatments (Figure 6.288).

The first axis of the ordination diagram divides those species such as the millipedes *Blaniulus guttulatus* and *Brachyiulus pusillus* which have positive correlations with the scarified treatment and those with a negative response such as the earthworms *Lumbricus castaneus* and *Apporectodea caliginosa*, and the woodlice *Philoscia muscorum* and *Trichoniscus pusillus*. Scarification appeared to influence species composition, with species more commonly associated with cropped or exposed habitats, such as the millipede *Blaniulus guttulatus* found in the scarified plots. Litter-dwelling species, such as the woodlice *Philoscia muscorum* and *Trichoniscus pusillus*, and the epigeic earthworm *Lumbricus castaneus*, with their requirement for surface residue to provide cover and food, had low densities in the scarified plots.

Overall, soil macrofaunal diversity and composition did not vary significantly between the three seed mix treatments but responded significantly to the field margin management treatments. Scarified plots had lower species densities of woodlice, a group that are well known for their sensitivity to soil disturbance. Scarification also reduced the species densities and/or abundances of the soil- and litter-feeding detritivores, although populations appeared to recover by the autumn.

Table 6.43. Results of general linear analysis with mixed models for the response of soil invertebrate abundance to seed mix (Seed), margin management (Management), and the interaction of these factors. Back transformed mean values are shown. Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05). Based on *post hoc* Tukey's tests, treatments that share the same letter do not differ significantly (P> 0.05)Management treatments that share the same letter do not differ significantly (P> 0.05).

Abundance Log$_e$ N+1		**Lumbricidae**	**Isopoda**	**Diplopoda**	**Chilopoda**
Seed	$F_{2,24}$=	0.24 NS	0.36 NS	0.74 NS	1.91
	Means				
	CS	171.9	44.20	21.75	7.42
	FG	182.6	39.50	21.67	10.50
	TG	172.8	54.80	24.50	7.33
Management	$F_{2,24}$=	1.01 NS	12.62***	2.5 NS	0.16
	Means				
	Cut	160.3	64.58 a	22.75	9.83
	Gram	193.3	58.58 a	18.33	7.83
	Scar	173.7	15.33 b	26.83	7.58
Seed × Management	$F_{4,24}$=	3.15 *	0.08 NS	0.54 NS	0.57

Table 6.44. Results of general linear analysis with mixed models for the response of soil invertebrate species richness to seed mix (Seed), margin management (Management) and the interaction of these factors. Back transformed mean values are shown. Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05). Based on *post hoc* Tukey's tests, treatments that share the same letter do not differ significantly (P> 0.05).

Species Richness		**Lumbricidae**	**Isopoda**	**Diplopoda**	**Chilopoda**
Seed	$F_{2,24}$=	0.22 NS	0.18 NS	0.62 NS	1.07 NS
	Means				
	CS	5.00	2.83 a	3.42	1.75
	FG	5.25	2.67 a	3.00	2.42
	TG	5.08	2.83 b	3.25	2.08
Management	$F_{2,24}$=	0.22 NS	5.6**	0.82 NS	0.27 NS
	Means				
	Cut	5.00	3.17 a	3.08	1.92
	Gram	5.08	3.00 a	3.50	2.25
	Scar	5.25	2.17 b	3.08	2.08
Seed × Management	$F_{4,24}$=	0.36 NS	1.24 NS	0.97 NS	1.44 NS

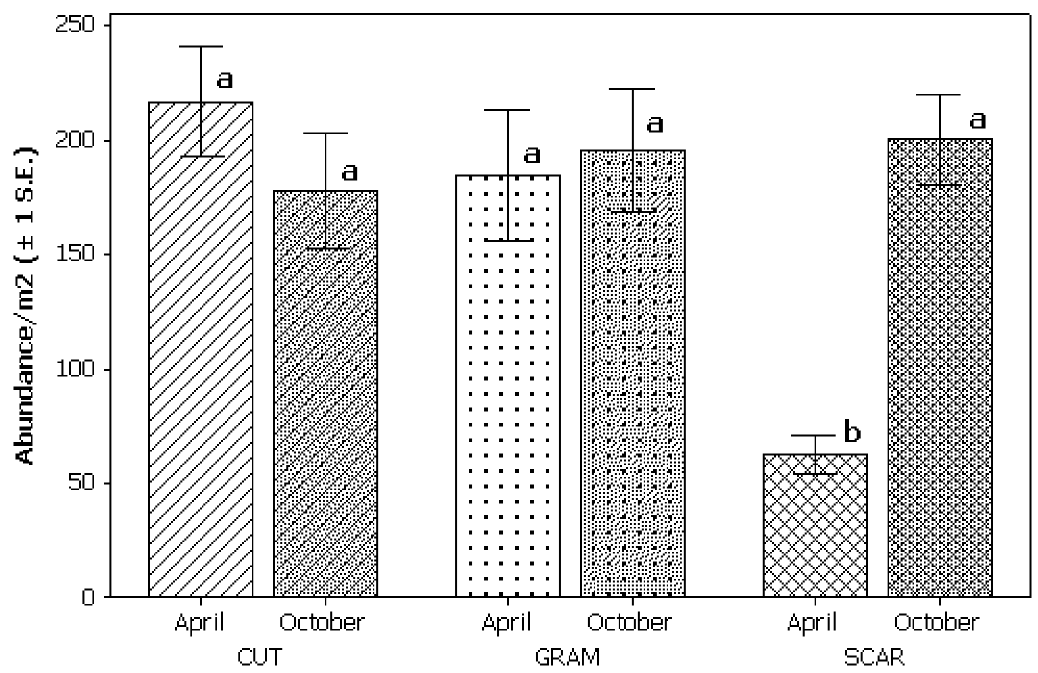
Table 6.45. Results of repeated measures analysis of feeding group abundances, for treatments (seed mix and management), month and all interactions. Back transformed mean values are shown. Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05). Based on *post hoc* Tukey's tests, treatments that share the same letter do not differ significantly (P> 0.05).

Abundance Loge N+1		**Litter-feeders**	**Soil-feeders**
Seed	$F_{2,24}$=	0.65 NS	0.75 NS
	Means		
	CS	50.71	66.29
	FG	51.25	70.79
	TG	60.08	65.33
Management	$F_{2,24}$=	7.87**	2.1 NS
	Means		
	Cut	61.67 a	59.96
	Gram	59.33 a	75.83
	Scar	41.04 b	66.63
Month	$F_{1,27}$=	13.01**	10.55**
Seed × Management	$F_{4,24}$=	1.21 NS	3.21*
Seed x Month	$F_{2,27}$=	0.26 NS	2.17 NS
Management x Month	$F_{2,27}$=	18.71***	10.16***
Management x Seed x Month	$F_{4,27}$=	0.55 NS	0.54 NS

Table 6.46. Results of repeated measures analysis of feeding group species richness responses to the treatments (seed mix and management), month and all interactions. Back transformed mean values are shown. Significance values are shown and defined as: * = P<0.05, ** = P<0.01, *** = P<0.001, NS = Not significant (P> 0.05). Based on *post hoc* Tukey's tests, treatments that share the same letter do not differ significantly (P> 0.05)

Species Richness		**Litter-feeders**	**Soil-feeders**
Seed	$F_{2,24}$=	0.39 NS	1.05 NS
	Means		
	CS	5.67	3.33
	FG	5.79	3.58
	TG	6.64	3.33
Management	$F_{2,24}$=	5.71**	0 NS
	Means		
	Cut	5.83 ab	3.42
	Gram	6.58 a	3.42
	Scar	5.08 b	3.42
Month	$F_{1,27}$=	12.69**	1.26 NS
Seed × Management	$F_{4,24}$=	1.79 NS	1.44 NS
Seed x Month	$F_{2,27}$=	0.58 NS	1.67 NS
Management x Month	$F_{2,27}$=	2.14 NS	1.67 NS
Management x Seed x Month	$F_{4,27}$=	1.1 NS	1.31 NS

(a)



(b)

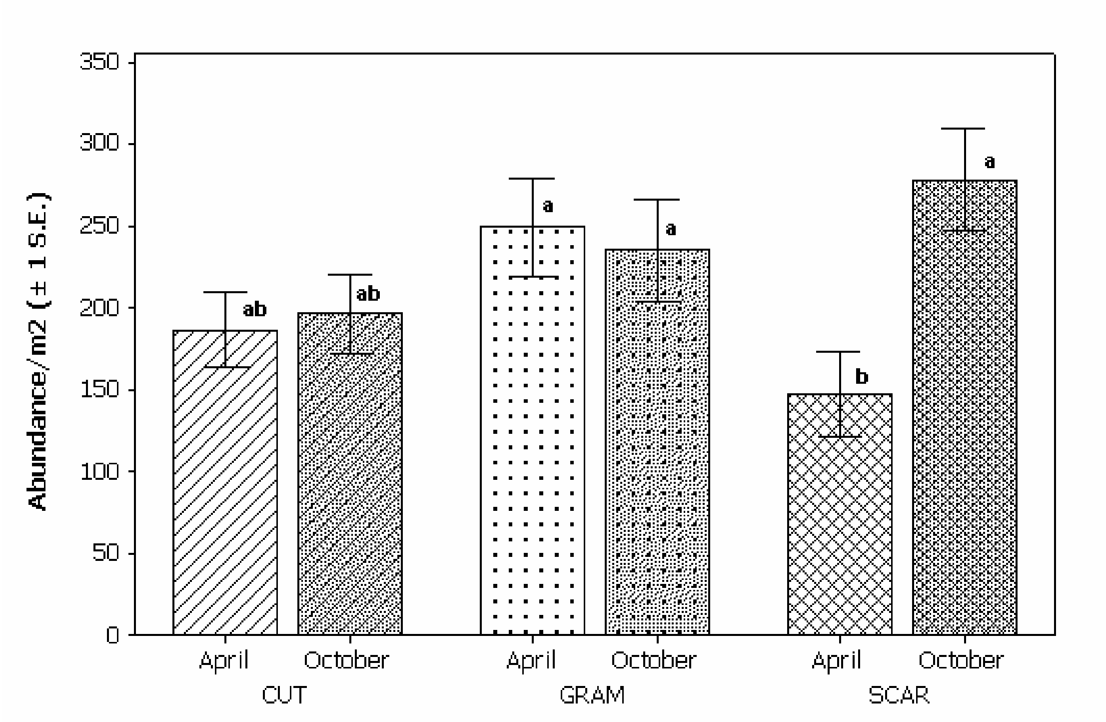


Figure 6.287. The response of feeding groups to field margin management varies with season: (a) litter-feeder abundance: (b) soil-feeder abundance (cutting = CUT; graminicide = GRAM; scarification = SCAR).

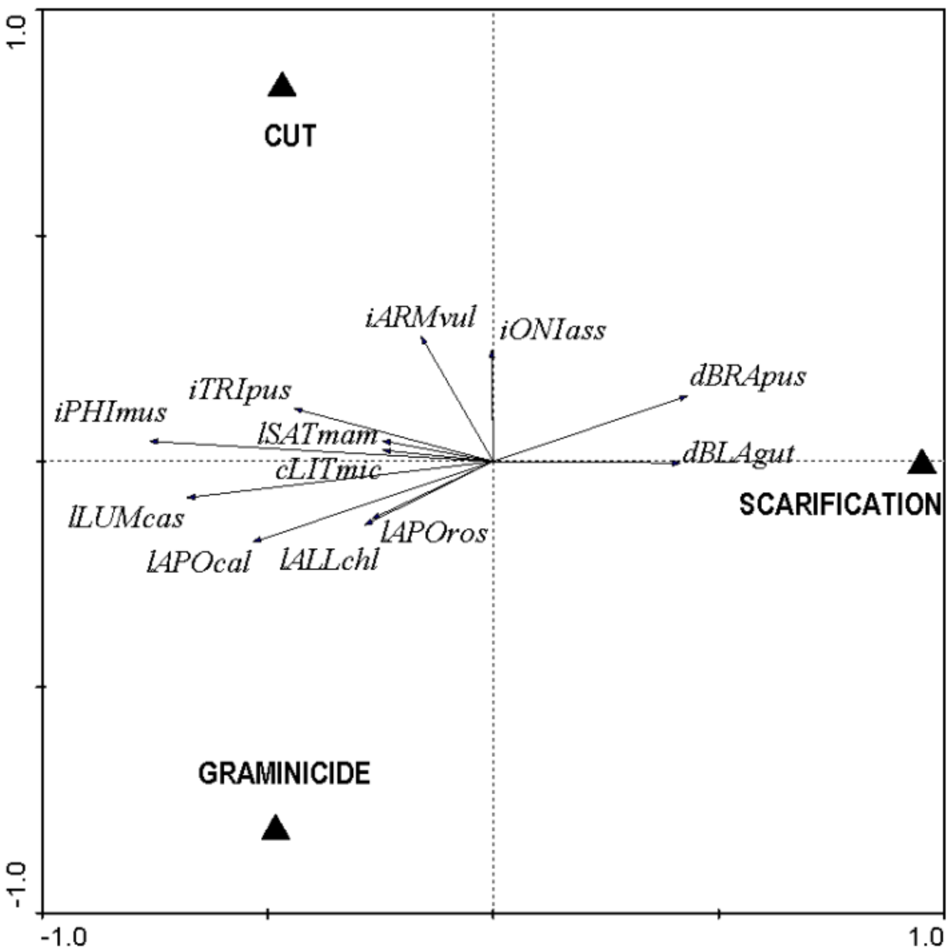


Figure 6.288. RDA triplot showing only species with a fit greater than 6%. The environmental variables are shown as filled triangles. Species: Lumbricidae (l): *lALLchl = Allolobophora chlorotica, lAPOcal = Aporrectodea caliginosa, lAPOros = Aporrectodea rosea, lLUMcas = Lumbricus castaneus, lSATmam = Satchellius mammalis:* Isopoda (i): *iARMvul = Armadillidium vulgare,* iONIass = *Oniscus assellus*, *iPHImus = Philoscia muscorum, iTRIpus = Trichoniscus pusillus*: Diplopoda (d): *dBLAgut = Blaniulus guttulatus, dBRApus = Brachyiulus pusillus:* Chilopoda (c): *cLITmic = Lithobius microps*.

6.3.4 Bumblebees & Butterflies

There were large significant differences in abundance of individuals and species number (richness) of forb flowers, bumblebees and butterflies per 125 m^2 treatment plot between sites in each year. These effects are to be expected because of differences in factors such as latitude, climate and seed mix composition between sites, and are therefore not examined here. Instead we will focus on the consistent treatment effects and interactions, as our aim is to find generalisations about appropriate management options for arable field margins.

The simple grass seed mix provided consistently fewer forb flowers for pollinating insects between May and September compared with the mixtures containing forbs, both in every year and overall (Table 6.47a). Moreover, the fine-leaved grass + forb mix consistently produced more flowers than the tussock grass + forb mix. Graminicide application, in 2004, 2006 and overall, significantly increased the abundance of forb flowers. There were no significant seed mix × management interactions in any year or overall. Similarly, there was no significant effect of year on the flower resource. The species richness of forb flowers was significantly higher in the fine-leaved grass + forb seed mix compared with all other treatments in every year and overall (Table 6.47b). Forb flower richness was also significantly higher in the tussock grass + forb mix compared with the all grass mix overall and in all years except 2006. There were also significant effects of management on the species richness of the forb flower resource for pollinators. Soil scarification significantly increased forb flower richness compared with just cutting in 2003, 2004, 2006 and overall. Graminicide application increased forb flower richness compared with cutting in 2006 and overall. However, there were no significant seed mix × management interactions or any effect of year.

As expected, the abundance and species number (richness) of forb flowers of perennial sown species were both significantly greater in the fine-leaved grass + forb seed mix compared with the other treatments (Table 6.48). Species richness and abundance of sown perennials was also greater in the tussock grass + forb mix compared with the all grass mix. In contrast, the abundance of flowers of unsown species was significantly higher in the all grass mix compared with the tussock grass + forb mix.

Graminicide application significantly increased the abundance of flowers of sown forbs compared with scarification. This effect was predominantly on perennial forbs. In contrast, scarification resulted in a significantly greater abundance and species richness of flowers of unsown forbs compared with cutting. Also, scarification resulted in a significantly greater species richness of flowering annual forbs compared with the other management treatments. Graminicide application resulted in a greater richness of annuals compared with cutting.

In total 12925 foraging bumblebees and 3219 *Psithyrus* were recorded on all three sites between 2004 and 2006. These comprised 7 species of bumblebee and 5 species of *Psithyrus*, including the rare (UKBAP) species *Bombus ruderatus* recorded every year at Boxworth. The majority of foraging bumblebees were recorded on field margins sown with the tussock grass + forb seed mix (51%) followed by the fine grass + forb mix (39%), and then the all grass mix (10%). Field margins managed by graminicide application received the greatest proportion of foraging visits (41%). The scarified and cut margins received a similar, lower proportion of foraging visits (30% and 29% respectively).

There was a highly significant positive relationship between the log transformed number of forb flowers per plot and the log abundance of bumblebees (log bee abundance = -3.28 + 0.700 × log flower abundance; R^2= 54.0%; $F_{1, 133}$= 158.15; P<0.001; Figure 6.89). There were also clear differences in the response of bumblebees to the different seed mixtures. Both abundance of individuals and species number of foraging bees were significantly greater in the seed mixtures containing forbs compared with the all grass mix in every year and overall (Table 6.49ab). However, there were no significant differences between the fine-leaved grass + forb and the tussock grass + forb seed mixes.

There were no significant effects of management or any seed mix × management interactions on bee abundance in any year or overall. However, graminicide application significantly increased the number of bumblebee species recorded in 2004 and overall. There were no significant interactions of seed mix and management on bee species richness or abundance.

Bee abundance changed significantly during the experiment, with peaks in 2004 and 2005. There was also a weak seed mix × year interaction reflecting large variations in bee species richness between years in the all grass seed mix.

There was a similar significant positive response to seed mixture containing forbs for the functional groupings of short- and long-tongued bumblebees, together with the individual species: *Bombus pratorum, Bombus pascuorum* and the brood parasites *Psithyrus* sp. (Table 6.50). *Bombus terrestris / lucorum* and *Bombus hortorum* were significantly more abundant in the tussock grass + forb seed mix compared with the other treatments. These species were also more abundant in the fine-leaved grass + forb seed mix compared with the all grass mix. In contrast, *Bombus lapidarius* was significantly more abundant in the fine-leaved grass + forb mix compared with the others. The BAP-listed bumblebee (*B. ruderatus*) was also significantly more abundant in the fine-leaved grass + forb mix compared with the others. There were no significant effects of management on any individual species. There were a number of significant year effects, but these showed no consistent pattern across species.

A total of 16144 foraging bumblebees (including *Psithyrus* sp.) were recorded visiting 54 flowering forb species. Plant species receiving the most foraging visits varied between the different field margin treatments, reflecting differences in flower abundance (Figure 6.290a). A total of 1477 bumblebees were observed foraging on margins sown with the all grass seed mix. The perennial weed *Cirsium arvense* and biennial *C. vulgare* accounted for 40% and 15% of these foraging visits respectively. Of the 7755 bees recorded on the tussock grass + forb margins, the sown forbs *Vicia cracca* (41%), *Dipsacus fullonum* (33%), *Centaurea nigra* (16%) and *C. scabiosa* (7%) accounted for the majority of foraging visits. The margins sown with the fine grass + forb mix provided the greatest range of forage species. The sown forbs *Lotus corniculatus* (40%), *C. nigra* (31%) and *Malva moschata* (4%), and the unsown forb *C. vulgare* (8%) accounted most of the 5586 foraging visits.

Patterns of bumblebee foraging were broadly similar in the three margin management treatments (Figure 6.290b). *V. cracca* (26%), *C. nigra* (23%) and *L. corniculatus* (18%) accounted for the majority of the 4364 foraging visits in the margins managed by cutting alone. In the scarified margins, *D. fullonum* (26%), *V. cracca* (17%) and *C. nigra* (14%) accounted for most of the 4604 foraging visits. In the margins managed by graminicide application, *C. nigra* (23%), *V. cracca* (23%) and *L. corniculatus* (15%) accounted for most of the 6150 visits.

The long-tongued bumblebee *B. pascuorum* was the most abundant species recorded (Figure 6.291). This species made most foraging visits (44%) to the sown species *V. cracca*. The next most abundant was the short-tongued species group *B. terrestris/lucorum* which also made most foraging visits *V. cracca* (37%), followed by *D. fullonum* (27%). *B. lapidarus* has an intermediate tongue length and mostly foraged on *L. corniculatus* (40%). The rare species *B. ruderatus* foraged mostly on the sown species *D. fullonum* and *C. nigra.*

A total of 8457 butterflies comprising 26 species were recorded on the three sites between 2004 and 2006. These included the notable butterfly species Brown argus and White-letter hairstreak. Most butterflies (39%) were recorded on margins sown with the tussock grass + forb seed mix, followed by the fine grass + forb mix (37%). Only 24% of butterflies were observed on the all grass seed mix. Approximately equal numbers of butterflies were recorded on each of the margin management regimes.

Butterflies showed a similar response to bumblebees to the different seed mix and management treatments. The abundance and species number of butterflies were significantly greater in the seed mixtures containing forbs compared with the all grass mix in every year and overall (Table 6.51ab). However, there were no significant differences between the fine-leaved grass + forb and tussock grass + forb seed mixes. There were no significant effects of management or any seed mix × management interactions on butterfly abundance or species number in any year or overall. However, there were significant year effects for both abundance and species richness, reflecting the colonisation of the margin plots by migrant butterfly species, such as Painted lady, in some years.

The functional groupings of mobile butterfly species were significantly more abundant in margins sown with the tussock grass + forb seed mix compared with the all grass mix (Table 6.52). In contrast, the abundance of immobile species was significantly higher in the fine grass + forb mix compared with the all grass mix. This reflected the response of the individual species. Large white, Painted lady and Peacock were significantly more abundant in the tussock grass + forb seed mix compared with the others. Green-veined white was more abundant in the seed mixes containing forbs compared with the all grass mix. In contrast, the immobile species Large skipper and Meadow brown were significantly more abundant in the margins sown with the fine grass + forb seed mix. There were no significant effects of management on any individual species. There were a number of significant year effects, but these showed no consistent pattern across species.

Table 6.47 Effects of seed mixture and management on a) abundance of individuals and b) the number of species (richness) of forb flowers per 125 m^2 plot. Values are cumulative totals for all visits in a season. Means with the same letter in the same column are not significantly different (P> 0.05).

a) Total forb flowers

	2003	2004	2005	2006	Overall
Seed mixture					
1. All grass	6008a	3272a	2836a	3043a	3790a
2. Tussock grass + forbs	10646a	9464b	10625b	8145b	9720b
3. Fine-leaved grass + forbs	20849b	16814c	19154c	19656c	19118c
Seed mix $F_{2,16}$	11.32***	64.08***	29.56***	209.45***	94.46***
Management					
1. Cut	12053	9138a	8982	8982a	9731a
2. Scarify	10635	7955a	9352	9352a	9417a
3. Graminicide	14817	12457b	14281	14281b	13481b
Management $F_{2,16}$	0.89ns	7.59**	3.88*	10.14***	8.08**
Seed mix × management $_{4,16}$	0.12	2.89ns	0.92ns	2.69ns	1.80ns
Time $F_{3,54}$					0.59ns
Time × Seed mix $F_{6,54}$					0.18ns
Time × Management $F_{6,54}$					0.09ns

b) Richness forb flowers

	2003	2004	2005	2006	Overall
Seed mixture					
1. All grass	13.5a	13.7a	12.0a	11.2a	12.6a
2. Tussock grass + forbs	16.9b	17.9b	15.7b	14.7a	16.3b
3. Fine-leaved grass + forbs	23.5c	23.9c	22.0c	20.5b	22.5c
Seed mix $F_{2,16}$	45.65***	25.74***	29.69***	23.60***	39.43***
Management					
1. Cut	16.4a	16.2a	14.7	12.8a	15.0a
2. Scarify	19.2b	20.4b	17.6	16.4b	18.4b
3. Graminicide	18.3ab	18.9ab	17.4	17.2b	17.9b
Management $F_{2,16}$	3.67*	4.48*	3.21ns	5.84*	5.41*
Seed mix × management $_{4,16}$	1.35ns	0.40ns	0.95ns	0.32ns	0.78ns
Time $F_{3,54}$					2.66ns
Time × Seed mix $F_{6,54}$					0.03ns
Time × Management $F_{6,54}$					0.93ns

* P<0.05, ** P<0.01, *** P<0.001, ns - no significant difference

Table 6.48. Effects of seed mixture and management on abundance and richness of sown and unsown forb flowers per 125 m^2 plot averaged across all years. Values are cumulative totals for all visits in a season. Means with the same letter in the same column are not significantly different (P> 0.05).

	Total sown species	**Richness sown species**	**Total unsown species**	**Richness unsown species**	**Total annuals**	**Richness annuals**	**Total perennials**	**Richness perennials**
Seed mixture								
1. All grass	561a	3.6a	3229b	9.1	1949	5.2	1841a	7.4a
2. Tussock grass + forbs	7961b	9.3b	1759a	7.0	1289	4.0	8431b	12.3b
3. Fine-leaved grass + forbs	16586c	13.7c	2532ab	8.7	1688	4.9	17430c	17.6c
Seed mix $F_{2,16}$	94.45***	202.07***	3.56ns	3.69*	1.90ns	3.08ns	99.41***	97.22***
Management								
1. Cut	8011ab	8.5	1720a	6.5a	1155	3.3a	8576a	11.7
2. Scarify	6260a	8.5	3157b	9.9b	1946	6.2c	7471a	12.2
3. Graminicide	10837b	9.5	2644ab	8.4ab	1824	4.6b	11656b	13.3
Management $F_{2,16}$	7.83**	2.48ns	3.49*	9.09**	3.13ns	16.83***	7.64**	2.49ns
Seed mix × management $_{4,16}$	2.03ns	1.00	0.25ns	0.67ns	0.22ns	0.92ns	2.09ns	0.71ns
Time $F_{3,54}$	0.53ns	8.54***	6.23**	5.93**	4.64*	10.90***	0.43ns	1.97ns
Time × Seed mix $F_{6,54}$	0.23ns	0.94ns	0.13ns	0.05ns	0.04ns	0.11ns	0.33ns	0.18ns
Time × Management $F_{6,54}$	0.19ns	1.48ns	0.60ns	0.16ns	0.77ns	0.30ns	0.14ns	0.65ns

* *P*<0.05, ** *P*<0.01, *** *P*<0.001, ns - no significant difference

Table 6.49. Effects of seed mixture and management on a) abundance of individuals and b) number of species (richness) of bumblebees per 125 m^2 plot. Values are totals for all visits in a season. Means with the same letter in the same column are not significantly different (P> 0.05).

a) Total bumblebees

	2003	2004	2005	2006	Overall
Seed mixture					
1. All grass	13.0a	3.8a	11.8a	4.2a	8.2a
2. Tussock grass + forbs	28.2b	55.5b	56.7b	31.9b	43.1b
3. Fine-leaved grass + forbs	27.0b	25.4b	51.6b	26.6b	32.7b
Seed mix $F_{2,16}$	10.44***	21.40***	15.35***	31.74***	29.51***
Management					
1. Cut	18.7	26.6	35.6	16.0	24.2
2. Scarify	22.4	20.7	37.4	21.8	25.6
3. Graminicide	27.2	37.5	47.2	24.8	34.2
Management $F_{2,16}$	1.53ns	0.75ns	0.01ns	2.60ns	1.04ns
Seed mix × management $_{4,16}$	0.58ns	0.36ns	0.46ns	0.13ns	0.17ns
Time $F_{3,54}$					4.14*
Time × Seed mix $F_{6,54}$					1.26ns
Time × Management $F_{6,54}$					0.36ns

b) Richness bumblebees

	2003	2004	2005	2006	Overall
Seed mixture					
1. All grass	2.6a	1.5a	2.0a	1.6a	1.9a
2. Tussock grass + forbs	4.6b	4.5b	3.9b	4.8b	4.5b
3. Fine-leaved grass + forbs	3.8b	4.4b	4.5b	4.2b	4.3b
Seed mix ANOVA $F_{2,16}$	23.65***	34.53***	23.58***	48.29***	54.08***
Management					
1. Cut	3.4	3.0a	3.4	3.1	3.2a
2. Scarify	3.6	3.1a	3.4	3.9	3.5ab
3. Graminicide	4.0	4.3b	3.7	3.7	3.9b
Management $F_{2,16}$	2.52ns	5.53*	0.62ns	3.17ns	3.74*
Seed mix × management $_{4,16}$	0.15ns	0.88ns	0.48ns	0.32ns	0.40ns
Time $F_{3,54}$					0.21ns
Time × Seed mix $F_{6,54}$					2.31*
Time × Management $F_{6,54}$					0.91ns

* P<0.05, *** P<0.001, ns - no significant difference

Table 6.50. Effects of seed mixture and management on the abundance of individual bumblebee species per 125 m[2] plot averaged across all years. Values are cumulative totals for all visits in a season. Means with the same letter in the same column are not significantly different ($P > 0.05$).

	B. terrestris/ B. lucorum	*B. pratorum*	*B. lapidarius*	*B. pascuorum*	*B. hortorum*	*B. ruderatus*	Total *Psithyrus*	Total short-tongued	Total long-tongued
Seed mixture									
1. All grass	1.9a	0.1a	1.8a	1.2a	0.5a	0.0a	2.6a	3.8a	1.7a
2. Tussock grass + forbs	10.3b	0.5b	4.9b	16.1b	3.5c	0.1ab	7.7b	15.7b	19.7b
3. Fine-leaved grass + forbs	3.2a	1.0b	12.0c	7.3b	1.4b	0.2b	7.6b	16.3b	8.9b
Seed mix ANOVA $F_{2,16}$	20.25***	13.64***	35.67***	24.42***	30.14***	3.63*	10.24***	30.07***	32.82***
Management									
1. Cut	4.4	0.4	5.7	7.3	1.3	0.1	5.0	10.5	8.7
2. Scarify	5.2	0.5	5.5	7.7	1.8	0.1	4.8	11.3	9.6
3. Graminicide	5.8	0.6	7.6	9.6	2.4	0.1	8.1	14.0	12.1
Management ANOVA $F_{2,16}$	1.02ns	0.19ns	0.99ns	0.30ns	2.93ns	0.14ns	1.74ns	0.89ns	0.81ns
Seed mix × management $_{4,16}$	0.16ns	0.18ns	0.37ns	0.08ns	0.82ns	0.11ns	0.51ns	0.16ns	0.08ns
Time $F_{3,54}$	3.02ns	3.91*	10.66***	0.96ns	5.51**	2.32ns	1.38ns	6.73**	0.84ns
Time × Seed mix $F_{6,54}$	0.74ns	1.33ns	1.19ns	0.57ns	1.59ns	1.33ns	1.70ns	0.83ns	0.69ns
Time × Management $F_{6,54}$	0.05ns	0.38ns	0.33ns	0.11ns	0.99ns	1.00ns	0.19ns	0.26ns	0.17ns

* $P<0.05$, ** $P<0.01$, *** $P<0.001$, ns - no significant difference

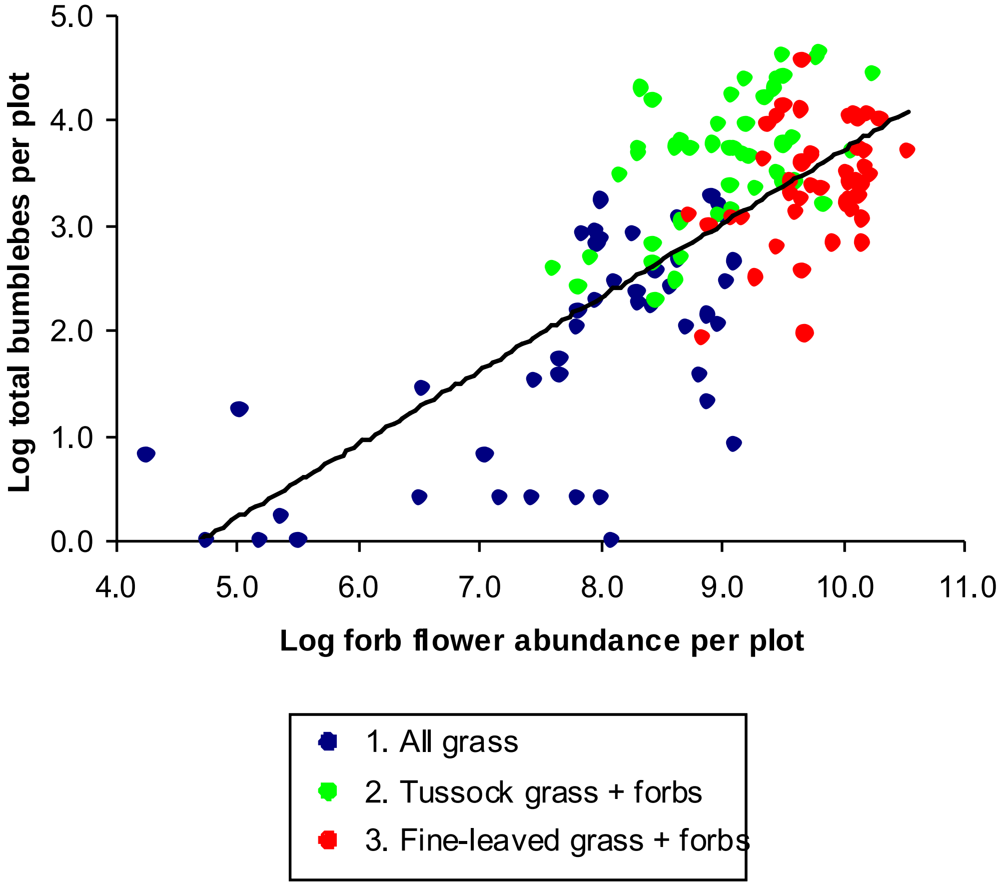
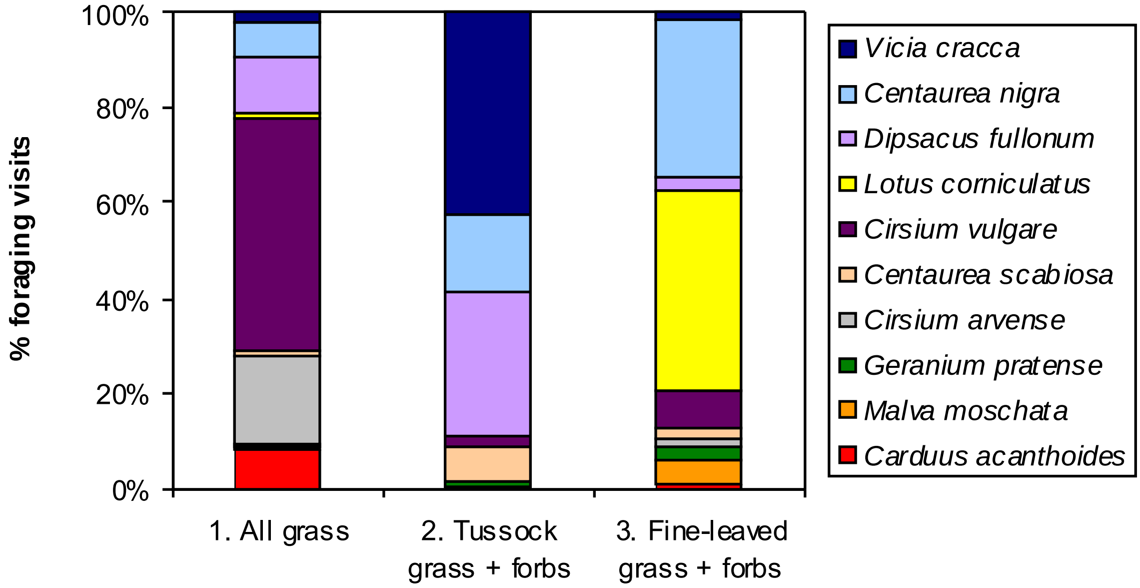


Figure 6.289. Relationship between log bumblebee abundance and log flower abundance per plot (log bee abundance = -3.28 + 0.700 × log flower abundance; $R^2 = 54.0\%$; $F_{1, 133} = 158.15$; $P<0.001$)

a) Seed mixture



b) Management

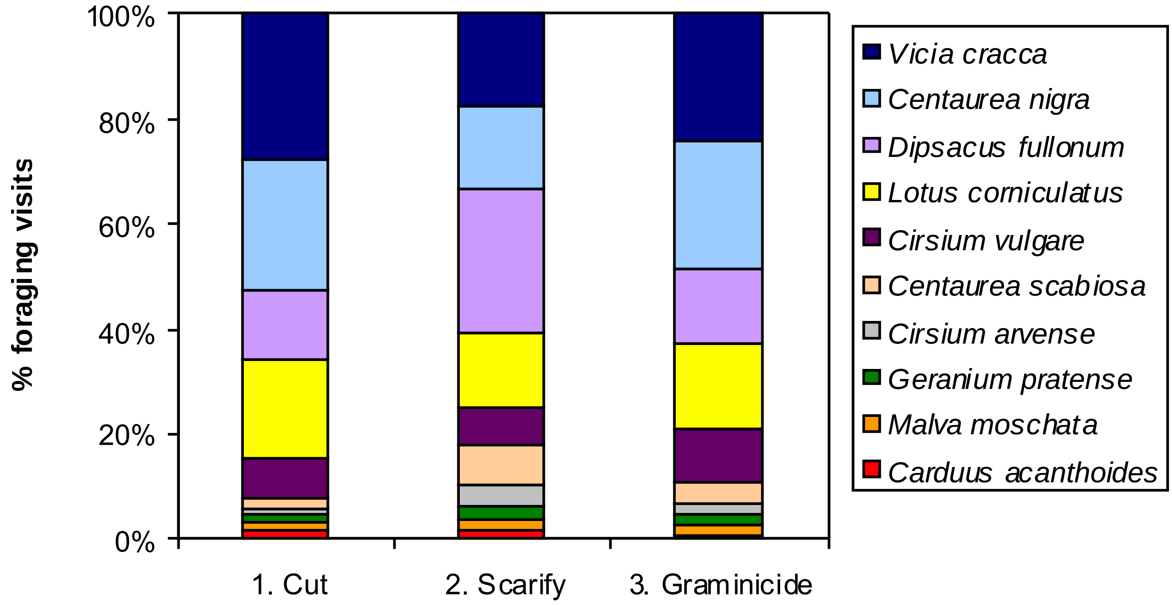


Figure 6.290. Flower utilisation by foraging bumblebees in the field margin treatments: a) seed mixtures; b) management.

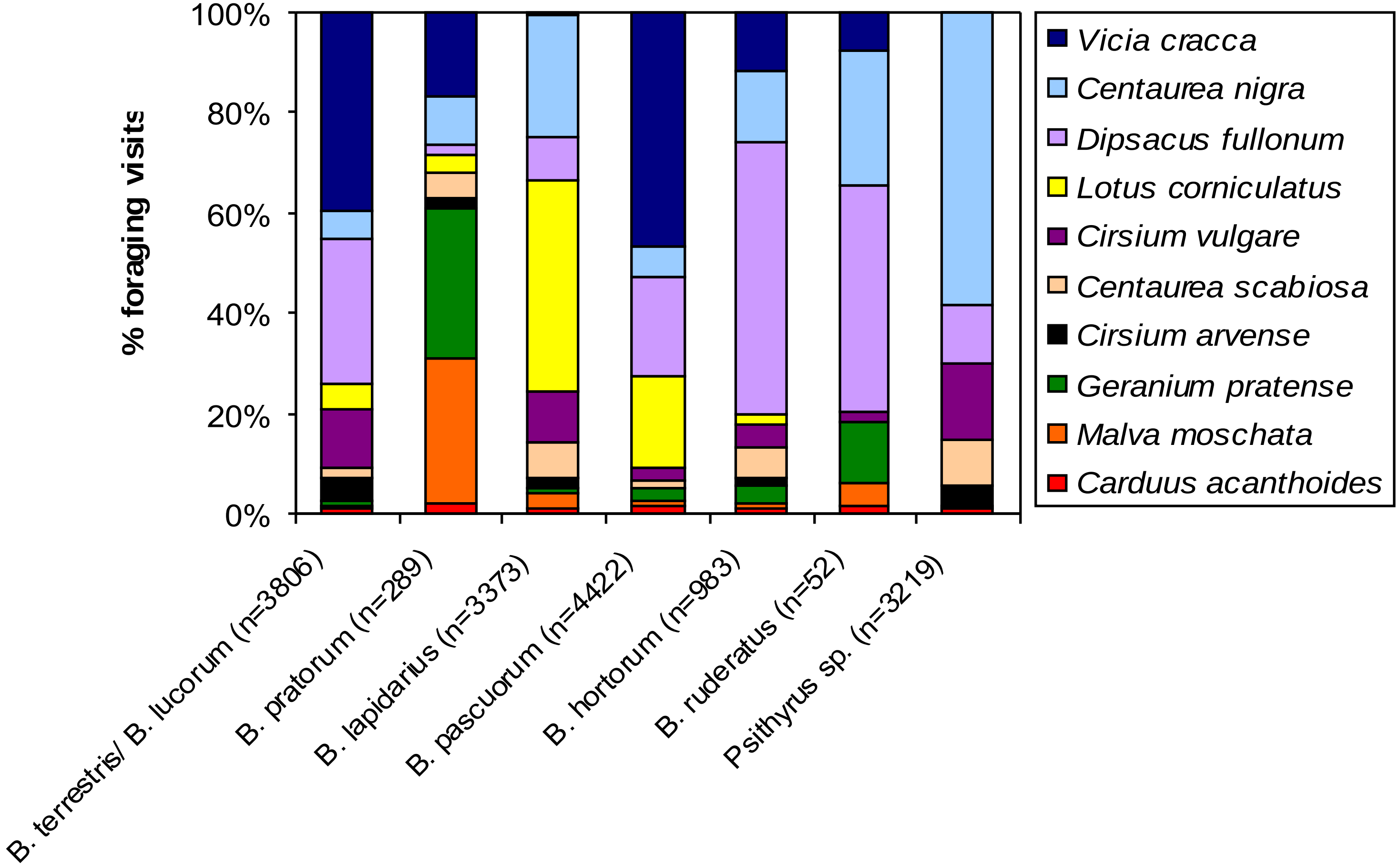


Figure 6.291. Pattern of flower visitation by the different bumblebee species.

Table 6.51. Effects of seed mixture and management on a) abundance of individuals and b) number of species (richness) of butterflies per 125 m^2 plot. Values are totals for all visits in a season. Means with the same letter in the same column are not significantly different (*P*> 0.05).

a) Total butterflies

	2003	**2004**	**2005**	**2006**	**Overall**
Seed mixture					
1. All grass	10.4a	12.0a	14.8	8.0a	11.3a
2. Tussock grass + forbs	21.1b	16.5b	21.3	15.2b	18.5b
3. Fine-leaved grass + forbs	15.7b	16.5b	22.6	13.7b	17.1b
Seed mix $F_{2,16}$	12.43***	9.54**	3.51*	9.90**	9.69**
Management					
1. Cut	14.1	14.9	21.3	10.9	15.3
2. Scarify	16.9	15.3	16.2	12.5	15.2
3. Graminicide	16.3	14.8	21.2	13.5	16.5
Management $F_{2,16}$	0.79ns	0.07ns	0.81ns	0.79ns	0.29ns
Seed mix × management $_{4,16}$	0.44ns	0.94ns	0.23ns	0.39ns	0.18ns
Time $F_{3,54}$					7.20***
Time × Seed mix $F_{6,54}$					0.64ns
Time × Management $F_{6,54}$					0.70ns

b) Richness butterflies

	2003	**2004**	**2005**	**2006**	**Overall**
Seed mixture					
1. All grass	5.0a	4.0a	4.7a	3.6a	4.3a
2. Tussock grass + forbs	7.1b	5.4b	6.1b	5.9b	6.1b
3. Fine-leaved grass + forbs	6.0ab	5.7b	6.2b	5.5b	5.9b
Seed mix ANOVA $F_{2,16}$	11.03***	8.70**	9.04**	9.96**	13.82***
Management					
1. Cut	5.6	5.1	5.7	4.6	5.3
2. Scarify	6.1	5.1	5.6	5.0	5.4
3. Graminicide	6.3	4.9	5.7	5.4	5.6
Management $F_{2,16}$	1.15ns	0.09ns	0.03ns	1.00ns	0.42ns
Seed mix × management $_{4,16}$	0.49ns	3.40*	0.78ns	0.29ns	0.62ns
Time $F_{3,54}$					4.40*
Time × Seed mix $F_{6,54}$					0.77ns
Time × Management $F_{6,54}$					0.34ns

* *P*<0.05, ** *P*<0.01, *** *P*<0.001, ns - no significant difference

Table 6.52. Effects of seed mixture and management on the abundance of the most commonly recorded butterfly species per 125 m^2 plot averaged across all years. Values are cumulative totals for all visits in a season. Means with the same letter in the same column are not significantly different (P> 0.05).

	Green-veined White	Large White	Painted Lady	Peacock	Small Tortoise-shell	Small White	Hedge Brown	Large Skipper	Meadow Brown	Ringlet	Small Skipper	Mobile species	Immobile species
Seed mixture													
1. All grass	0.8a	0.7a	0.2a	0.3ab	0.3	1.6	1.4	0.1a	3.4a	1.1	0.5a	4.2a	7.1a
2. Tussock grass + forbs	1.6b	1.5b	1.3b	0.8b	0.5	1.9	1.0	0.3ab	4.9ab	2.0	1.6b	8.0b	10.5ab
3. Fine-leaved grass + forbs	1.4b	1.1ab	0.5a	0.2a	0.4	2.2	1.6	0.4b	5.6b	1.6	0.9ab	6.0ab	11.1b
Seed mix ANOVA $F_{2,16}$	7.06**	9.54**	9.04**	3.83*	0.67ns	1.68ns	1.37ns	4.34*	4.31*	2.47ns	10.08***	6.09*	3.92*
Management													
1. Cut	1.0	0.9	0.5	0.3	0.3	1.6	1.5	0.3	4.8	1.7	1.3	4.8	10.5
2. Scarify	1.4	1.0	0.9	0.7	0.5	2.3	1.0	0.2	4.0	1.4	0.8	7.1	8.1
3. Graminicide	1.4	1.3	0.6	0.4	0.4	1.8	1.5	0.3	5.0	1.6	0.9	6.3	10.2
Management ANOVA $F_{2,16}$	1.31ns	3.09ns	1.48ns	1.57ns	1.62ns	2.46ns	1.26ns	0.74ns	1.08ns	0.23ns	2.98ns	2.34ns	1.39ns
Seed mix × management $_{4,16}$	1.15ns	0.44ns	0.50ns	0.69ns	0.22ns	1.04ns	0.38ns	0.48ns	0.94ns	0.17ns	0.93ns	0.30ns	0.61ns
Time $F_{3,54}$	18.38***	26.38***	19.45***	6.85**	12.55***	0.79ns	6.16*	2.86ns	4.79*	7.03**	7.66***	13.36***	10.61***
Time × Seed mix $F_{6,54}$	1.71ns	0.86ns	5.39*	3.66*	4.50**	0.27ns	0.26ns	0.64ns	0.83ns	0.75ns	1.50ns	3.94**	0.43ns
Time × Management $F_{6,54}$	0.77ns	1.30ns	0.67ns	0.83ns	0.51ns	0.27ns	1.04ns	1.59ns	1.39ns	0.07ns	0.49ns	0.57ns	0.80ns

* P<0.05, ** P<0.01, *** P<0.001, ns - no significant difference

6.3.5 Birds

The results for birds are presented in Table 6.54. Between 2003 and 2006 there was a significant increase in the absolute densities of birds using margins and a significant increase in the relative proportion of birds using margins (compared with the total number recorded within the 100 m transect band). Thus, the proportionate use of margins increased from 5.6% in 2002, to 9% in 2003, and to 29% in 2006 (Figure 6.291a). Margins occupied 5.6% of the observational area. The effect was especially pronounced at High Mowthorpe (Table 6.54a; Figure 6.291b). There was a significant seasonal increase in margin use, from April to July for all species combined (Likelihood ratio: $\chi 23 = 12.5$, $P < 0.006$; Figure 6.291c).

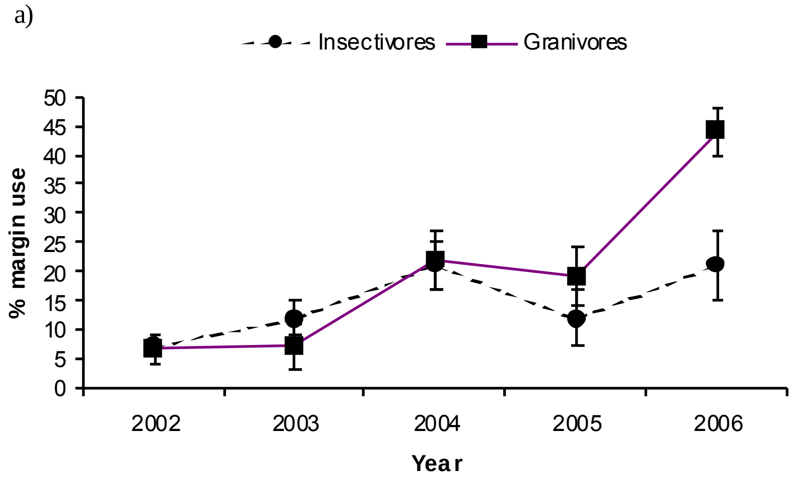
Margin management treatments were a stronger and more consistent predictor, across years, of bird densities than initial seed-mix type (Table 6.54a). Differences between seed mixes were only significant in the final experimental year, 2006, during which, the highest bird densities were recorded on tussock and fine grass mixes (both containing forbs), rather than the CS (grass) mix (Figure 6.292a). For management effects, bird densities were significantly higher on scarified and graminicide-treated plots than on cut margins (Figure 6.292b).

6.3.6 Trophic linkages

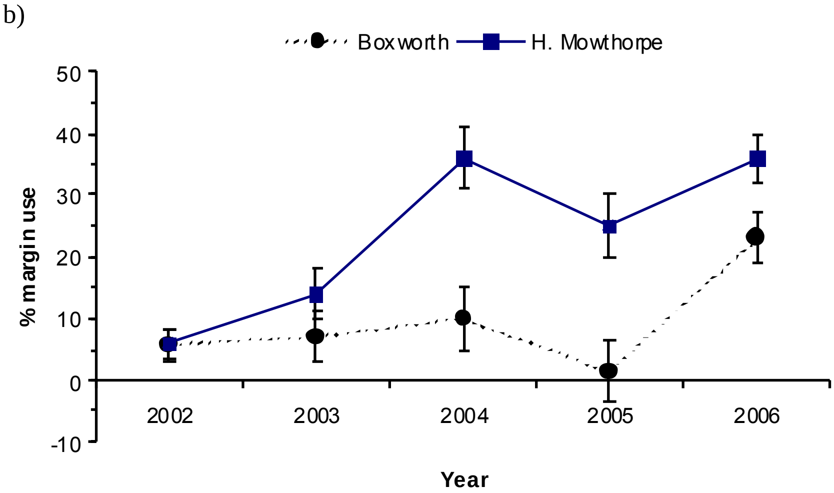
6.3.6.1 Vegetation – Invertebrate linkages

The RDA analysis of beetle assemblage responses from 2003 to 2006 was carried out separately for each of the three sites (Table 6.53). This multiple RDA approach was used to account for large between-site variations in beetle species composition. However, although beetle species composition may have varied considerably between sites on clay, sand and chalk soils, there were clear similarities in the nature of the responses to seed mix, management and the continuous measures of plant community structure and sward architecture. For all sites beetle assemblage structure was seen to respond significantly to the interactions between year and seed mix, management, plant community structure and sward architecture. Respectively, these explained 51.1%, 36.7% and 32.5% of the variance in the beetle data for High Mowthorpe, Gleadthorpe and Boxworth. At High Mowthorpe each of the nine combinations of seed mix and management treatment interactions with year (e.g. 'year * tussock grass + scarification' or 'year * fine grass + graminicide') resulted in beetle assemblage structures that differed significantly from each other (Figure 6.293). However, while the interaction between the tussock grass seed mix and scarification had a significant effect on beetle assemblage structure at the Gleadthorpe site, this was not the case for the interactions between scarification and either the fine grass and forbs or CS seed mixes. All other interactions between seed mix and management had significant effects on beetle assemblage structure at the Gleadthorpe site (Figure 6.294). The Boxworth site showed the weakest overall responses to the interaction between seed mix and management. In the case of the tussock grass and forbs seed mix, there was no significant effect of management on beetle assemblage structure. For field margins established with the fine grass and forbs seed mix the addition of scarification was to result in beetle assemblage that differed significantly in structure from those found in the remaining seed mix and management combinations. This was not, however, the case for the beetle assemblages of the fine grass and forbs seed mix when managed by either cutting or graminicide. At the Boxworth site the CS seed mix in combination with either cutting or graminicide management resulted in the creation of beetle assemblages that differed significantly in structure from those found in the remaining seed mix and management combinations (Figure 6.295).

a)



b)



c)

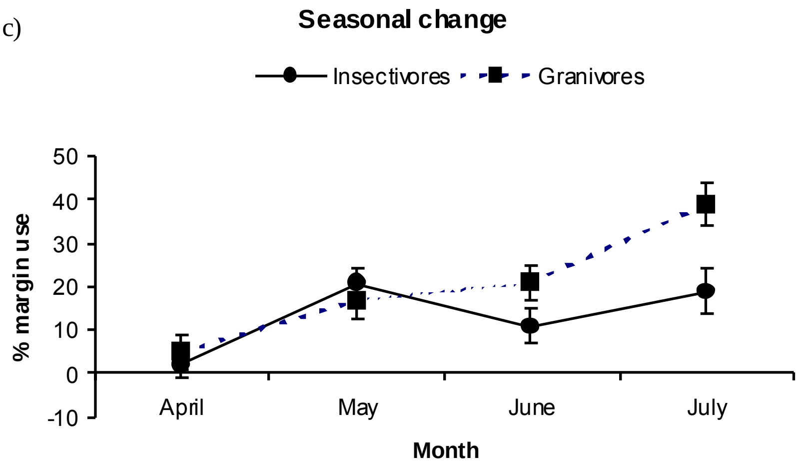
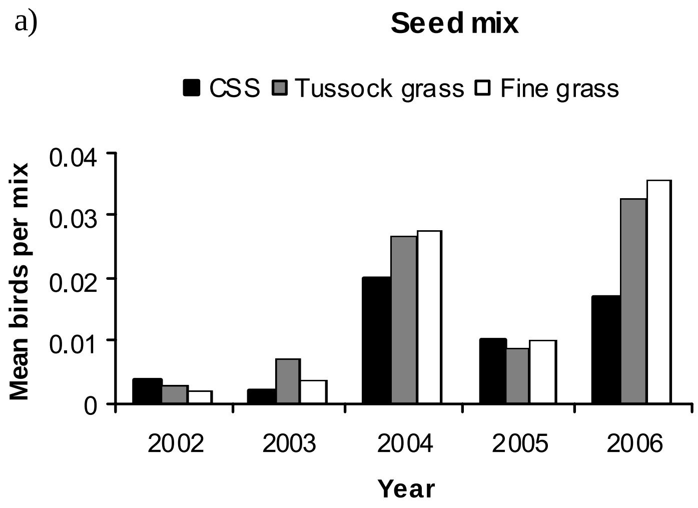


Figure 6.291. The relative temporal change in the mean percentage use of field margins at (a) by functional group per year, (b) the two study sites by year, and (c) by functional group for each month: April to July. Error bars = ± 95% confidence limits.

a)



b)

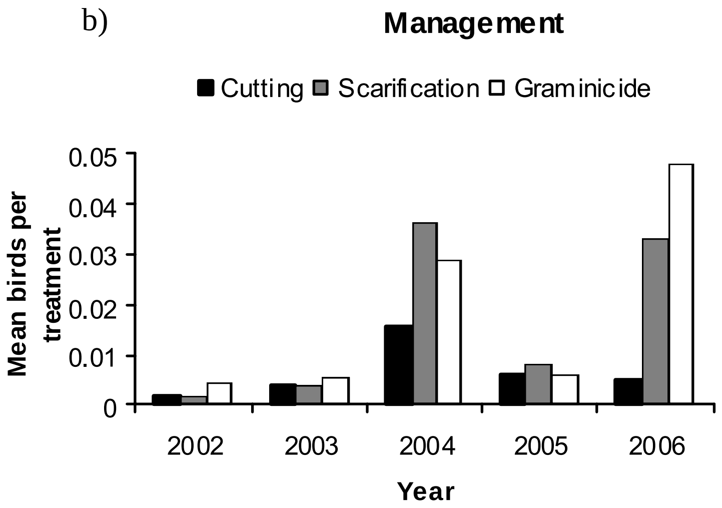


Figure 6.292. The mean number of birds (all species) per visit, for each year, recorded on (a) the total area available for each seed mix type or (b) the total area available of each management treatment type. Seed mix 'CSS' refers to a standard Countryside Stewardship Scheme mix available to most farmers.

When between site successional patterns in beetle assemblage structure from 2003-2006 were plotted on RDA biplots there were consistent between-site patterns (Figure 6.293, Figure 6.294 & Figure 6.295). Characteristically, the three different seed mixes used to establish the field margins resulted in successional changes in beetle assemblage structure that diverged from each other. For both the Boxworth and Gleadthorpe sites, seed mix was the principal factor driving divergence in beetle assemblage structure over the four year period. The effects of management superimposed over the underlying seed mix treatments, were relatively minor changes in the successional patterns of divergence in the assemblage structure of the beetles. High Mowthorpe differed from this general pattern of seed mix being the principal factor dictating successional patterns in beetle assemblage structure. For this site high levels of divergence over the four year period were found for all seed mixes where scarification had been used as margin management.

The interactions between year and the continuous measures of between-plot variation in plant community structure and sward architecture were also seen to influence beetle assemblage structure (Table 6.53). In particular sward architectural complexity was found to influence assemblage structure at all three sites, although in each case those beetle species that responded were different. The across-site responses to the Shannon diversity measure of sward architecture were seen for the overall measure of sward diversity, as well as that for the diversity of tussock grasses and legumes. The only other continuous measure of between plot variability to have a universal effect across all three sites was the percentage of bare ground. Although percentage of bare ground was measured as a continuous environmental variable its extent was likely to have been directly influenced by the effectiveness of scarification. The diversity of grass species within the margin plots also influenced beetle assemblage structure at High Mowthorpe and Gleadthorpe, although conversely legume species diversity was seen to be important only at Boxworth. The diversity of non-legume forbs influenced beetle assemblage structure, although only at High Mowthorpe and Boxworth. Typically the variance in the species data explained by the interaction between year and the continuous environmental variables was low, and rarely exceeded 10%.

Table 6.53. Results for the temporal split-plot redundancy analyses of beetle assemblage responses to the interactions between year and seed mix, management, and the continuous measures of plant community structure and sward architecture. Results are presented for all three sites, although separate analyses were performed in each case. Significance values are indicated by: ns = not significant at p>0.05; * = p<0.05; ** = p<0.01; *** = p<0.001.

Environmental interaction	**Mowthorpe**	**Gleadthorpe**	**Boxworth**
Treatment interactions			
Seed mix × Year	F = 4.06*** (18.1 %)	F = 2.16*** (9.5 %)	F = 2.79*** (11.9 %)
Management × year	F = 2.46 *** (10.7 %)	F = 0.99* (4.5 %)	F = 1.33* (6.06 %)
Seed mix × Management × Year	F = 2.45 *** (35.7 %)	F = 1.65*** (20.2 %)	F = 1.54*** (25.7 %)
Effects of year for each treatment combination			
TG &Cutting × Year	*F = 1.36**	*F = 1.14***	*F = 1.28 ns*
TG & Scarification × Year	*F = 2.05****	*F = 1.20***	*F = 1.00 ns*
TG & Graminicide × Year	*F = 1.40****	*F = 1.16***	*F = 1.21 ns*
FG &Cutting × Year	*F = 2.57****	*F = 1.13**	*F = 1.02 ns*
FG & Scarification × Year	*F = 2.03****	*F = 0.94 ns*	*F = 2.24****
FG & Graminicide × Year	*F = 2.75****	*F = 1.52****	*F = 1.40**
CS &Cutting × Year	*F = 1.94****	*F = 1.15**	*F = 1.85****
CS & Scarification × Year	*F = 1.84****	*F = 0.76 ns*	*F = 1.29 ns*
CS & Graminicide × Year	*F = 1.95****	*F = 1.15**	*F = 1.46**
Continuous environmental effects			
Architecture H'_{All}	F = 3.32*** (7.2 %)	F = 2.03*** (4.5 %)	F = 2.00** (4.5 %)
Architecture $H'_{Tussock}$	F = 4.91*** (10.3 %)	F = 1.83*** (4.2 %)	F = 2.73*** (6.1 %)
Architecture $H'_{Legumes}$	F = 3.11*** (6.8 %)	F = 2.17*** (3.6 %)	F = 2.42** (3.6 %)
% Bare ground	F = 3.12*** (6.8 %)	F = 2.17*** (4.8 %)	F = 1.67*** (3.8 %)
Grass diversity (H')	F = 4.77*** (10.0 %)	F = 1.58*** (3.6 %)	F = 1.26 ns
Forb diversity (H')	F = 3.61*** (7.8 %)	F = 1.08 ns	F = 1.84** (4.1 %)
Legume diversity (H')	F = 0.81 ns	F = 1.31 ns	F = 3.06* 2.3 %)
Overall model (all sig. treatment and continuous environmental effects)	**F = 1.94*** (51.1 %)**	**F = 1.52*** (36.7 %)**	**F = 1.61*** (32.5 %)**

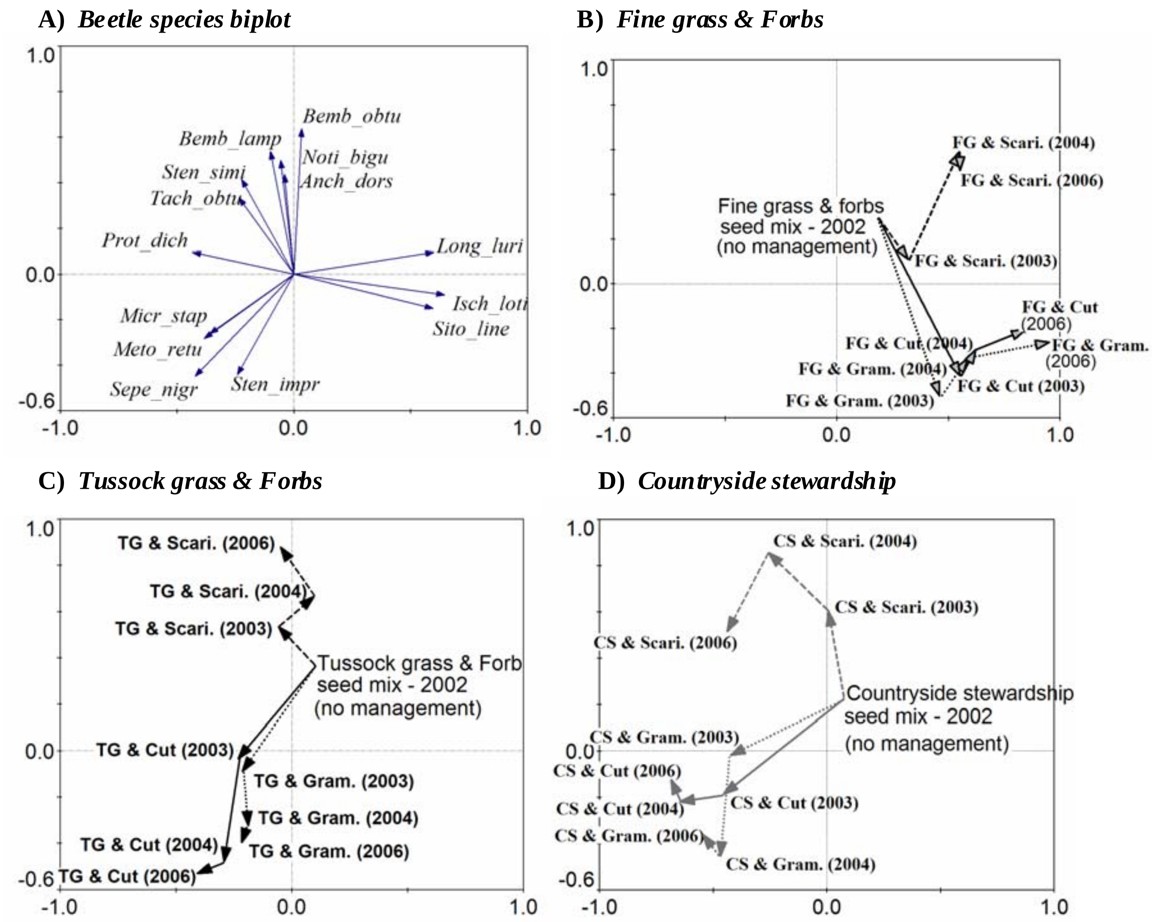


Figure 6.293. Ordination diagrams of the RDA for years 2003, 2004 and 2006 based on the beetle assemblages from the High Mowthorpe site only. Biplots are: A) A beetle species scatter plot, where beetle species name abbreviations represent the first four letters of the generic and specific names; B) The temporal interaction between sample year and the management treatments for the fine grass and forbs seed mix only; C) The temporal interaction between sample year and the management treatments for the tussock grass and forbs seed mix only; D) The temporal interaction between sample year and the management treatments for the countryside stewardship seed mix only. The change with time of the beetle assemblages is emphasized by the connection of the centroids of the year × treatment interaction with arrows, from the 2003 × treatment (start of first arrow) to the 2004 × treatment (end of first arrow) to the 2006 × treatment (end of second arrow). Centroids of transformed plot scores for the three seed mixes in 2002 have been included in the RDA model as supplementary sites only. These had no effect on the overall model (which is based on 2003 – 2006 data only) and have been included to provide a reference point for the successional trajectories in response to the management treatments. Only selected species with the best fits to the first two axes of the ordination have been shown.

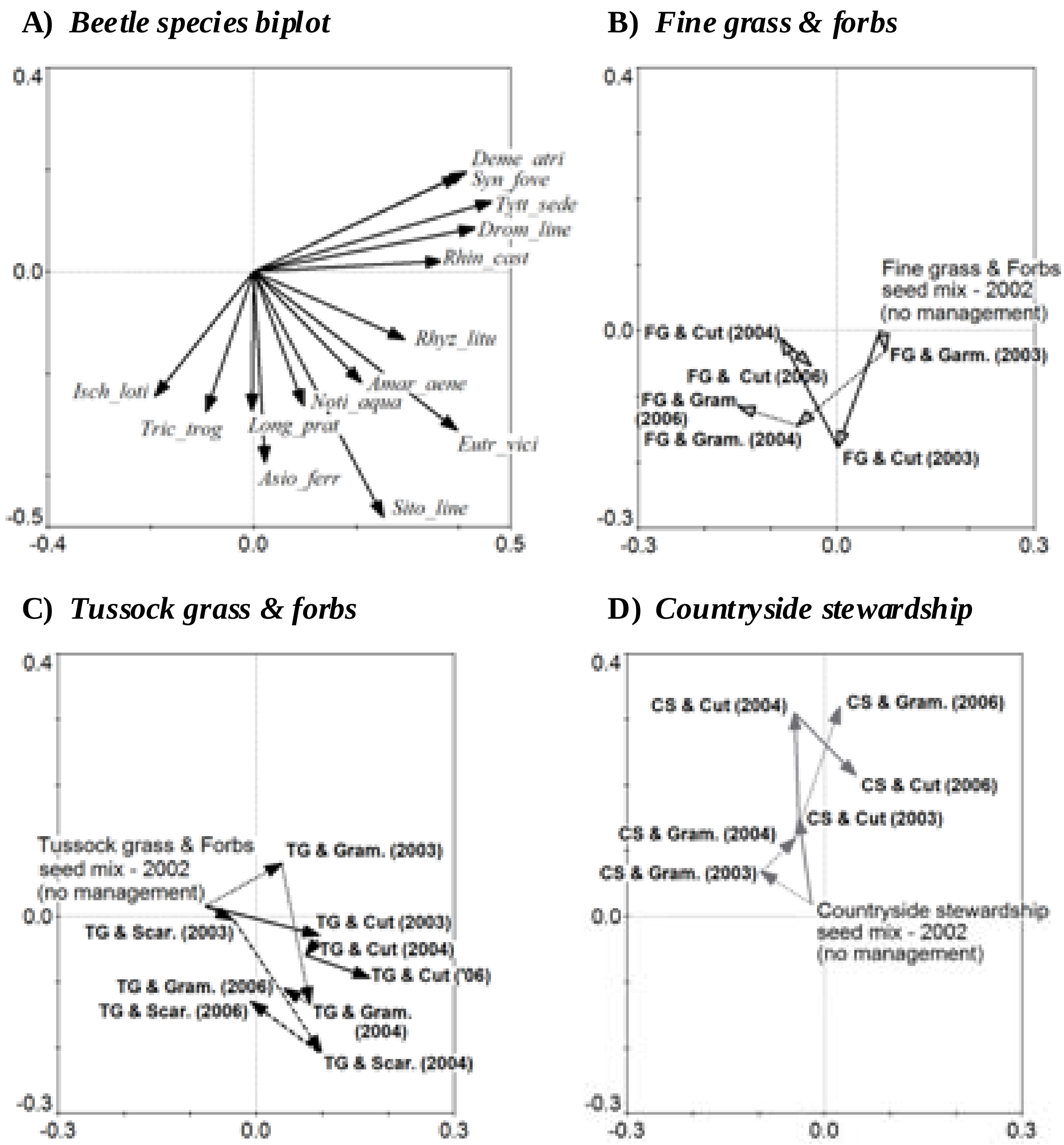
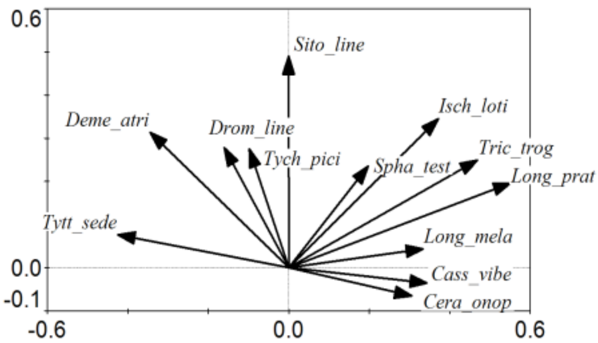
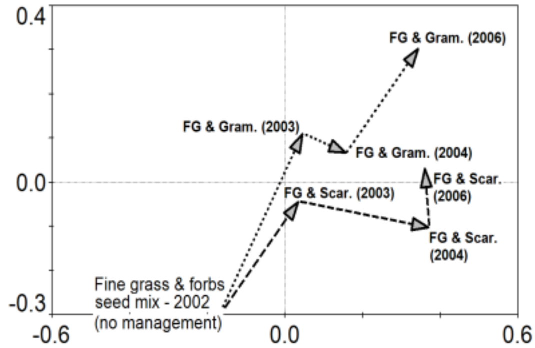


Figure 6.294. Ordination diagrams of the RDA for years 2003, 2004 and 2006 based on beetle assemblages at Gleadthorpe. Biplots are: A) beetle species scatter plot, where species name abbreviations are the first four letters of the generic and specific names; B) The temporal interaction between year and management for the fine grass and forbs seed mix only; C) The temporal interaction between year and management for the tussock grass and forbs seed mix only; D) The temporal interaction between year and management for the countryside stewardship seed mix only. The change with time of the beetle assemblages is emphasized by the connection of the centroids of the year × treatment interaction with arrows, from the 2003 × treatment (start of first arrow) to the 2004 × treatment (end of first arrow) to the 2006 × treatment (end of second arrow). Centroids of transformed plot scores for the three seed mixes in 2002 have been included in the RDA model as supplementary sites only. These had no effect on the overall model (which is based on 2003 – 2006 data only) but provide a reference point for the successional trajectories in response to management treatments. Only selected species with the best fits to the first two axes of the ordination have been shown.

A) *Beetle species biplot*





C) *Countryside stewardship*

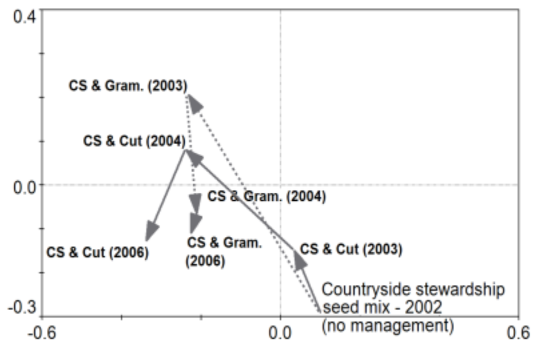


Figure 6.295. Ordination diagrams of the RDA for years 2003, 2004 and 2006 based on the beetle assemblages from the Boxworth site only. Biplots are: A) A beetle species scatter plot, where beetle species name abbreviations represent the first four letters of the generic and specific names; B) The temporal interaction between sample year and the management treatments for the fine grass and forbs seed mix only; C) The temporal interaction between sample year and the management treatments for the countryside stewardship seed mix only. The change with time of the beetle assemblages is emphasized by the connection of the centroids of the year × treatment interaction with arrows, from the 2003 × treatment (start of first arrow) to the 2004 × treatment (end of first arrow) to the 2006 × treatment (end of second arrow). Centroids of transformed plot scores for the three seed mixes in 2002 have been included in the RDA model as supplementary sites only. These had no effect on the overall model (which is based on 2003 – 2006 data only) and have been included to provide a reference point for the successional trajectories in response to the management treatments. Only selected species with the best fits to the first two axes of the ordination have been shown.

6.3.6.2 Vegetation – Bird linkages

For relationships between bird densities and vegetation attributes between 2003 and 2006, see Table 6.54a – showing a series of univariate tests. These were preliminary Spearman rank tests, used to identify key co-variables for the principle models. The data show a significant positive response of bird densities on margins to vegetation cover, and a significant negative relationship with vegetation height. No other vegetation variables were significant.

The results from the multivariate analysis are presented in Table 6.54b, where the data show:

(a) negative effects of vegetation height,

(b) positive effects of vegetation cover but only significant in fine grass swards,

(c) a significant effect of margin seed mix largely driven by differences in 2006,

(d) a much stronger significant effect of margin management treatment than seed-mix effect.

6.3.6.3 Invertebrate – Bird linkages

For relationships between bird densities and invertebrates see Table 6.55 summarising preliminary Spearman rank tests. These univariate tests show a positive response of bird densities to beetle abundance on margins and especially the abundance of 'diurnal' carabids. There was no significant relationship between bird density and any other invertebrate group.

These results are largely consistent with the univariate analyses, but, when carabid abundance was added to the models, two previously significant vegetation variables ('height' and 'percentage cover'), and 'seed mix' became non-significant effects. There was also a significant interaction between margin management and carabid abundance, whereby the relationship between birds and carabids was strongest in scarified or graminicide-treated swards relative to the cut swards (Table 6.55). The results from the full models are important as they suggests that the key influence on the distribution of birds in margins was prey abundance (linked to vegetation cover), tempered by accessibility through margin management.

Table 6.54. A summary of a General Linear Model analysis of bird counts, for two functional groups (Insectivores and Granivores) using margin plots between 2003 and 2006. The effect probabilities are defined as: *P =< 0.05, **P < 0.01, ***P < 0.001, followed by the direction of the effect for each independent variable. Sample size: 'n' = total number of individuals for each functional group.

	Insectivores (n=684)	**Effect**	**Granivores (n=1212)**	**Effect**
(a) GLM model Margin + boundary counts, Poisson: repeated measures (unit = counts):				
Site	***	HM>BO	***	HM>BO
Year (2003-2006)	**	2006=04=05>03	***	2006=04>05=03
Month: (4-7 (8 - HM site only))	*	(8)=7=6>5=4	**	(8)>7=6>5=4
Margin management	***	S>=G>>C	***	G>=S>>C
Margin seed mix	*	FG=TG>CS	**	FG=TG>CS
Site*treatment	Ns		Ns	
	Dispersion = 0.23		Dispersion = 0.41	
	Insectivores (n=139)	**Effect**	**Granivores (n=307)**	**Effect**
(b) GLM model Margin counts only, Poisson: repeated measures (unit = counts):				
Site	***	HM>BO	***	HM>BO
Year (2003-2006)	***	2006=04>05>03	***	2006=04=05>03
Month: (4-7 (8 - HM site only))	**	(8)=7>6>5=4	***	(8)>7>6=5>4
Margin management	***	S>=G>>C	***	G=S>>C
Margin seed mix	*	FG=>TG>>CS	ns	(FG=TG>CS)
Site*treatment	Ns Dispersion = 0.10		Dispersion = 0.21	

Model factors: 'Site' - two levels (HM = High Mowthorpe, BO = Boxworth); 'Management' - three levels (C = Cutting, S = Scarification, G = Graminicide) and 'Seed mix' - three levels (CS = Countryside Stewardship Scheme, TG = Tussock, FG = Fine grass).

Table 6.55. Spearman rank correlations comparing seed-eating and insectivorous bird species abundance on field margins with single vegetation or invertebrate variables.

	Granivorous	Variable	Insectivores
a) Spearman rank univariate tests: (n=270):			
Both sites, years 2002-2006	Effect	Variable	Effect
	Rho = 0.18**	Vegetation cover	Rho = 0.15*
	Rho =-0.12**	Vegetation height	Rho =-0.18**
	Rho = ns	Vegetation height variance	Rho = ns
	Rho = -0.14*	TG vegetation cover	Rho = 0.15*
	Rho = 0.18**	FG vegetation cover	Rho = 0.15*
	Rho =-0.10 ns	Bare ground	Rho =-0.11 ns
	Rho = 0.25***	Total beetles	Rho = 0.25***
	Rho = ns	Beetles 2-5mm	Rho = 0.21***
	Rho = 0.25***	Diurnal carabids	Rho = 0.24***
	Rho = 0.19**	Total inverts	Rho = 0.22***

Table 6.56 A GLM analysis of bird abundance in margins (data combined from May, June and July) showing the relationship with the strongest and most consistent invertebrate variable (ground beetle abundance in June), as well as management treatment, plus interaction term. The direction of effects that were significant (where α = 0.05) or approaching significance, and were positive unless otherwise indicated (abbreviations: see footnote).

b) GLM models: best fit binomial multivariate tests: (n=540): All species were combined due to poor model fits for analyses of separate functional groups.

Both sites, years 2002-2006	Dispersion=1.12	Main effect	Both sites, years 02, 03, 04 & 06.
Year	$\chi^2_3 = 37.8$*	2006>2004>2003	$\chi^2_2 = 14.8$*
Site	$\chi^2_1 = 3.82$*	HM > BO	$\chi^2_1 = 3.8$*
Vegetation cover	$\chi^2_1 = 5.3$*	+ive	
Vegetation height	$\chi^2_1 = 5.1$**	-ive	$\chi^2_1 = 2.3$ ns
TG vegetation cover	$\chi^2_1 = 2.2$	+ive	$\chi^2_1 = 0.5$ ns
FG vegetation cover	$\chi^2_1 = 8.8$**	+ive	$\chi^2_1 = 4.9$*
Seed mix	$\chi^2_2 = 6.7$*	See Table 6.54	$\chi^2_1 = 0.4$ ns
Management	$\chi^2_2 = 24.4$*	See Table 6.54	$\chi^2_2 = 4.2$*
Diurnal carabids	Not entered	+ive	$\chi^2_1 = 11.54$***
Diurnal carabid*management	Not entered	S>=G>C	$\chi^2_2 = 10.71$**

Model factors: 'Site' - two levels (HM = High Mowthorpe, BO = Boxworth); Management' - three levels (C = Cutting, S = Scarification, G = Graminicide).

6.4 CONCLUSIONS AND RECOMMENDATIONS

6.4.1 Weeds and agronomy

The results confirm that the margins caused few problems for the commercial cropping of the fields in the experiment after their establishment. The use of Fusilade on the margins was shown to cause crop damage in susceptible crops up to 2 m into the cropped area; this could be prevented by spraying on calm days. Slug problems experienced during the experiment would be controlled by routine applications of pellets to susceptible crops. Annual weed populations, in general, were not exacerbated by the presence of a margin. Perennial weeds such as docks and thistles were found in margins, but monitoring over a longer time period would be required to confirm that these did not cause problems in the crop. Routine herbicide applications and cultivations kept populations of the perennial weeds in check for the duration of this work, and this would be expected to continue.

6.4.2 Vegetation

Following the successful establishment of the seed mixes at all sites, scarification was the only treatment to maintain the number of sown species present, although to some extent this was site specific. The maintenance of species richness in grassland communities is dependent on the provision of safe sites within the sward, enabling germination and seedling development (Bullock, 2000). Disturbance type is therefore strongly influential in structuring plant communities. Based on hay meadow management, cutting is frequently used to manage field margin communities. However, in the absence of aftermath grazing, which creates gaps in the sward, reductions in number of sown species, especially of the forbs, are often observed (Berendse et al., 1992; Marshall & Nowakowski, 1995). The treatment of scarification resembles an extreme form of aftermath grazing, enabling regeneration from sown and unsown seed. Such a positive response to scarification has also been observed in grasslands undergoing diversification (Westbury et al., 2006; Pywell et al., 2007). The timing of scarification is also instrumental and a delay in application at High Mowthorpe until 28th April in 2006 might explain the reduced number of sown species recorded in June. Ideally, scarification should be done in early March to encourage spring germination and to reduce disturbance to ground nesting birds.

As with cutting, the graminicide treatment failed to provide substantial gaps in the sward for regeneration, but was observed to reduce the dominance of susceptible grasses and promote the abundance of forbs already established. The benefits of fluazifop-P-butyl in promoting forb abundance in other sown margins have also been demonstrated (e.g. Marshall & Nowakowski, 1996. In the current study, although forb abundance was greater in plots treated with fluazifop-P-butyl, the optimum application frequency for biodiversity gains was not investigated. A yearly application of fluazifop-P-butyl might be detrimental for biodiversity if plots contain an abundance of susceptible grasses as in the TG mix. Following successive applications, fluazifop-P-butyl resistant grasses including *Festuca rubra* and *Deschampsia cespitosa* were promoted, while grass diversity and overall values of grass reproductive resource abundance decreased. A less frequent application of graminicide might be more beneficial, although a single application of fluazifop-P-butyl at half rate is unlikely to be sufficient to promote species diversity (Marshall & Nowakowski, 1994, Westbury & Dunnett, *submitted*). A further consideration for the use of fluazifop-P-butyl is whether the application to field margins established with a low abundance of susceptible species is beneficial; responses need to be tested against an untreated control, rather than relative to the treatments of cutting and scarification. An alternative to using fluazifop-P-butyl in swards with low occurrences of susceptible grasses might be to promote the abundance of the hemiparasite *Rhinanthus minor* (yellow rattle). *R. minor* was a species sown as a component in the FG mixes at all sites and is associated with increases in forb diversity and abundance (Pywell et al., 2004a; Westbury et al., 2006; Westbury & Dunnett, 2007). Persistent populations however failed to establish, possibly owing to unsuitable sward management for this species.

As a consequence of opening up the sward through the destruction of living vegetation, the overall value of the sward with respect to total reproductive resource abundance was lower with scarification than cutting or graminicide. Young vegetative individuals of sown species were observed, but in many cases existing adult plants had not accumulated sufficient resources after scarification to enable flowering. Consequently, annual scarification to create approximately 60% disturbance is likely to increase the ruderal nature of the community, promoting short-lived perennials, biennials and annuals at the expense of the long-lived perennials. Therefore, as the occurrence of desirable perennial forbs in arable fields is usually negligible, the promotion of unsown forbs (typically annuals) with annual scarification might be expected to have greater benefits in grass only margins. In turn this will increase the value of otherwise resource-limited swards. An increased abundance of annuals in grass margins is also likely to have benefits for farmland birds and invertebrate groups such as Coleoptera (Marshall et al., 2003). However, most annuals associated with arable situations have been shown to provide relatively poor pollen and nectar resources for bees and butterflies (Pywell et al., 2006). The accessibility of the sward with respect to coarse grain structure, architectural complexity and percentage bare ground was also generally greater with scarification. However, despite access to resources being potentially high, the lower resource abundance associated with scarification suggests a lower sward value than with cutting or graminicide. Calculations of time spent foraging versus benefits gained would help to determine the overall benefit of the sward treatments for farmland birds.

It is evident that the value of the swards with respect to species diversity, resource abundance and sward architecture varied between seed mixes and sward treatment. It is important to note that the aim of SAFFIE was not to develop optimal seed mixes and their management; it was to investigate the responses of three different plant communities to three different sward management techniques. The seed mixes were based on the provision of resource type: the tussock grass and forb mix was used to provide a habitat suitable for some ground-dwelling invertebrates that require a spatially heterogeneous habitat, while the fine grass and forb mix was used to increase insect diversity, including pollen and nectar feeders. The grass only mix was sown to represent the standard “cheap” mix typical of the majority of Countryside Stewardship and now Environment Stewardship Entry-Level field margin agreements. The three different sward treatments were applied to investigate the manipulation of these field margin communities to enhance vegetation architecture in an effort to promote the diversity, abundance and availability of food sources and nesting habitats for farmland birds.

In terms of resource provision, it is evident that the FG mix containing the greater number of species provided the greatest pollen and nectar resource. Furthermore, the low values of coarse grain structure indicated an improved access to such resources. The TG mix also provided important nectar and pollen resources, especially in plots treated with fluazifop-P-butyl, but sward access was still relatively low. Of the resources produced by the forbs, the majority were provided by only a few key species, for example *Achillea millefolium*, *Leucanthemum vulgare* and *Lotus corniculatus* in the FG plots, and *Dipsacus fullonum* and *L. vulgare* in the TG plots.

Consequently, this implies that not all forb species need to be sown in the mixes, although the effects of community simplification have not been tested on higher taxa. Because of the lower sowing rate of the CS mix and no additional competition from sown forbs, the resource value of these grass margins was enhanced through a greater abundance of unsown species. Scarification further increased their value, demonstrating the potential of this treatment to promote species number and diversity. The sowing of key forb species into grass only (CS) margins in conjunction with scarification is likely to be a successful technique for enhancing the value of species-poor margins.

The decision of which seed mix to sow and sward treatments to apply should be based on sound ecological principles and depend on the complement of resources required. In most instances a variety of margin types, managed with a variety of techniques is recommended (Edwards et al., 2007).

6.4.3 Invertebrates (except bees and butterflies)

For the 'non-pollinator' invertebrates, the seed mixes used in the initial establishment of the margins and the subsequent management practices of scarification, graminicide and cutting, were seen to have direct effects on total abundance and species richness of a number of taxa. However, of the eight invertebrate taxa considered, neither abundance nor species richness was influenced by the interaction between seed mix and management. Although year did not interact with either seed mix or management, to impact on the abundance or species richness of these taxa (with the exception of larval mass), it did have an effect across all treatments. Typically, change in abundance and species richness of these taxa from 2003 to 2006 fell into one of two temporal patterns. The first was a humpback relationship where either abundance or species richness peaked mid term throughout the margin succession (2004) before dropping again in 2006. This humpback pattern was seen for the abundance of the beetles, Symphyta and Lepidopteran larvae, St Mark's flies, true bugs and Orthoptera. The second temporal pattern was characterised by a continued rise from 2003 in either abundance or species richness, or alternatively these parameters plateaued in 2004. Such a constant increase or plateauing pattern was common where the species richness of these taxa was considered, and was seen for the species richness of the beetles, true bugs and planthoppers, as well as for spider and planthopper abundance. Both of these temporal patterns suggest that the margins required a period of 1-2 years following the start of management before high abundances and species richness in these taxa were found. Conversely, the presence of a humpback relationship, suggests that the useful life of the margins, independent of seed mix or management, may be limited, such that 3-year-old margins are more important for invertebrates than those at 5 years. In most cases this humpback relationship reflects a population decline in a few early successional species of invertebrates that were numerically dominant in the first years of margin establishment. For example, the true bug *Nysius ericae* was a rapidly colonising species that dominated the fauna of the Gleadthorpe site in the first years of margin establishment, although had largely disappeared by 2004. The tendency for species richness to either plateau or continue to increase over the five year period is linked with the establishment of certain key floral resources or the development of sward architectural complexity throughout the life of the margins (Dennis et al., 1998; Woodcock et al., in press).

The importance of the seed mix used to establish the margins could be related to functional characteristics of the invertebrate taxa in question, specifically whether or not they were likely to benefit more from a floristically diverse or architecturally complex sward. In contrast to the Countryside Stewardship mix, both the tussock grass and fine grass seed mixes contained large number of forb species. For phytophagous invertebrates from a variety of taxa the increased availability of these forbs provided additional host plant resources within the tussock and fine grass field margins. In the case of the beetles, their increased species richness in both of these treatments is linked to this increased availability of forb host plant resources.

For those invertebrate taxa that were either entirely predatory or polyphagous the importance of this forb component in the seed mix was not apparent. Instead the presence of tussock grasses in both the Countryside Stewardship and tussock grass and forbs seed mixes provided key architectural resources for a number of taxa. For example such tussock grasses provide important structures for both the constructions of webs, as well as the provision of refuges. For the beetles, tussock grasses are a well known and important habitat for many polyphagous/ predatory species, e.g. within the families of Carabidae and Staphylinidae (Dennis et al., 1998; Luff, 1966). For a number of phytophagous invertebrates forbs are not particularly important host plants. For these groups the benefit of adding forbs to the seed mix was relatively unimportant, and where fine grasses were also relatively unimportant host plants, the fine grass and forbs seed mix was a poor resource. For the Symphyta and Lepidoptera larvae, where there was a large number of species that fed on grasses, this was likely to be one of the factors contributing to the lower mass of in this group within the fine grass and forbs margins.

Margin management had an important effect on either the abundance or species richness of the ground beetles (pitfall trap samples), beetles in general, true bugs, planthoppers and spiders. The probable mechanism was though the effect of margin management on the architectural complexity of the sward. For example in the case of the abundance of the Symphyta and Lepidoptera larvae, planthoppers and spiders, soil scarification had a negative impact. This is likely to be related to the negative impact of scarification on sward architectural complexity reducing the availability of plant structures, for food, or as refuges and web building structures. In the case of the spiders the vast majority of the overall abundance was made up of the small, predominantly web-building family, the Linyphiidae. It was for this family that the loss of sward architectural complexity probably had the greatest negative impact in the scarified margin treatments. In contrast, the wolf spiders (Lycosidae), a ground dwelling group that actively hunt rather than use webs, tended to be more abundant on the scarified plots. While the wolf spiders were much less abundant than the money spiders, they were frequently an order of magnitude greater in size and so were potentially a far more important food resource for birds.

Although the negative impact of scarification was significant for those taxa that were dependent on architecturally complex swards, scarification benefited a number of invertebrate groups that use particular components of the sown seed mixtures. This was related to the fact that scarification increased the establishment of some forbs within the sward, and in the case of some taxa (e.g. weevils and leaf beetles), these were important host plants,. The importance of scarification for the beetles reflects differences in host plant preferences not shared with other taxa. Specifically, phytophagous beetles tended to feed predominately forbs rather than grasses, and so benefited from the increased colonisation of these plants within the scarified plots. In contrast, for the planthoppers or the Stenodeminae grass bugs, the negative impact of scarification reflects a reduction in the density of their principal host plants, the grasses (Denno, 1994). This suggests that good populations of planthoppers in terms of abundance and species richness, within an arable farming context, are best maintained within structurally dense, grass-dominated swards, e.g. field margins. This importance of the overall architectural complexity of the grasses within the margins for the planthoppers may in part reflect the fact that many species are oligophagous or polyphagous. As a result overall loss of sward structure may be far more important for such polyphagous grass feeders than loss of species richness alone. The importance of scarification was not limited to the above-ground invertebrate fauna, and both the abundance and diversity of soil- and litter-feeders responded to the effects of management, although not to seed mix. Lower abundances and species densities were found in the scarified plots in the spring, although these did increase later in the year to either equal or be greater than those of the other management treatments. This initial negative impact of scarification is attributed to the high levels of soil disturbance that resulted in the loss of surface residues of dead plant material that were important as both cover and food for the soil macro fauna.

The RDA analysis of the beetle assemblages tested for the interaction between year and assemblage level response to seed mix, management and the continuous measures of plant community structure and sward architecture. Across all sites changes in beetle assemblage structure from 2003 to 2006 were influenced by seed mix, management and the interactions between these two treatments. This identified seed mix as the driving factor influencing successional changes in the structure of the beetle assemblages. For management the general pattern seen across all three sites was that the effects of scarification, cutting and graminicide were superimposed over those of seed mix. This resulted in relatively subtle variation in the successional changes in beetle assemblages over the four year period, relative to that caused by the seed mixes. The only exception to this general pattern was for the High Mowthorpe site where scarification was seen to be particularly important in structuring the beetle assemblages over the four year period. It is important to note that the importance of these interactions between seed mix and management were not shown for the beetles in the split-plot ANOVA analyses where only total beetle abundance and species richness were considered. Thus it is probable that the effect of the interaction between seed mix and management may be important in structuring the assemblages of some of the other taxa considered in this study.

Assemblage level response of the beetles to the continuous measures of plant community structure and sward architecture was also found. Of particular across-site importance were the measures of sward architectural complexity. For all sites overall sward architecture, as well as that of the tussock grasses and legumes, had direct impacts on the structure of successional changes in the beetles. As already alluded to above, the architectural complexity of the tussock grasses was found to be particularly important for predatory/ polyphagous species, particularly members of the Carabidae and Staphylinidae. This reflects the importance of these structures, both as a habitat and as refuges for this component of the field margin fauna. Legume architecture was less likely to be of importance to these predatory taxa, but rather to the large number of phytophagous beetles that used the legumes as host plants. For many of these phytophagous beetles their larval stages utilised specific components of the legumes that were particularly associated with architecturally complex swards. For example many species of Apionidae weevils have larval stages feed exclusively on either inflorescences or seed heads, e.g. *Protapion apricans (*Kirby). The importance of bare ground across all sites was likely to be related to a number of the issues highlighted above for scarification. In particular the establishment of some key forb species included in the seed mixes was highest in scarified plots. Species diversity of forbs, legumes and grasses proved to be important in structuring beetle assemblages over the four years for at least some of the sites. Such an assemblage-level response for the beetles was thought to be driven by associations by a number of phytophagous species with host plants that were found predominantly in floristically diverse margins.

While the study has highlighted the importance of field margins as a semi-natural resource for native invertebrates, comparisons between the different seed mixtures used in their establishment has highlighted the importance of the inclusion of forbs. The establishment of field margins using the countryside stewardship seed mix remains a useful and cost effective approach that will benefit invertebrate species that show preferences for architecturally complex swards, e.g. ground beetles or spiders. However, this mixture is of limited value for phytophagous invertebrates, although only where their dominant host plants are forbs, e.g. beetles. Even when host plants are predominantly grasses there seems to be little evidence that fine grasses provide an important resource. Therefore the combination of tussock grasses to provide architectural structure in combination with forbs as resources for phytophagous species provides a good all round seed mix for a variety of invertebrate taxa. The effect of margin management on the invertebrates shows more between-taxa variability. Specifically scarification will benefit those species that require the establishment of certain host plants within the margins, while it will be detrimental for those that require an architecturally complex sward.

6.4.4 Bumblebees and butterflies

The results confirmed the importance of providing a diversity of pollen and nectar resources for the conservation of bumblebee and butterfly populations within intensively managed landscapes. The large stock of arable field margins sown with simple, low-cost grass seed mixtures provide relatively few pollen and nectar resources for foraging bumblebees and butterflies (Pywell et al., 2006). This reflects the inhibiting effect of the dense grass sward on colonisation by forb species from the seed bank or hedge base. Indeed the primary pollen and nectar resources in these habitats tend to be pernicious weed species, such as *Cirsium vulgare* and *C. arvense* (Pywell et al., 2005). However, where tussocky grasses are sown, the dense, sheltered vegetation structure is important habitat for hibernating and nesting bumblebees (Kells & Goulson, 2003). Moreover, some sown grasses are important larval food plants for declining farmland butterfly species (Feber et al., 1996).

The composition of the seed mixture had the primary effect on the abundance and diversity of flower resources, and bumblebees and butterflies. Sowing a more complex and costly seed mixture including perennial forbs is an effective means of directing succession on impoverished arable land to rapidly provide good quality foraging habitat for pollinating insects (Carvell et al., 2004; Pywell et al., 2004b; Pywell et al., 2006). Indeed, the majority of foraging visits by bumblebees during this study was to sown perennial forb species. Both the tussock grass and fine grass + forb seed mixes appeared to be equally as good for bees and butterflies in the arable situation. This reflects the successful establishment of key forage species, such as *Vicia cracca* and *Centaurea nigra*, in both treatments. It also reflects the high mobility of both groups which enable them to utilise resources in all margin treatments throughout the season. More detailed analysis is required of the pattern of usage at different times of the year by different species and castes in order to determine more subtle differences between seed mixtures. The tussock grass + forb seed mix appeared to provide a compromise between the provision of nesting and hibernation habitats for bees, and summer foraging resources (Meek et al., 2002; Carvell, et al., 2004). In contrast, the fine-leaved grass seed mix contained a greater number of forb species and therefore provided the greatest abundance and diversity of foraging resources for a similar cost to the tussock grass + forb mixture (Pywell et al., 2006).

Subsequent management of the established field margin vegetation had secondary effects on the abundance and diversity of flowering forbs, bees and butterflies. Graminicide application had a consistently beneficial effect on the abundance and species richness of flowering forbs which in turn had a beneficial effect on the diversity of the bumblebee assemblage. This reflected the effectiveness of this method of eliminating or reducing the competitive ability of tall grass species on these fertile ex-arable soils. Other studies have successfully used selective herbicides to introduce forb species to fertile ex-arable sites (Westbury, 2001). Soil scarification with power harrows is an effective means of creating gaps for germination to facilitate grassland diversification (Pywell et al., 2007). This management treatment increased the richness of flowering annual forbs on the arable margins by encouraging germination of annual species from the soil seed bank rather than the colonisation of established perennial forbs. However, these annual species have been shown to provide relatively poor pollen and nectar resources for bees and butterflies (Pywell et al., 2005).

In conclusion, seed mixture composition had the primary effect on pollinating insects and management regime had a secondary effect. The absence of significant interactions between seed mixture and management options suggests these effects are additive. Sowing a diverse seed mixture of perennial forbs is the most effective means of creating foraging habitat for bees and butterflies on arable field margins. Application of graminicide is a practical option for enhancing the value of the large area of species-poor grass margins for pollinators.

6.4.5 Birds

These analyses indicate that birds were responding, first to higher prey densities, associated with vegetation cover (two co-related variables), and secondly to margin management, with a tendency for birds to forage in scarified or graminicide-treated plots. The data suggest that birds were using swards that allow greater access to prey, either because the sward was open and patchy (scarified), or because the sward had a more varied composition of forbs. The importance of access to prey has been the subject of considerable recent attention for farmland birds. Detailed studies now show important relationships between birds' relative use of cereal field margins when foraging access is improved (Douglas, pers. comm.).

The experiment showed only a weak effect of sown seed-mix on margin use by birds, with differences only becoming apparent after four years of management, possibly because the characteristics of the different seed mixes became more distinctive over time. As such, the lowest bird densities were associated with the standard 'Countryside Stewardship' mix, while the difference between the tussock and fine grass mixes was indistinct (perhaps favouring the fine grass mix, but inconsistent between years. In contrast, strong effects were associated with the management of the field margins. In particular, an association with scarified and graminicide-treated margins, compared with cut margins, indicated that birds were responding to ground accessibility.

Both functional groups increased their proportional use of margins between years and over the course of a summer. An increase in margin use between years, 2002 to 2006, was most likely a response to margins developing their vegetation characteristics, perhaps alongside the establishment of invertebrate populations. The seasonal increase in usage implied that particular margin characteristics became relatively more suitable for foraging birds than surrounding crops or habitats, despite a negative response to taller average sward heights (cf. Stoate, 1999). Again this indicated that the margins provided an increasing food resource for birds, or a relatively accessible food resource compared with the surrounding crops, suggesting a response to both food abundance and foraging access. This conclusion was supported by a statistically significant interaction, where higher bird densities were associated with higher ground beetle densities, but especially within the scarified and graminicide managed swards (not cut swards). The addition of beetle data to the analysis and this interaction cause previously significant effects of vegetation density to fall out of the model, implying that they these variables were confounding co-variates, rather than direct effects in their own right.

The recognition that field margins or buffer strips can mature as habitats, for birds and other taxa, over time (years) may be important, particularly for their adoption as agri-environment measures. Short-term monitoring assessments of quality or margin use, based on newly established swards within agri-environment schemes, could lead to misleading conclusions as regards their effectiveness to support or birds or other wildlife. Otherwise, an investigation into the proportion of habitat required to maintain populations of invertebrates, relative to that which promotes bird access, may be of future interest.

Agri-environment schemes (AES) are a key conservation delivery mechanism for farmland birds, and were also part of the government's Public Services Agreement to reverse population declines for 19 species by 2020 (www.Defra.gov.uk). Field margins or buffer strips are an important component of these schemes, largely due to their practical popularity and high level of uptake amongst farmers. Klein & Sutherland (2003) sent out a strong message for the necessity to monitor carefully the effectiveness of options within AES, so as to deliver both wildlife benefits and value for money for taxpayers. At times, bird use of field margins can be exceptionally low (Douglas pers. comm.). Their value can be equivocal, being affected by structure, composition and, probably also, by the availability of nearby habitats. In England, cereal field margins are managed under the main English agri-environment schemes (Countryside Stewardship and now Environmental Stewardship) as grass margins or buffer strips, with a wide remit of potential benefits for "creating new habitat for small mammals, invertebrates and birds…" (www.Defra.gov.uk). This study indicates that current management may not optimise the potential of this widely adopted conservation measure, for birds at least. Indeed care may be required to evaluate both practical and affordable modifications.

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6.6 REFERENCES

Banaszak, J. (1980) Studies on methods of censusing the numbers of bees (Hymenoptera: Apoidea). *Pol. Ecol. Studies* **6**, 355-366.

Berendse, F., Oomes, M.J.M., Altena, H.J. & Elberse, W.T. (1992) Experiments of the restoration of species-rich meadows in the Netherlands. *Biological Conservation* **62**, 59-65.

Bullock, J.M. (2000). Gaps and seedling colonisation. In *Seeds: The ecology of regeneration in plant communities* (ed M. Fenner), pp. 375-395. CAB International Publishing, Wallingford, UK.

Carvell, C., Meek, W.R., Pywell, R.F. & Nowakowski, M. (2004) The response of foraging bumblebees to successional change in newly created arable field margins. *Biological Conservation* **118**, 327-339.

Dennis, P., Young, M.R. & Gordon, I.J. (1998) Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed, indigenous grasslands. *Ecological Entomology* **23**, 253-264.

Denno, R F. (1994) Influence of habitat structure on the abundance and diversity of Planthoppers. In *Planthoppers: Their Ecology and Management*, pp.140-160.

Edwards, P., Westbury, D.B., Sutton, P. & Marshall, E.J.P. (2007) Principle considerations for arable field margin establishment and management. *Aspects of Applied Biology* **81**, 199-205.

Feber, R.E., Smith, H. & Macdonald, D.W. (1996) The effects on butterfly abundance of the management of uncropped edges of arable field. *Journal of Applied Ecology* **33**, 1191-1205.

GenStat Release 7.0 (2003) Lawes Agricultural Trust. Rothamsted Experimental Station, UK.

GenStat Release 8.1 (2005) Lawes Agricultural Trust, Rothamsted Experimental Station, UK.

Kells, A.R. & Goulson, D. (2003) Preferred nesting sites of bumblebee queens (Hymenoptera: Apidae) in agroecosystems in the UK. *Biological Conservation* **109**, 165-174.

Klein, D. & Sutherland, W.J. (2003) How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology* **40**, 947–969.

Luff, M.L. (1966) The abundance and diversity of the beetle fauna of grass tussocks. *Journal of Animal Ecology* **35**, 189-208.

Marchant, J.H., Hudson, R., Carter, S.P. & Whittington, P.A. (1990) *Population Trends in British Breeding Birds*. BTO, Tring

Marshall, E.J.P., Brown, V.K., Boatman, N.D., & Lutman, P.L. (2003) The role of weeds in supporting biological diversity within crop fields. *Weed Research*, **43**, 77-89.

Marshall, E.J.P. & Nowakowski, M. (1994) The effects of Fluazifop-P-Butyl and cutting treatments on the establishment of sown field margin strips. In *Field margins: Integrating agriculture and conservation* **58**, pp. 307-312. British Crop Protection Council, Surrey, UK, Brighton.

Marshall, E.J.P. & Nowakowski, M. (1995) Successional changes in the flora of a sown field margin strip managed by cutting and herbicide application. In Brighton *Crop Protection Council -Weeds*, pp. 973-978. Croydon British Crop Protection Council, Brighton.

Marshall, E.J.P. & Nowakowski, M. (1996) Interactions between cutting and a graminicide on a newly-sown grass and wild flower field margin strip. *Aspects of Applied Biology* **44**, 307-312.

Maxwell, S.E. & Delaney, H.D. (2003) *Designing experiments and analysing data*. 2nd edition. Lawrence Erlbaum Associates, Mahwah, NJ.

Meek, W.R., Loxton, R., Sparks, T.H., Pywell, R.F., Pickett, H. & Nowakowski, M. (2002) The effect of arable field margin composition on invertebrate biodiversity. *Biological Conservation* **106**, 259-271.

MVSP (1999) *Multivariate Statistical Package*; Version 3.1. Kovach Computing Services, Anglesey, UK.

Pielou, E.C. (1969) *An Introduction To Mathematical Ecology*. Wiley-Interscience, New York, USA.

Pollard, E., Elias, D.O., Skelton, M.J. & Thomas, J.A. (1975) A method of assessing the abundance of butterflies in Monks Wood National Nature Reserve in 1973. *Entomologist's Gazette* **26,** 77-88

Pollard, E. & Yates, T.J. (1993) *Monitoring Butterflies for Ecology and Conservation.* Chapman and Hall, London.

Prŷs-Jones, O.E. & Corbet, S.A. (1991) Bumblebees*. Naturalists' Handbooks* **6**. The Richmond Publishing Co. Ltd., Slough.

Pywell, R.F., Bullock, J.M., Walker, K.J., Coulson, S.J., Gregory, S.J. & Stevenson, M.J. (2004a) Facilitating grassland diversification using the hemiparasitic plant *Rhinanthus minor*. *Journal of Applied Ecology* **41**, 880-887.

Pywell, R.F., Walker, K.J., Warman, E.A. & Bullock, J.M. (2007) Enhancing grassland diversity using slot-seeding and harrowing. *Aspects of Applied Biology* **82**, 191-198.

Pywell, R.F., Warman, E.A., Sparks, T.H., Greatorex-Davis, J.N., Walker, K.J., Meek, W.R., Carvell, C., Petit, S. & Firbank, L.G. (2004b) Assessing habitat quality for butterflies on intensively managed arable farmland. *Biological Conservation* **118**, 313-325.

Pywell, R.F., Warman, E.A., Carvell, C., Sparks, T.H., Dicks, L.V., Bennett, D., Wright, A., Critchley, C.N.R. & Sherwood, A. (2005) Providing foraging resources for bumblebees in intensively farmed landscapes. *Biological Conservation* **121**, 479–494.

Pywell, R.F., Warman, E.A., Hulmes, L., Hulmes, S., Nuttall, P., Sparks, T.H., Critchley, C.N.R., & Sherwood, A. (2006) Effectiveness of new agri - environment schemes in providing foraging resources for bumblebees in intensively farmed landscapes. *Biological Conservation* **129**, 192-206.

SAS (2002) *Statistical Analysis System*: Version 9.1. SAS Institute, Cary, NC, USA.

Schabenberger, O. & Pierce, F.J. (2002). *Contemporary Statistical Models for the Plant and Soil Sciences*. CRC Press, London, UK.

Shannon, C E, & Weaver, W. (1963) *The Mathematical Theory of Communication*. Urbana, USA: University of Illinois Press.

SPSS (2002) *Statistical Package for the Social Sciences*; Version 11.5. Chicago, USA.

Stace, C. (1997) *Field Flora of the British Isles*. Cambridge University Press, Cambridge, UK.

Stewart, K.E.J., Bourn, N.A.D., & Thomas, J.A. (2001). An evaluation of three quick methods commonly used to assess sward height in ecology. *Journal of Applied Ecology* **38**, 1148-1154.

Stoate, C. (1999) The influence of field boundary structure on breeding territory establishment of whitethroat *Sylvia communis* and yellowhammer *Emberiza citronella*. In: Boatman, N.D., Davies, D.H.K., Chaney, K., Feber, R., de Snoo, G.R., Sparks, T.H. (eds) *Field margins and buffer zones: ecology, management and policy*. *Aspects of Applied Biology* **54**.

Teräs, I., 1983. Estimation of bumblebee densities (Bombus: Hymenoptera, Apidae) *Acta Entomologica Fennica* **42**, 103-113.

ter Braak, C.J.F., Šmilauer, P. (1997) *CANOCO for Windows version 4.0*. Centre for Biometry Wageningen, Wageningen.

Warren, M.S. (1992) Butterfly populations. In: Dennis, R.L.H. (Ed.) *The Ecology of Butterflies in Britain*. pp. 73-92. Oxford University Press, Oxford.

Westbury, D.B. (2001) Shifting the competitive balance: the use of Rhinanthus minor and other techniques to promote forb abundance on productive sites. PhD Thesis, The University of Sheffield.

Westbury, D.B., Davies, A., Woodcock, B.A. & Dunnett, N.P. (2006) Seeds of change: the value of using *Rhinanthus minor* in grassland restoration. *Journal of Vegetation Science* **17**, 435-446.

Westbury, D.B. & Dunnett, N.P. (2007) The impact of *Rhinanthus minor* in newly established meadows on a productive site. *Applied Vegetation Science* **10**, 121-129.

Westbury, D.B. & Dunnett, N.P. (accepted). The promotion of forb abundance: a chemical or biological solution? *Basic and Applied Ecology*.

Woodcock, B.A., Potts, S.G., Westbury, D.B., Ramsay, A.J., Lambert, M., Harris, S.J., Brown, V.K. (In press) The importance of sward architectural complexity in structuring predatory and phytophagous invertebrate assemblages. *Ecological Entomology*.

APPENDIX 1 CROP ROTATIONS

Boxworth

Year	Crop
2001	winter oilseed rape / winter beans
2002	winter wheat
2003	winter wheat
2004	spring beans
2005	winter wheat
2006	winter wheat

Gleadthorpe

	Crops for each field		
Year	Waterworks (Rep 1 & 2)	Nr.Kingston (Rep 3)	South Field (Rep 4 & 5)
2001	spring barley	spring barley	winter wheat
2002	winter barley	winter barley	potatoes
2003	oilseed rape	parsnips / spring barley	sugar beet/ spring barley
2004	winter wheat	spring oilseed rape	spring barley
2005	oilseed rape	winter wheat	winter barley
2006	winter wheat	oilseed rape	set-aside/spring wheat

At Gleadthorpe, where two crops are shown, the first is the main field crop and the second is the 12 m boundary put in for the SAFFIE experiment.

High Mowthorpe

	Crops for each field		
Year	Kirby field (Rep 1)	Crow tree (Rep 2)	Crow wood (Rep 3-5)
2001	winter wheat	winter wheat	2/3 potatoes, 1/3 spring beans
2002	winter wheat	potatoes	winter wheat
2003	winter barley	winter wheat	winter wheat
2004	w. oilseed rape	winter wheat	winter barley
2005	winter wheat	spring beans	w. oilseed rape
2006	winter barley	winter wheat	winter wheat

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The SAFFIE Project Report

Chapter 7 – Experiment 3 – Assessing the integrated effects of crop and margin management

(Pages 524 - 635)

Sustainable Arable Farming For an Improved Environment

SAFFIE

Enhancing Biodiversity





7 EXPERIMENT 3: ASSESSING THE INTEGRATED EFFECTS OF CROP AND MARGIN MANAGEMENT

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Chapter 7 contents

7.1 SUMMARY

The 26 field sites were located on working arable farms in England and Scotland. The farms were located in five clusters, the most northern sites in East Lothian, Scotland and the most southern in south Essex. In the west there was a cluster of 5 farms in Herefordshire and Shropshire and in the east several sites in Suffolk and Essex. Experiment 3 covered a total area of 856 ha, located on predominantly clay-based soil types. This SAFFIE experiment covered between 25 and 45 ha on an individual farm, located on one to four adjacent or spatially separated fields. Arable rotations were predominantly winter cropped (70%) with first and second wheat the dominant crops. A range of break crops was grown including, winter oilseed rape, set-aside, barley, peas, onions and potatoes. All crops were managed by the host farmer.

Undrilled patches (UP) were established on all sites as the best within-crop option from Experiment 1.1 (Chapter 4). Two margin types, tussock grasses + flowers and fine grasses + flowers were used on each site in equal lengths. The best margin management treatment from Experiment 2 (Chapter 6), scarification, was tested in spring 2005 and 2006.The four treatments comprised: (T1) conventional wheat with no margins; (T2) wheat with undrilled patches and margins; (T3) conventional wheat and margins; (T4) wheat with undrilled patches and no margins.

In spring 2003, 28 km of margin were sown on the sites between 18 March and 26 May. Drilling was delayed in Scotland due to wet weather. Margins were 6 m wide and accounted for 4% of the field area in which they were drilled. There were two seed mixtures; a fine grass mixture with 16 broad-leaved forbs and a tussock grass mix with 11 broad-leaved forbs. After an establishment year a margin treatment of scarification was done in spring 2004 by cultivation with a power harrow to a depth of 2.5 cm to achieve 60% soil disturbance.

The results showed that there were no adverse effects on weed, pest or disease levels from incorporating margins and undrilled patches into a winter dominated arable rotation.

For all species and species groups, bird densities and territories were consistently higher (1.3 - 2.8 times) in fields with margins (4% of field area) and two undrilled patches per hectare than on a normal conventional crop. This response was consistent also for Farmland Bird Index species and Biodiversity Action Plan species, for which farmland recovery is particularly desirable. The results indicate that birds were responding to fields containing both field margins and UP.

The combination of UP and field margin resulted in the highest density of skylark nests. An unexpected result was that this combination also had the highest level of nest predation by mammalian predators. This led to an overall low level of productivity compared to the other treatments. However, if UP's are placed >50m from margins then the predation effect had much less impact and productivity is as good as UP's with no patches (T4) and much higher than conventional (T1).

In sown field margins, birds responded to higher beetle and spider abundances, to more complex swards comprising a non-vegetative, litter component – but with only weak links to seed-mix composition. In wheat crops, birds responded to the presence of UP (large-scale open ground), and bare ground at a fine-scale at foraging locations within the crop – but with only weak links to invertebrate abundance.

The effect of creating bare ground and foraging access in dense crops and field margins was the single most important management action to affect a significant increase in bird densities and breeding territories for both field and boundary nesting species. Open ground can be achieved at relatively low cost by scarification in margins, and by creating UP at the recommended rate in wheat crops. For birds, margin sward content in terms of the grass/flower mix, is best managed to encourage beetles (especially carabidae) and spiders (Arachnidae).

Overall the sown margins and UP had relatively few effects on the numbers of invertebrates within the crop and, therefore, the abundance of food available to farmland birds. There was some evidence that invertebrates were remaining within the margins rather than dispersing into the adjacent crop as would be expected if the margins provided more desirable resources. The low levels of weeds within the crop may also have inhibited colonisation by phytophagous invertebrates and their associated predators. On the other hand, there was an indication that invertebrate predation may have been higher where margins and patches were present, so that the effects of the margins were obscured. The establishment of wider field margins and UP would not appear to be a suitable technique for boosting food supplies for farmland birds within crops nor predatory insects for pest control.

This project has provided a remarkable insight into the importance of manipulating crop and margin structure to influence the accessibility of food for birds and other wildlife and challenged our understanding on the impact predators can play in our management plans. The combination of UP's and 6m field margins form a very good basis for improving biodiversity in intensively managed cereal dominated agriculture.

7.2 INTRODUCTION

7.2.1 Background

This chapter provides the results from SAFFIE Experiment 3, which integrates the best field centre management from objective 1 and the best margin management from objective 2.

7.2.1.1 Reasons for selection of undrilled patches (UP) as the best field centre management

The decision to select the management technique for the field centres was taken at the end of August 2003 based on 2002 data from Exp. 1.1 (agronomic, weeds, invertebrates and birds, Chapter 4), plus a provisional assessment of skylark territory and nest numbers from 2003. This was to allow adequate notice to the experimental sites sowing cereal crops in autumn 2003. Exp. 1.1, tested conventionally drilled winter wheat against winter wheat with UP (2 /ha) and wide-spaced (double normal width) drill rows (WSR).

<u>Agronomy</u>

There was no significant difference in yield between treatments but yield was lowest in WSR. Wheat plants were more crowded within the row in WSR, which could potentially result in poorer spray penetration. In addition, some seed drills were unable to cope with wide rows and tramlines. Therefore, there may be a need to refer back to equipment manufacturers to refine the technique before this treatment could be implemented widely. In some (very few) UP, it was necessary to spray off certain pernicious arable weeds that were also poor wildlife food resources.

Invertebrates

There was some evidence that UP encouraged *Harpalus* and *Notiophilius* carabid beetles. Mean total carabid capture was significantly different between treatments, with the greatest numbers occurring in the patches and the lowest in WSR. Carabids are known to be important dietary components of a number of declining farmland birds, including grey partridge, lapwing, skylark and starling. No differences were found in invertebrate numbers between the conventional and WSR treatments.

Weeds

There was no difference in weed cover for any of the categories of weeds between conventional and UP treatments. but, it was found that broad-leaved and grass weed levels were greatest in the patches. Species richness was found to be significantly greatest in the patches, with similar numbers of species in both conventional and WSR . Some patches contained good numbers of weeds that were beneficial to invertebrates and birds but, in others, there were numerous pernicious grass weeds or charlock. There was no differences in weed cover between conventional and WSR for any of the categories of weeds. Farmer perceptions that more weeds were present earlier in the wide-spaced rows were found to be false. While this indicated that weed infestation was unlikely to be problem in WSR, there were also no indications that populations of beneficial weeds benefited from this treatment.

Skylarks

Numbers of Skylark territories (singing males) varied significantly with treatment. Over the whole breeding period, the mean number of singing males was greatest on UP, while WSR supported fewer males than even the conventional. On all treatments, the number of territorial males decreased later in the summer. However, on UP the decrease was not as pronounced as on the other treatments. Similar results were found for the number of nests. Numbers of chicks leaving the nest per attempt was greater in UP than in the conventional later in the breeding season. WSR treatments also produced a greater number of chicks per attempt, although the number of nests found was small.

On balance UP was chosen as the best field centre management technique.

7.2.1.2 Reasons for adopting scarification as the margin management treatment

The decision to select this margin management technique was taken in January 2005 based on data (plants, invertebrates and birds) collected in 2003 from Exp. 2 (Chapter 5). This experiment tested three management techniques; Cutting (mown to 15 cm in spring), Scarification (60% soil disturbance) and Graminicide (half rate application of Fusilade Max in spring).

Based on the discussions at the Research Group Meeting it was agreed to combine all the results into a summary table by assigning semi-quantitative ‘scores’ to those criteria deemed important. Scores used were 1, 2 or 3, with 3 denoting the greatest benefit or best response. Table 7.1 summarises the output of the SAFFIE Research Group discussion.

The categories were selected by group consensus to reflect the biodiversity value of plants and invertebrates, the value of food resources for birds, agronomic concerns and ease of management application. Five categories (invertebrate abundance, invertebrate diversity, pollinators, unsown plant diversity and sown plant diversity) were noted as being of primary importance and were allocated a weighting factor.

The sum of these scores was calculated in addition to the total scores for all categories. Bird data was thought to be insufficient to provide evidence to differentiate between management treatments, and therefore is not included in the summary table. Access to the margin food resources was based purely on observational evidence, and while probably reflecting genuine trends it was decided to leave these scores out of the table calculations. Deleterious invertebrates scores were not entered as those groups analysed so far (slugs) show no differences between management treatments or seed mix. Information for other groups is pending completion of the analysis, but early indications are that there are unlikely to be any major differences.

Table 7.1 Summary of scores used to select margin management treatments.

	Tussock			Fine		
Category	Cut	Scar	Graminicide	Cut	Scar	Graminicide
Invertebrate Abundance	2	1	3	1	2	3
Invertebrate Diversity	-	-	-	1	3	2
Pollinators	1.5	3	1.5	1.5	3	1.5
Deleterious invertebrates	-	-	-	-	-	-
Unsown plant diversity	1	3	2	1	3	2
Sown plant diversity	3	1	2	3	1	2
Pernicious weeds	2.5	1	2.5	2.5	1	2.5
Diffuse pollution	pending	pending	pending	pending	pending	pending
Farmer ease	3	2	1	3	2	1
(Access for birds)[1]	(2)	(3)	(1)	(2)	(3)	(1)
All scores	**13**	**11**	**12**	**13**	**15**	**14**
Weighted scores	**7.5**	**8**	**8.5**	**7.5**	**12**	**10.5**

[1] Not included in sum of scores

Based on existing information for the Tussock grass mix, there was no clear overall difference in management treatments when considering total scores or weighted scores. Weighted scores or the Fine grass mix suggested that the scarification treatment was marginally favoured over the cutting treatment, but the difference was not marked. Both the graminicide and scarification treatments appeared to enhance invertebrate abundance and diversity more than the cutting treatment, a difference which was reflected in the floral community. It was also thought that scarification offered a more extreme form of management that had not been tested previously.

On balance scarification was chosen as the preferred margin management technique.

7.2.2 Objective

The overall aim was to enhance farmland biodiversity by integrating novel habitat management approaches, in the crop and non-cropped margins, to develop more sustainable farming. Improving the understanding of interactions should lead to increases in invertebrate and seed abundance, and their availability, and will be of particular benefit to farmland birds.

7.3 MATERIALS AND METHODS

7.3.1 Field sites

There were 26 sites as detailed in Table 7.2, which were located in five clusters (Figure 7.1).

Table 7.2 Details of site location and soil type.

Site ID.	Cluster	Site name	Location	Soil type
BX	CA	ADAS Boxworth	Cambridgeshire	Clay
GK	CA	Grange Farm (Knapwell)	Cambridgeshire	Clay
UW	CA	Cock Fen Farm	Cambridgeshire	Organic/Clay
TP	CA	The Poplars	Northants	Clay
HM	HE	High Meadow Farm	Shropshire	Clay
WH	HE	Whitehouse farm	Herefordshire	Sandy Clay Loam
LH	HE	Lower House Farm	Herefordshire	Sandy Clay
CG	HE	Castle Grounds Farm	Herefordshire	Silty Clay Loam
TC	HE	Titley Court	Herefordshire	Clay
BE	LI	Blankney Estate	Lincolnshire	Sandy Limestone
CG	LI	Cotes Grange Farm	Lincolnshire	Sandy Clay Loam
AF	LI	Austen Fen Farm	Lincolnshire	Clay
GF	LI	Grange Farm	Lincolnshire	Sandy Limestone
CH	LI	Coates Hall Farm	Lincolnshire	Sandy Clay Loam
RA	EA	Round Bush Farm (a)	Essex	Clay Loam
RB	EA	Round Bush Farm (b)	Essex	Clay Loam
DH	EA	Deal Hall	Essex	Silty Clay
DA	EA	Dairy Farm (a)	Sufflolk	Clay
DB	EA	Dairy Farm (b)	Suffolk	Clay
BM	EA	Blackmoor Farm	Suffolk	Sandy Clay Loam
HF	EA	Highland Farm	Suffolk	Chalky Boulder Clay
PA	SC	Peaston Farm (a)	East Lothian	Clay Loam
PB	SC	Peaston Farm (b)	East Lothian	Clay Loam
OE	SC	Oxnam Estates	Roxburghshire	Clay Loam
ME	SC	Mallerstain Estate	Berwickshire	Clay Loam
TF	SC	Townhead Farm	East Lothian	Clay Loam

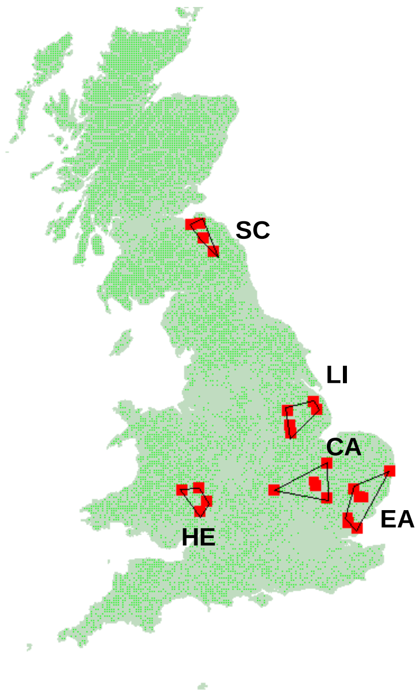


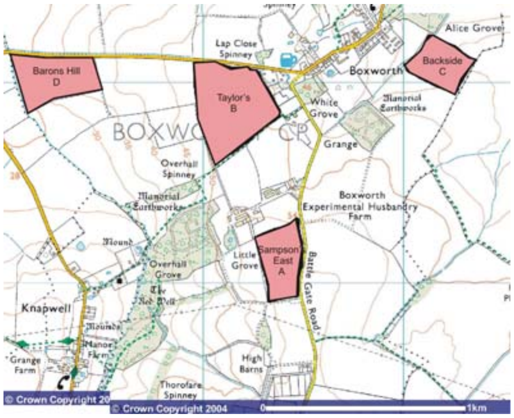
Figure 7.1 Location map showing the five SAFFIE clusters

7.3.2 Treatments

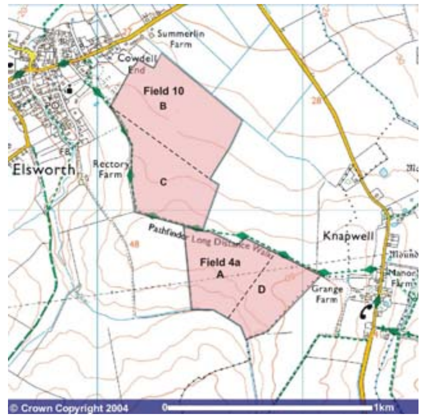
There were 26 farms and each farm represented a replicate. Each farm provided 4 areas (fields or sub-divisions of fields) each approximately 5 ha or greater. Each of the four areas was allocated to one of four treatments (Table 7.3). Within farms treatments were not replicated. Treatments were carried out during the three-crop years 2003/2004, 2004/2005 and 2005/2006. In any one of the three years, approximately two thirds of sites were in winter wheat. The remaining sites were in a break crop, generally winter-sown but a spring crop or rotational set-aside was allowed. No assessments were made in the field centres during the break crop year. The four areas at each farm could be grouped as a single block or spatially separated, examples of field treatment layout can be seen in Figure 7.2.

Table 7.3 Treatments (UP=undrilled patches).

No.	Field treatment	Margins
T1	Conventional field centres	No
T2	Field centres containing 2 UP per ha	Yes
T3	Conventional field centres	Yes
T4	Field centres containing 2 UP per ha	No



ADAS Boxworth



RSPB Grange Farm

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Figure 7.2 Layout of treatments at ADAS Boxworth and RSPB Grange farm.

At each field site the aim was to drill winter wheat crops in the rotation in two out of three years. All wheat crops were drilled with the host farmers' drill, where possible using the same variety and seed rate in all four treatments and using the farmers' normal row spacing. Details of the rotations are in Table 7.4, breakcrops comprised of winter oilseed rape, onions, winter and spring beans, oats, set-aside, linseed, winter barley, peas and potatoes. Treatment area sizes are detailed in Table 7.5.

Table 7.4 Crop rotation on each site.

Site ID.	Cluster	2004	2005	2006
BX	CA	Breakcrop	WW1	WW2
GK	CA	WW1	WW2	Breakcrop
UW	CA	WW1	Breakcrop	WW2
PO	CA	WW1	Breakcrop	WW1
HM	HE	WW1	WOSR	WW1
WH	HE	WW1	WW2	Breakcrop
LH	HE	WW1	Breakcrop	T1, T4 WW1
				T2, T3 Breakcrop
CF	HE	WW1	Breakcrop	WW1
TC	HE	WW1	Breakcrop	WW1
BE	LI	WW1	Breakcrop	WW1
CG	LI	WW1	WW2	Breakcrop
AF	LI	Breakcrop	Breakcrop	WW1
GN	LI	WW1	Breakcrop	WW1
		T3 W Barley		
CH	LI	Breakcrop	WW1	WW2
RA	EA	WW1	Breakcrop	WW1
RB	EA	WW1	WW2	Breakcrop
DH	EA	Peas	WW1	WW2
DA	EA	WW1	Breakcrop	Breakcrop
DB	EA	Breakcrop	WOSR	WW1
BM	EA	WOSR	WW1	WW2
HF	EA	WW1	WW2	Breakcrop
PA	SC	WW1	T1 T2 Spring Barley	Breakcrop
			T3 T4 WW2	
PB	SC	WOSR	WW1	WW2
OE	SC	WW1	Set-aside	WW1
ME	SC	WW1	WW2	Breakcrop
TF	SC	WW1	WW2	Breakcrop

Legend: WW1 – 1st winter wheat; WW2 – 2nd winter wheat; WW3 – 3rd winter wheat.

Table 7.5 Treatment size (ha)

Site ID.	Cluster	T1	T2	T3	T4	Total length of Tussock grass margin (m)	Total length of Fine grass margin (m)
BX	CA	8.0	9.6	7.5	9.2	665	675
GK	CA	10.5	10.5	10.5	10.5	619	619
UW	CA	1.0	6.0	12.6	7.5	624	624
PO	CA	9.3	6.9	6.7	9.0	488	484
HM	HE	5.2	8.2	5.5	6.6	411	411
WH	HE	8.2	8.0	9.0	5.9	481	422
LH	HE	8.6	6.2	9.1	4.7	592	509
CF	HE	8.8	5.4	7.9	7.9	414	427
TC	HE	12.3	11.5	7.2	7.2	617	617
BE	LI	8.2	8.8	8.8	8.2	622	622
CG	LI	9.3	8.0	8.1	11.4	501	501
AF	LI	7.2	6.5	8.0	4.5	490	490
GN	LI	8.3	6.2	9.6	10.0	576	576
CH	LI	8.5	9.9	10.8	9.6	620	620
RA	EA	6.6	7.5	7.0	5.6	473	473
RB	EA	8.1	6.1	7.0	9.7	550	550
DH	EA	15.1	11.0	10.7	6.7	637	637
DA	EA	9.1	8.3	7.2	4.8	474	474
DB	EA	11.0	10.0	8.3	9.1	560	560
BM	EA	4.3	6.5	7.0	9.7	532	532
HF	EA	12.2	7.4	7.4	8.9	458	458
PA	SC	5.2	5.2	7.0	8.0	484	484
PB	SC	8.0	10.0	6.8	6.0	668	668
OE	SC	7.9	9.9	18.8	8.2	738	738
ME	SC	6.6	8.7	11.9	8.7	570	570
TF	SC	7.4	7.4	8.3	5.0	695	695

7.3.2.1 Creation of undrilled patches (UP)

During drilling the drill was turned off or lifted up during travel to leave an unsown area of 16–25 m^2. The distances over which the drill was lifted, for specific drill widths were as follows.

Drill width (m)	UP length (m)
3	5.3 to 8
4	4 to 6
6	3 to 4
8	3

The positions of the UP in the fields were not critical, but host farmers were asked not to create the UP on tramlines. UP were at least 24 m from the edge of the field.

If the UP were not created at drilling they were sprayed between full emergence of the crop (approx. 6 weeks after drilling, when rows were visible) and prior to GS 13 (3 leaves) using glyphosate at 360 g active substance (a.s.)/l to kill off the wheat.

7.3.2.2 Margins

Seed mixtures

There were two seed mixtures; a) Fine leaved grass plus broad-leaved forbs (FG) and b) Tussock grass plus broad-leaved forbs (TG). Details of the species composition can be found in Table 7.6 and Table 7.7. Seed mixtures were common across all sites and were similar to those used in SAFFIE Experiment 2 (Chapter 6). The seed was purchased from a central source and sown using farm implements local to the site at a sowing rate of 35 kg/ha.

Table 7.6 Details of seed mixtures used: fine leaved grass plus broad-leaved forbs (FG).

Species	**Common Name**	**% (weight)**
Grasses		
Agrostis capillaris	Common Bent	5.0
Cynosurus cristatus	Crested Dogstail	35.0
Festuca rubra ssp. *commutata*	Red Fescue	15.0
Festuca rubra ssp. *juncea*	Red Fescue	25.0
Broad-leaves/Forbs		
Achillea millefolium	Yarrow	0.5
Centaurea nigra	Common Knapweed	1.2
Daucus carota	Wild Carrot	1.0
Galium verum	Lady's Bedstraw	1.4
Geranium pratense	Meadow Cranesbill	0.6
Knautia arvensis	Field Scabious	1.2
Leontodon hispidus	Rough Hawkbit	1.0
Leucanthemum vulgare	Oxeye Daisy	1.4
Lotus corniculatus	Birdsfoot Trefoil	0.5
Malva moschata	Musk Mallow	1.4
Plantago lanceolata	Ribwort Plantain	1.0
Primula veris	Cowslip	1.1
Prunella vulgaris	Selfheal	1.0
Ranunculus acris	Meadow Buttercup	3.3
Rhinanthus minor	Yellow Rattle	1.0
Rumex acetosa	Common Sorrel	1.0
Vicia cracca	Tufted Vetch	1.4

Table 7.7 Details of seed mixtures used: tussock grass plus broad-leaves/forbs (TG).

Species	**Common Name**	**% (weight)**
Grasses		
Alopecurus pratensis	Meadow Foxtail	4.0
Dactylis glomerata	Cocksfoot	16.0
Deschampsia cespitosa	Wavy Hair-Grass	8.0
Festuca pratensis	Meadow Fescue	20.0
Festuca rubra spp. *rubra*	Red Fescue	20.0
Holcus lanatus	Yorkshire Fog	4.0
Phleum pratense	Timothy	8.0
broad-leaves/forbs		
Achillea millefolium	Yarrow	1.2
Centaurea nigra	Common Knapweed	2.7
Centaurea scabiosa	Greater Knapweed	1.6
Daucus carota	Wild Carrot	2.4
Dipsacus fullonum	Wild Teasel	1.6
Galium mollugo	Hedge Bedstraw	2.0
Geranium pratense	Meadow Cranesbill	1.0
Lathyrus pratensis	Meadow Vetchling	1.0
Leucanthemum vulgare	Oxeye Daisy	2.0
Silene dioica	Red Campion	3.0
Vicia cracca	Tufted Vetch	1.5

Layout

The length of margin sown in each treatment was 4% of the field area up to a maximum field size of 10 ha. This meant 80 m of margin were sown for every 1 ha of field. The total amount of margin was split between two sides of the field; margins were located in discussion with the host farmer and aimed to avoid footpaths and other undesirable areas. Two replicates of each seed mixture were drilled at each site, alternating the seed mixture on each length of margin. Examples of layout are detailed in Figure 7.3. Margin seed mixtures were not drilled around corners. A standard Countryside Stewardship seed mixture was used to complete field sides and drill any corners.

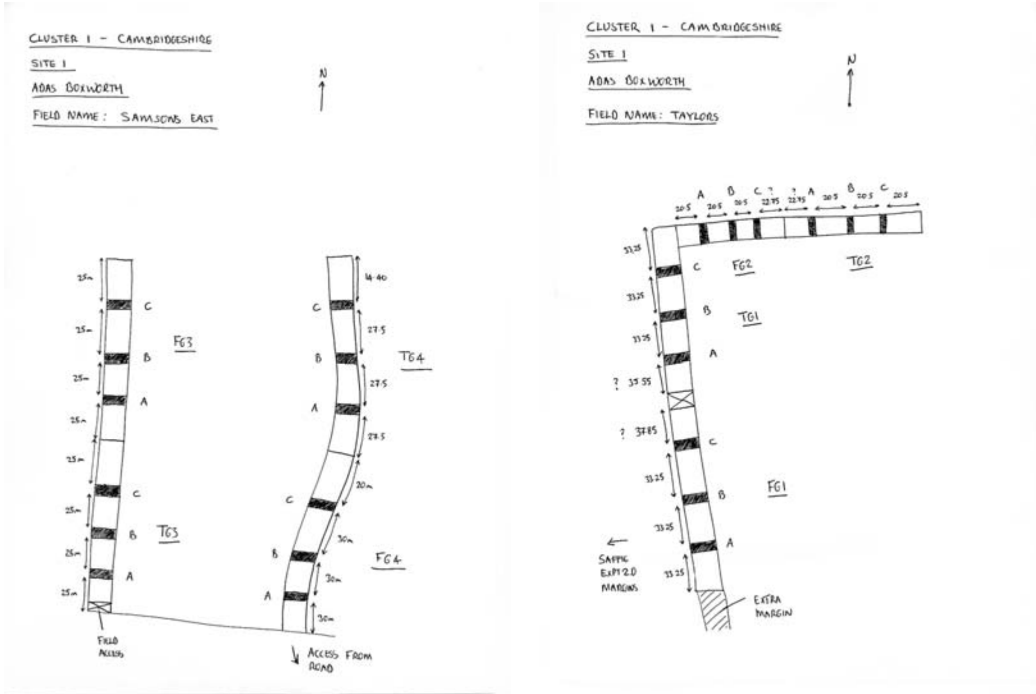

Figure 7.3 Examples of margin layout at ADAS Boxworth.

Due to the variation in margin length at all sites; a defined length of 60 m was assessed along each length of margin. This was divided into three, 20 m lengths (sampling blocks), distributed equally over the margin length. For example, if the margin was 100 m long, the buffer distance between each 20 metre sampling-block was 10 metres (Figure 7.4). However, the buffer distance was adjusted to avoid field access and large overhanging trees etc.

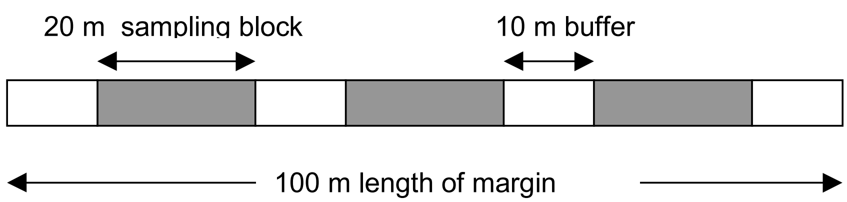

Figure 7.4 Layout of sampling blocks on margins

The host farmer or a contractor accompanied by ADAS staff drilled the margins during spring 2003. Actual drilling dates are detailed in Table 7.8.

Table 7.8 Margin drilling date in spring 2003

Site No.	Cluster		Site No.	Cluster	
BX	CA	28 March	RA	EA	20 March
GK	CA	10 April	RB	EA	20 March
UW	CA	30 March	DH	EA	24 March
TP	CA	7 April	DA	EA	6 May
HM	HE	26 March	DB	EA	6 May
WH	HE	18 March	BM	EA	21 March
LH	HE	25 March	HF	EA	10 April
CG	HE	10 April	PA	SC	11 April
TC	HE	27 March	PB	SC	11 April
BE	LI	19 March	OE	SC	12 April
CG	LI	28 March	ME	SC	26 May
AF	LI	31 March	TF	SC	11 April
GF	LI	27 March			
CH	LI	10 April			

7.3.3 Management

7.3.3.1 In-field crop management

Crops in all treatments were managed to the ICM standard following guidelines in "Arable cropping and the environment – a guide" HGCA/DEFRA 2002. As far as possible the wheat variety and all inputs were the same in all 4 treatments.

In the break crop year, break crops were, as far as possible, the same in all fields. Inputs and varieties could vary between break crop fields

7.3.3.2 Undrilled patches

Undrilled patches received the sprays applied to the field. At the end of the season there was an option to spray out serious weed infestations with glyphosate.

7.3.3.3 Space between hedge and crop or margin and crop

Crops were drilled as close to the margin or hedge base vegetation as could practically be achieved with farm machinery. The narrow strip between crop and margin or hedge base was left untreated.

7.3.3.4 Margins

<u>Establishment year (2003)</u>

During the establishment year the host farmer was encouraged to mow margins to a height of 7.5–15 cm as necessary to control volunteer crops and annual weeds. This typically required 2–3 cuts between May and September. As far as possible margins were not used as tracks during the experimental period and remained unsprayed.

Treatment years (2004, 2005 and 2006)

Margins were mown in spring 2004. Results from Experiment 2 (Chapter 6) led to the selection of scarification as the chosen treatment for the margins in 2005 and 2006. The reasons behind the choice are detailed in 7.2.1.2. Scarification was achieved by the same methods used in Experiment 2. A power harrow was used, set at a suitable depth to cultivate the top 2.5 cm of the soil, with the aim of creating 60% soil disturbance. Scarification was done in early spring (March/April) when the ground was in suitable condition (not too wet or dry). In late winter 2004, host farmers and farm managers attended a workshop where the correct method of scarification was demonstrated.

7.3.3.5 Hedges

Hedges in all 4 treatments were treated identically, wherever possible.

7.3.4 Methods of data collection

7.3.4.1 General habitat information

Using information supplied to ADAS by the landowner/tenant and mapping visits by BTO and RSPB staff, the following data were recorded annually for all treatment areas:

- The crop-type in the treatment, plus the areas (ha) of the crop, experimental (margins and UP) and non-experimental (e.g. cropping, boundary characteristics) features present.

- A boundary-height index, calculated as for Ex1.1, and, for certain species or functional groups, more detailed attributes of the boundary, including presence of water-retaining ditches and boundary type.

- The habitat adjacent to the treatments. For the skylark analyses, these were used to calculate 'Adjacent habitat scores', as for Ex1.1. For other bird species, for which less detailed information on habitat selection was generally available, a score was calculated for the proportion of the treatment bounded by a series of key habitats, including grassland, oilseed rape and spring-sown arable crops. These are known to have impacts on a number of farmland bird species.

These data were used to assess the influence of experimentally manipulated and non-experimentally manipulated habitats in and around the treatments on birds, and on other response variables in the trophic linkage analyses.

7.3.4.2 Agronomy

The wheat plant population was recorded in the spring, in 20 x 0.5 m lengths of row per treatment. Weed levels were monitored in March/April and June/July by sketch mapping patches. Fertile tiller numbers were recorded in June/July, in 20 x 0.5 m lengths of row, or 20 x 0.1 m^2 quadrats per treatment. Disease and pests were monitored at each visit. Crop yields were recorded at harvest by the host farm.

7.3.4.3 Margin vegetation

Species cover

Botanical assessments were done during July in 2004, 2005 and 2006. In each 20 m sampling block botanical composition was determined from six quadrats measuring

0.5 x 0.5 m (0.25 m^2). The six quadrats were divided equally between the margin: crop interface and the margin : hedge interface, leaving a buffer of approximately one metre to take into account edge effects. All species were identified and assigned a percentage cover value according to an eight-point scale (1 = < 1%, 2 = 1-5%, 3 = 5-10%, 4 = 10-20%, 5 = 20-40%, 6 = 40-60%, 7 = 60-80% & 8 = 80-100%). Percentage bare ground and litter cover within each replicate quadrat was also recorded, but as absolute values.

Vegetation Structure - coarse grain structure

The 'drop disc method' (Stewart et al., 2001) was used to provide an indication of height and leaf and stem density within the sward canopy. A standard disc weighing 200 g with a diameter of 300 mm was dropped from a height of one metre down a vertically held ruler. In total, 20 measurements were taken diagonally across each sampling block at one metre intervals. Height readings were taken as the distance from the ground where the drop disc comes to rest.

7.3.4.4 Margin Invertebrates

Two collection methods were employed to sample key invertebrate groups in Experiment 3. These methods were complementary in terms of target groups collected and the single sampling date was timed to coincide with late season emergence of adults of Coleoptera and Hemiptera.

An August sample for invertebrates in Experiment 3 was based on their availability as potential food sources for birds and reflects also the periods of high abundance for the invertebrate taxonomic groups sampled (Table 7.9)

Table 7.9 Rationale for selecting sample times for each method

Method	**Timing**	**Rationale**
Vacuum	August	Encompasses nesting period of skylark and collects widest range of groups fed to nestlings.
Sweep	August	Primarily collects larvae which are abundant during this period
		Key period of insect abundance.

Vacuum and sweep net sampling were done in August for 2004-6 to sample sward active invertebrates.

Vacuum sampling.

A Vortis suction sampler (manufactured by Burkard, UK) was used to collect 3 samples per plot in Exp 3; with each sample comprising 15 ten second sucks made by moving the Vortis vertically down on the vegetation (catch from each group of 15 sucks will be pooled). Samples were evenly spaced out along the plot. Invertebrates were removed from debris by pooter and stored in 70% alcohol prior to sorting and identification.

Vortis was the preferred method for margins, as it was effective at collecting invertebrates from early successional predominantly grass swards. The Vortis suction sampler has methodological advantages over other suction sampling methods as there is limited impedance of airflow into the collecting chamber resulting from dislodged vegetation during sampling. The Vortis is, however, less suitable for sampling within crops, as the narrow aperture of the sampling tube often limits its use within relatively high and structurally complex crops, such as wheat or barley. For this reason the D-vac was a more appropriate collecting device for crop sampling and was used when sampling sward invertebrates within the crop. A degree of comparability between the two methods is achievable by considering the abundance of invertebrates within samples in terms of the unit area over which they were collected. Vortis sample area (15 sucks) is 0.174 m^2.

Sweep netting.

Two 10m transects comprising 20 sweeps were made in each plot for Exp. 3. The larvae were separated and weighed using a balance accurate to ±0.001g to give a measure of wet larval biomass within the experimental plots. Orthoptera were identified in situ or retained in 70% alcohol. The number of Tipulidae and Bibionidae (both Diptera) were also recorded. Nets were standard sweep nets (Watkins and Doncaster, UK) and identical for crop and margin

Taxonomic approach

Beetles of the families Carabidae, Chrysomelidae, Curculionidae and Apionidae were identified to species, as were all true bugs (Heteroptera) and all planthoppers and allies (Auchenorrhyncha).. Abundance of spiders was also recorded. All other invertebrates were counted and assigned to a category 'other'. All individuals within the taxonomic groups identified to species, as well as those falling within the category of 'other' were assigned to size class: <2 mm, 2-5 mm, 5-10 mm, > 10 mm. This was intended to provide information on the overall distribution of biomass, as well as its distribution within taxonomic groups considered to be of direct importance to birds as food sources.

7.3.4.5 Within crop vegetation

Four of the five clusters were sampled; the number of clusters sampled was restricted by the amount of time available. All four treatments were sampled on each farm. Two transects were established, 24 m apart, perpendicular to each sown margin and a control in treatments 1 and 4 without a sown margin. Each transect originated at the edge of the cultivated area whether a margin was in place or not. Quadrats were placed at 0, 1, 2, 4, 8, 16, 32 and 96 m on 'no margin' and tussock grass margins Any effects of the margin on the crop vegetation were not expected beyond 4 m, therefore fine grass margins were sampled only at 0, 1, 2 and 4 m to compare the impact of the two margin types on the weed vegetation adjacent to the margin. At each position, one quadrat (0.25 m^2 i.e. 0.5 m x 0.5 m) was sampled on two occasions in early June and late June/early July. The quadrat defined as 0 m was placed between 0 and 0.5 m, 1 m was between 1 and 1.5 m etc. In 2005 and 2006, an additional quadrat was sampled in the margin immediately adjacent to that at 0 m (i.e. between 0 and –0.5 m). In each year, sites where the rotation was winter wheat were sampled.

In each quadrat percent cover of each plant species was recorded plus crop, bare ground viewed from above the canopy, bare ground viewed from below the canopy and litter. Cover was recorded in the following categories, with the midpoint value used for analysis: 0-1%, >1-2%, >2-5%, >5-10%, >10-20% and then in 10% bands up to >90-100%. Total plant cover could sum to more than 100% because vegetation was present at different heights in the canopy.

As vegetation structure may be an important factor in the use of cropped areas by other organisms such as invertebrates and birds, a graduated board method was used to assess the overall vegetation structure. Estimates of the proportion of the board obscured by crop and weeds were made at different heights in order to build up a profile of vegetation structure. A graduated board (1 x 0.25 m) was placed vertically, perpendicular to the crop rows, with a crop row in the centre of the board. The board was divided into 10 sections, each 10 cm high, and the proportion of each section obscured was estimated by viewing the board horizontally from a distance of 1 m. The board was placed 25 cm from the quadrat and viewed through the quadrat with 25 cm in front and behind. Vegetation structure was assessed at 0, 1, 2, 4 m in all three years.

7.3.4.6 Within crop invertebrates

Sampling rationale

Sampling was carried out to: i) determine the effect of margin treatment on key beneficial invertebrates (predatory and those important as food for farmland birds) within the cropped area; ii) establish how far this effect extended from the margins into the field; iii) establish whether there is an enhanced effect of undrilled patches when combined with margins; iv) provide data to investigate field-level trophic analyses between vegetation, invertebrates and birds.

Sampling strategy

The experimental design required that 15 sites were sampled twice over three years by sampling ten sites in each year. Each site was sampled in both first and second year wheat. Two transects, 20m apart were located on either end of the sampling block (see Figure 7.5) within each margin type. Transects extended from the tussocky grass and control margins into the field and were sampled at 0m (interface between crop and margin), 16m, 32m and 96m. Transects from the fine grass mix were sampled at 0, 16, and 32m. The length of margin available restricted the distance into the field at which sampling was meaningful. At 96m invertebrates could have originated from either margin type and so this sampling point was used to compare the difference between fields with and without margins. The staggered sampling points accounted for known spatial variation in invertebrate distributions. Sampling dates coincided with vegetation assessments.

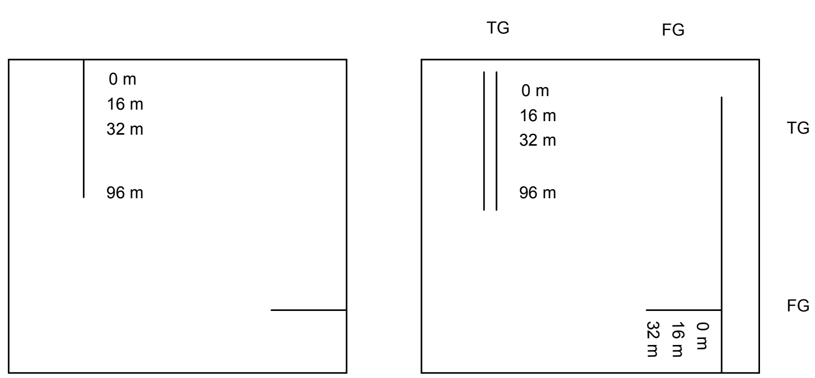

Figure 7.5 Within field invertebrates: schematic example of within field sampling strategy

Pitfall, suction and sweep net samples were taken as described in Table 7.10, thereby encompassing the period when invertebrates are most abundant and skylarks are breeding.

Samples were taken using three methods to ensure the full range of invertebrates present within the field was collected, as summarised in Table 7.10.

Sampling method

Suction sampling was carried out with a Dvac suction sampler the preferred method of sampling a mature cereal crop. At each sampling location, two Dvac samples consisting of 5 sucks of 10 seconds duration were taken 2m apart. Data were pooled for analysis. Sweep net samples were taken from an undisturbed area adjacent to the Dvac sampling locations using a standard D-frame kite net (Watkins and Doncaster E679). One sweep net sample of 20 sweeps was taken at each sampling position along each transect. Pitfall samples were collected using 6 cm diameter, white plastic pitfall traps, half filled with 50% ethylene glycol (antifreeze), 50% water and unscented detergent (supplier: A W Gregory & Co Ltd., Glynde House, Glynde Street, London, SE4 1RY; product: No. 8 white). Two pitfall traps were installed at each sampling point along the transect, within 2m of the botanical sampling quadrat. Each trap was left open for 7 days. The contents were identified separately but pooled within sample position for analysis. 2800 samples were processed to the taxonomic level shown in Table 7.11. Sample timing reflected chick food availability.

Table 7.10 Within field invertebrates: rationale for sampling methods

Sampling technique	**Sampling time**	**Rationale**
Suction	early June (weeks 1-2), early July (weeks 1-2)	Method which collects the widest range of key groups fed to nestlings.
Sweep	early-June	Primarily collects sawfly and lepidopteran larvae.
Pitfall	early-June, early-July	Estimates activity/density of ground active invertebrates.

Taxonomic approach

Invertebrates were identified to a level appropriate for assessing their value as a resource for birds or as crop pest predators, as outlined in Table 7.11. Abundance of each group was recorded. These groups where then combined to form composite variables for analysis (see 7.3.5.2).

Table 7.11 Within field invertebrates: Taxonomy

Group	Common name	Sampling method	Taxonomic level
Araneae	Spiders	Vacuum + pitfall	Family
Opiliones	Harvestmen	Vacuum + pitfall	Order
Homoptera	Bugs	Vacuum + sweep	Family
Heteroptera	True bugs	Vacuum + sweep	Family
Auchenorrhynca	Hoppers	Vacuum + sweep	Family (not nymphs)
Sternorrhyncha	Aphids	Vacuum + sweep	Family
Diptera	Flies	Vacuum + sweep	Family
Orthoptera	Grasshoppers	Sweep	Order
Hymenoptera	Bees, wasps, ants	Sweep + vacuum	Symphyta
			Formicoidea
Lepidoptera	Butterflies, moths	Sweep	Order (larvae)
Neuroptera	Lacewings	Sweep + vacuum	Order
Coleoptera	Beetles	Vacuum + pitfall	Family
Chrysomelidae	Leaf beetles	Vacuum	Species (if necessary)
Curculionidae	Weevils	Vacuum	Species (if necessary)
Carabidae	Ground beetles	Vacuum and pitfall	Species
Staphylinidae	Rove beetles	Vacuum and pitfall	Species

7.3.4.7 Birds

The type of assessments differed between year, individual species and whether the site was in experimental wheat. They included measures of territory and nest density, breeding performance and foraging behaviour. Fieldworkers trained in the relevant techniques carried out collection of all bird data.

<u>Data from mapping methods</u>

Data were collected using Common Birds Census (CBC) type mapping methodology (Marchant et al. 1990), on all sites and in all years (including a baseline year in 2003 and those in break crops during 2004-06), except in a few cases where the experimental layout of the site was incorrectly implemented (see 7.3.1). In each year, eight visits per site were made between the beginning of April and mid July. A route was walked around the entire field perimeter (following the outermost tramline, running parallel to the field boundaries, or along the margin/crop interface), recording on a map the location and behaviour of all bird species seen/heard, using standard BTO two-letter species codes and activity symbols. Recording was undertaken only during the morning in still, dry weather conditions.

Each bird recorded ('individual registrations') on the maps was assigned to one of three habitat categories: (i) the 6m wide experimental margins (subdivided into fine grass or tussock grass sections), (ii) boundary features (e.g. hedges, tracks and ditches) and (iii) cropped areas. If individuals were recorded in multiple habitat categories, treatments or overlapping the boundary between a treatment and the adjacent habitat, all positions were mapped but, to avoid double counting, the first observation only was used in the subsequent analyses.

Clusters of bird registrations accumulated over a single breeding season were used to define 'territories' of species likely to have been breeding on the treatments. To ensure continuity between sites and years, territory clusters were defined by a single trained member of the BTO staff, using the methods outlined by Marchant (1990). If birds were recorded in more than one treatment (or overlapping a treatment and an adjacent habitat), all positions were mapped to allow proportional allocation of territories to the various treatments/adjacent habitats. The total number of territories calculated for each species for a given habitat or treatment, included the sum of the proportions of each territory which overlay that particular habitat or treatment.

The numbers of individual registrations or territories were then compared between:

- The four treatment types.

- Over time, reflecting temporal shifts in response to the development of both experimentally manipulated (margins and UP) and non-experimentally manipulated (e.g. crop) vegetation, and associated food resources. Temporal change was studied (i) within year or (ii) between years, depending on the analysis.

- Specific habitat features within the treatments, e.g. margin type and cropped area

Data from routes walked around the entire field perimeter were also used to assess the distribution of foraging birds at the above scales. In summer, these data were extracted from the CBC information. In winter, transect counts were made during 2004-05 and 2005-06 on all experimental margins on 10 farms in Cambridgeshire and East Anglia, where the two seed mixes, tussock mix and fine grass mix, were compared. Margins were either cut in autumn, in order to consolidate the sward for experiments in the following summer, or left uncut. The cut/non-cut treatment allowed an analysis of the winter use of field margins by birds, in relation to both seed-mix and cutting regime. An initial early winter count was made during November, and a repeat late-winter visit during late January or early February. Bird records were then assigned to one of three habitat categories used in the analyses of the breeding season data.

<u>Data from nest observations:</u>

For a sub-set of farmland passerines for which UP or field margins were expected to provide potential foraging or nesting habitat, data on differences in nest survival rates, nest productivity, nestling condition and brood reduction were collected to provide an indication of the relative values of the four experimental treatments. These included skylark, yellow wagtail, meadow pipit, dunnock, blackbird, song thrush, common whitethroat, yellowhammer, corn bunting, reed bunting, chaffinch and linnet (see Appendix 1 for scientific names). Nestling biometrics were recorded only for species that nested predominantly in the field centre, as, for species nesting predominantly on the treatment boundary, measures of body-condition and growth rate were liable to be heavily influenced by conditions outside of the treatment blocks. Nests were located and their success, contents and nestling biometrics recorded according to the methods outlined for Ex. 1.1.

During summer 2006, efforts were made to identify the predators of ground-nesting passerines (skylark, yellow wagtail and yellowhammer[1]) and to determine whether predators varied between treatments or with proximity to margins. This was

[1] Yellowhammer is variously included in both suites of ground-nesting and hedge-nesting species, as it constructs nests in both hedgerows and on the ground within grass margins. Camera deployment was only on nests in the latter habitat.

achieved by deploying 10 remote-sensor camera units on seven farms in wheat in the English site-clusters. The camera units were assembled especially for this project following the methods used on previously successful RSPB studies of nest predation. The units consisted of three parts, (1) a small video camera mounted on a copper pole 60 cm long which could be pushed into the ground, (2) a water tight box, connected to the camera by a five metre cable, in which a recording unit and infra-red timer were housed and, (3) a 12 volt battery connected to the box by a one metre cable.

Once skylark nests were located, the camera was placed approximately 0.5 m away, facing at an angle of 45° into the nest. Care was taken not to allow vegetation to obscure the view or to disturb access to the nest by adult birds. The field of view was adjusted using a hand held television monitor temporarily connected to the recording unit. When this was correctly positioned, the camera started recording when any movement in the field of view around the nest was detected. The watertight box and the battery (wrapped in a waterproof bag) were concealed in the crop, 5 m away from the nest. The units were programmed to record three images at 0.3-second intervals every time movement was detected. Recording would then be suspended for 10 seconds and only resume if movement were detected again. The motion detection was set to its lowest sensitivity to stop the camera being triggered by wind movement of vegetation. The image quality and resolution were set at their lowest values; still allowing the images to be viewed adequately without filling the memory cards too quickly. An infrared light source illuminated the field of view so movement could be detected during darkness. A timer programmed to switch on at dusk and off at dawn, controlled the light source. The images were recorded on to SD digital memory cards, which were replaced every three days (along with the battery) so the images could then be reviewed and saved. When the cameras were not deployed on nests, they were used to monitor movement of potential predators and prey along linear features, such as margins and tramlines.

7.3.4.8 Trophic links

Links between birds and the accessibility (as determined by vegetation structure) and abundance of their food, were calculated at four different scales:

- At the wider-scale, within the entire treatment (weighted by relative areas of crop and margins sampled)
- At the wider-scale, within crop
- At the wider-scale, within margins
- At the fine-scale, within the immediate area of the foraging location ('hotspots')

Analyses at the wider-scales used data from the following sites and years (Table 7.12), and details of the variables collected and used to analyse these links between bird records and the availability of food at the are given in sections 7.3.4.3 to 7.3.4.6.

Data from Experiments 1.1 and 2 showed that certain species, or guilds of species, preferentially selected UP or certain types of experimental margins for foraging. In order to demonstrate whether birds selected small, discrete parcels of habitat as forage sites in response to food abundance, vegetation structure (which may determine the accessibility of food, ease of movement and ability to detect predators), or to a combination of these factors, fine-scale habitat assessments were carried out at foraging locations in the crop and margins. If close to the walked route, transect counts provided very precise identification of the exact spots foraging birds were flushed from. However, they did not provide data on how frequently a bird makes use of that location; as once flushed by the observer, birds are unlikely to return to that spot. Data (e.g. Morris et al. 2002) show it is desirable to differentiate locations that were revisited, as they varied in terms of the vegetation and invertebrate numbers from locations that were foraged in only once or not at all. Therefore, visit frequency to forage locations was assessed by watching adults provisioning nestlings.

Table 7.12 Availability of data on predictor variables for trophic-level analyses. Black = within crop and margin data, Dark Grey = margin data only, Light Grey = within crop data only. Bird data available for all sites and years.

Site Code	Cluster	2004	2005	2006
BX	CA		Black	Black
GK	CA	Black	Black	
UW	CA	Black		Black
BE	LI	Black		Black
CH	LI		Black	Black
RA	EA	Black		Black
DH	EA		Black	Black
BM	EA		Black	Black
HF	EA	Light Grey	Black	
PA	SC	Black		
PB	SC		Black	Black
OE	SC	Light Grey		Black
ME	SC	Black	Black	
TF	SC	Black	Black	

On the same day following a forage watch, detailed habitat assessments were made at foraging locations (= ‘hotspots’). At the end of the watch, entry and exit points of foraging birds clearly pinpointed to within a 5 m radius were marked using a flexicane. Birds were not flushed to confirm the exact foraging locations during the watch, as it disrupted their feeding effort and hindered the identification of spots that received multiple foraging visits. However, in 40% of hotspot assessments, the precise location of foraging was confirmed as returning birds were flushed from assessment location when they were marked with flexicanes at the end of the nest watch period. Locations where birds entered and exited more than 5 m apart were discounted, as the identification of the foraging location was judged too imprecise. Single foraging visit ’hotspots’ were only assessed if the foraging occurred during the middle section of the watch; otherwise, there was a possibility that the number of visits to that location may have been underestimated, due to birds foraging there before the start of or after the end of the observation period.

Data on vegetation composition, structure and invertebrate food abundance were recorded at ‘hotspots’ by placing a 2 m x 2 m grid at the equidistant point between entry and exit locations. For each hotspot, the grid was subdivided into four equal sampling blocks of 1 m^2, which in turn were sub-divided into four equal sampling sub-units of 0.5 m^2. Vegetation composition and structure were recorded in three 0.5 m^2 sub-units, placed in two of the 1 m^2 sampling blocks diagonally opposite the foraging location. Invertebrate food abundance was recorded in the other two diagonally opposite 1 m^2 sampling blocks. Data on vegetation density at ground level and at canopy was recorded by five digital images around the marker (Figure 7.6). Identical assessments were then carried out at a nearby paired location (a minimum of 20 m away from the 'hotspot'), where no birds were seen foraging ('coldspots'). Where similar habitat was available, 'coldspots' were placed in a northerly direction of the corresponding 'warm/hotspot', a minimum of 20 m away. If similar habitat was not available in that direction (e.g. in margins), the 'coldspot' was located >20 m in any direction where similar habitat existed. Where 'hotspots' occurred on habitat interfaces (e.g. between crop and margin), the 2 m x 2 m grid was orientated so that one vegetation 1 m^2 sample block and one invertebrate 1 m^2 sample block were in each habitat.

To determine the sward surface height, one 200 g drop-disc measurement was taken from the centre of each 0.5 m x 0.5 m block. To avoid vegetation compaction, this was performed before carrying out the visual assessments. Visual assessments of cover were recorded for bare ground (observed vertically above the ground), grass weeds (all species combined) and of species in flower and in seed. The recorded cover values did not necessarily add up to 100% because there may be an overlapping of the components recorded. To ensure repeatability between observers, digital camera images were used to assess vegetation density at (i) the vegetation canopy and (ii) ground level. To assess canopy-closure, a camera was placed on the ground at the foraging location and a photo taken upward towards the sky. To assess vegetation cover just above the ground, at bird's eye level, the camera was placed on a small block at the foraging location, so the lens was approximately 8 cm above the ground. A white board was placed 0.5 m away from the camera lens and a photo taken looking through the crop or grass stems towards the white background. This process was repeated, so that four photos of the ground cover were taken clockwise at 360 degrees around the foraging location (or 'coldspot' marker).

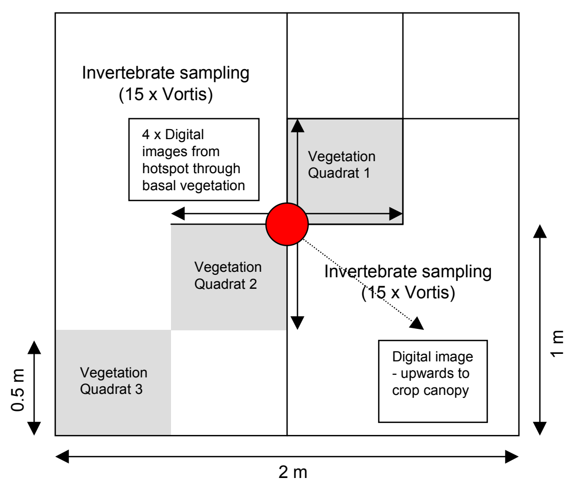

Figure 7.6 Diagrammatic representation of sampling strategy for hotspots & coldspots

Invertebrates were sampled with a vortis in two 1 m^2 sampling blocks in each spot, using a sequence of 15 x 10 s samples spaced evenly across the sample area. Vortis sampling could not be carried out in extremely wet conditions (including heavy dew on the ground) as this resulted in samples sticking to the inside drum. Samples were taken in equal proportion from the ground and basal vegetation, to reflect the foraging substrates of key bird species, e.g. skylark. A killing agent (ethyl acetate soaked paper) was added to a 100 ml pot with a lid when the sample was removed from the machine to insure that insects do not fly away when the sample was sorted. Material collected from each sample was hand sorted in a tray to separate soil and plant material from the invertebrates. Invertebrates <2 mm in length were also discarded, as being unimportant in the diet of birds. Samples were then weighed (subtracting the weight of the pot) on a field balance sensitive to ±0.01 g in a wind-free environment (e.g. a weather writer or inside a car). Samples were retained in 70% alcohol for later identification.

7.3.5 Statistical analysis

7.3.5.1 Within crop vegetation

Because of the complexity of the analysis and the likelihood of generating false positive results by analysing all possible variates, only a subset of variates were analysed: all weeds, desirable species, undesirable weeds, arable weeds, crop, bare ground viewed from above the canopy and structure at 0 – 20 cm from ground level (see chapter 5 for details of desirable and undesirable groupings).

7.3.5.2 Within crop invertebrates

The objective of entomological work in experiment 3 was to assess the effect of experimental treatments on invertebrate abundance with respect to their value as a food resource for birds or for crop pest control. To this end a number of composite variables were calculated, as outlined in Table 7.13.

7.3.5.3 Within crop analyses

All data were analysed using ANOVA in Genstat 9.1 (2006 Lawes Agricultural Trust). The complete model for transect data was an ANOVA with nested block structure (Site/Field/Transect/Sample/Repeat) and a treatment structure designed to deal with unequal number of transects between margin types (Year+Patch*(Margin/MType) *Position*sample date). Vegetation data (which analysed margin type separately) and mid-field samples (those taken at 96 m) were analysed using a modified version of this model. Weed data were angular transformed and invertebrate data were $\log_{10}(x+1)$ transformed before analysis.

Table 7.13 Invertebrate taxa included within each composite variable

a) Ground active (sampled using pitfall traps)

Variate	Composition
Seed eating carabids	Carabid genera that include many seed eating species: Amara and Harpalus
Predators	Predatory taxa: Araneae, Lycosidae, Carabus spp., Nebria brevicollis, Notiophilus biguttatus, Loricera pilicornis, Trechus quadristriatus, Asphidion flavipes, Bembidion lampros, Bembidion obtusum, Poecilus cupreus, Pterostichus madidus, Pterostichus melanarius, Calathus fuscipes, Anchomenus dorsalis, Demetrius atracapillus, Tachinus spp., Tachyporus chrysomelinus, Tachyporus hypnorum, Tachyporus nitidulus, Tachyporus obtusus, Steninae, Stenus spp., Paedurus littoralis. Staphylinidae, Philonthus spp., Philonthus cognatus, Xantholinus spp.
Boundary carabids	Those Carabidae which are known to over-winter in the boundary: Carabus spp., Nebria brevicollis, Asphidion flavipes, Bembidion lampros, Anchomenus dorsalis, Agonum muelleri, Demetrius atricapillus
Boundary staphylinids	Those Staphylinidae which are known to over-winter in the boundary : Tachinus spp., Tachyporous chysomelinus, Tachyporpous hypnorus, Tachyporus nitidulus, Tachyporus obtusus, Stenus spp., Paederus littoralis, Xantholinus spp.
Field carabids	Those Carabidae which are known to over-winter in the field: Notiophilus biguttatus; Loricera pilicornis, Trechus quadrustriatus, Poecilus cupreus, Pterostichus madidus, Pterostichus melanarius, Calathus fuscipes, Zabrus tenebrioides, Harpalus affinis, Harpalus rufipes
Field staphylinids	Those Staphylinidae which are known to over-winter in the field: Philonthus cognatus
Total Invertebrates	Sum of taxa

b) Crop active (suction and sweep samples analysed separately)

Variate	Composition	References (where appropriate)
SFI (Skylark food Index)	Sum of Snails, Plant bugs and hoppers (all Hempitera), sawflies (Symphyta), Beetles (Carabidae, Staphylinidae, Elateridae, Nitidulae, Chrysomelidae), Weevils (Apionidae) and flies (all Diptera)	Calculated from skylark faecal samples collected in Ex. 1.1
YHI (Yellowhammer Index)	Sum of spiders + Tipulidae (craneflies) + Coleoptera (beetles) + plant bugs/hoppers + aphids + butterfly & moth caterpillars	Hart *et. al*., 2006
CFI (Chick Food Index)	(0.00614*plant bugs&hoppers)+(0.0832*(leaf beetles&weevils)+(0.000368*aphids)+(0.1199*caterpillars)+(0.1411*ground&click beetles)	Potts & Aebischer, 1991
4FI (4 Food Index)	Sum of harvestmen+caterpillars (Lepidoptera&Symphyta)+Orthoptera	Brickle *et. al*. 2000
(TI) Total Invertebrates	Sum of taxa	

7.3.5.4 Birds

General Linear Mixed Modelling (GLIMMIX macro in SAS: Littell et al. 2002), with site and a siteXfield interaction term included as random factors in all models, were used to identify those predictors explaining significant variation in the response variables. Type-III significance tests of fixed effects used Wald *F* tests and Satterthwaite's approximation to the denominator 'degrees of freedom'. The AIC-based multi-model comparison approach (Whittingham et al. 2005) was not used as this experiment tested specific hypotheses about the effects of a small number of predictor variables on a multi-centre trial.

In response to recent concerns over the use of stepwise modelling in ecology and behaviour (Whittingham et al. 2006), full models were first constructed incorporating all predictors. Significance of predictors in the full models were then compared to results from a manual step-down process, where the least significant variables were sequentially removed until a Minimum Adequate Model (MAM) was reached in which all variables were retained at $P \leq 0.05$ (Crawley 1993). When significance of variables at the $P \leq 0.05$ level did not differ between the two approaches (most cases), the result from the MAM is given but if a variable was significant in only one approach, this is clearly indicated in section 7.4.5. In the analysis of bird densities, a manual step-down process was used to compare both effects of predictor variables and models fits to the data of model permutations, to an original full model containing all fixed variables. Consistently non-significant variables were removed unless their interaction with a second variable was itself significant. So minimum adequate models were compared to full models but also to interim model permutations to look for and interpret fixed effects as consistent or not.

Only a few individual species e.g. skylark, were abundant enough to analyse separately. Species responses to treatments were therefore analysed within taxonomically and/or ecologically similar groups (see Appendix 1). Amalgamating species into such groups was difficult since, by definition, species are ecologically distinct. In addition, nearly all bird species (bar only one or two obligate seed-eaters) in summer seek invertebrates to feed to their chicks. However, the ecology of the groups below may differ in the way species search for food or in the way parents forage for themselves when among crops or field margins. They represent and are defined as:

1. Taxonomic group response variables:

- Insectivorous passerines: e.g., wren, dunnock & thrushes (Turdidae);

- Finches & tree sparrow: i.e., seed-eating passerines.

- Buntings (yellowhammer, reed bunting and corn bunting); a distinct group of seed-eating passerines, all of conservation concern in the UK. On farmland, these species also frequently and typically seek food on or near the ground (although reed bunting may forage amongst bushes/reeds).

- Skylark and yellow wagtail were treated independently, being two species that both nest and forage within fields, typically away from field boundaries.

2. Functional group response variables (based on the way they typically acquire food in summer):

- Gleaners: species that tend to glean invertebrates from vegetation.

- Probers: species that tend to search for invertebrates on the ground or around basal vegetation.

3. <u>Conservation-based group response variables:</u>

- Passerines included in the UK government's 'Farmland Bird Index (FBI) for monitoring bird population trends on farmland in England.

- Species subject to national Biodiversity Action Plans (BAP species) listed due to declining populations, being species of high conservation concern.

Predictors tested in all models as fixed effects (along with their interaction terms) were 'treatment' (four-level factor), 'year' (a variable two, three or four-level factor, dependent on whether the data included a baseline assessment or break crops) and variable measures of surrounding boundaries and habitat (see section 7.3.4.1). If a score for the proportion of the treatment bounded by a key habitat was included, the percentage figures were arcsine transformed.

A two-level factor 'period' was also included in some models. For breeding season data, it represents the split between 'early' (April-May) and 'late' (June-July) phases, based on the timing of the majority of first and subsequent nesting attempts (see Chapter 1.1 for a detailed explanation of the relevance of the division for skylark); while for winter data it refers to 'early' (November) or 'late' (January-February) counts.

Additional predictors included in certain models were: 'management' (presence of autumn cut) and 'stubble' (presence of adjacent stubble) for the winter data; and seed 'mixture' (fine or tussock grass) for the foraging data. For the purpose of the analyses, winter data from margins and boundary were lumped, as bird records from the margins alone were very sparse.

Variations in clutch sizes; numbers of territories, nests or foraging birds were modelled with Poisson errors and log-link functions. Data from the eight CBC counts made annually were analysed using repeated measures. In analyses of density, log area or log margin length were included as offsets to control for differences in treatment size or margin block length. Back-transformed outputs represent bird densities per unit area (1ha or 10ha of treatment; or 100m or per 1ha of margin). Only nests for which the maximum clutch size was known with certainty were included in the analysis of the number of eggs laid.

The mean nestling body condition of each brood (normal errors and identity link), Mayfield daily failure rates of nests (DFR) and the proportion of nestlings in a brood starved or predated (binomial errors and a logit link function) were modelled using the methods outlined for Ex. 1.1. For analyses of nest predation rates, the approach was similar to the Mayfield daily failure and survival rates outlined in Johnson (1979), but as the focus was on losses to predators and not nests failing for other reasons (abandonment, starvation, accidentally destroyed/collapsed), this set of models did not include nests lost to causes other than predation. Here, the response variable, daily survival rate, was calculated for each nest according to the following equation: *Daily survival rate = Number of nest exposure days without predation / Total number of exposure days*. The formula: *1- Daily survival rate* gives the rate of nest predation per day; here termed 'daily predation rate' (DPR). As most losses were attributable to predation, the daily predation probability presented here were in fact very similar to the 'true' daily failure and survival rates. An 'overall nest predation rate' (OPR) was then calculated to estimate the percentage of nests (depredated and successful) lost to predators over the average duration of a successful nest from first egg laying until the young left the nest (e.g. 22 days for Skylark). Binomial models were also constructed to examine Skylark nest predation in the four SAFFIE experimental treatments. Nest productivity figures were calculated using data on daily nest survival rates, the numbers of eggs laid, the numbers of nestlings hatched and the numbers of nestlings leaving the nest, as in Donald et al. (2002).

Unless stated in 7.4.5, analyses derived from the CBC count data included all sites and years for which the correct experimental design was present. CBC data were also analysed using a core 14 sites, which followed the experimental protocol for all three years (plus the baseline in 2003). Models were constructed with and without the inclusion of bird records from the margins and boundaries. Nest data was analysed only for sites in wheat (as no within-crop best practice management was possible in break crops) from the English sites (as nest data from Scotland was known to be incomplete). For individual species models, sites were excluded from the analysis if they were outside the normal breeding range or the treatments contained unsuitable habitat. In these cases, the numbers of sites used in the analysis are stated in 7.4.5. The number and location of sites contributing to the winter and fine-scale foraging analyses are outlined in 7.4.5 and 7.4.6.

As data on nest predators came from a single year and usually involved small sample sizes, no attempt was made to analyse it using formal statistical methods. Thus, figures presented in 7.4.5 are tabulated sums of the raw data.

7.3.5.5 Trophic Links

<u>Field Scale:</u>

Analyses of trophic links between bird records and availability of their food were modelled using Poisson error General Linear Mixed Modelling (GLMM), with site and a siteXfield interaction term included as random factors. Models were constructed using data collected from within the entire treatment (weighted by the relative areas of crop and margins sampled), unless otherwise stated. The response variables were defined as the number bird registrations (either individual species or functional groups, for which see Appendix 1) from the CBC visits (count data) during the period June and July. This was the period from which vegetation structure and invertebrate data was taken.

A variety of predictors were included as fixed effects:

- Variation in vegetation structure (measured by drop-disc)
- Variation in bare ground
- Variation in litter cover
- Plant species diversity. For obligate seedeaters only
- Mean biomass of ground-active invertebrates ≥2 mm in length. For crop-dwelling, ground-foraging insectivores only.
- Mean biomass of ground-active invertebrates ≥2 mm in length, for orders (insects) or classes (non-insects) ‘important’ in the diet (Wilson et al. 1996). For crop-dwelling, ground-foraging insectivores only.
- Mean biomass of foliar invertebrates ≥2 mm in length. For foliar-gleaning insectivores only.

- Mean biomass of foliar invertebrates ≥2 mm in length, for orders (insects) or classes (non-insects) 'important' in the diet (Wilson et al. 1996). For crop-dwelling, ground-foraging insectivores only.

- Mean suction sample catch biomass of invertebrates ≥2 mm in length. For all insectivores. Calculated separately for within-crop and margins, as suction sampling methods varied between the two habitats.

- Mean suction sample catch biomass of invertebrates ≥2 mm in length, for orders (insects) or classes (non-insects) 'important' in the diet (Wilson et al. 1996). For all insectivores. Calculated separately for within-crop and margins, as suction sampling methods varied between the two habitats.

For vegetation structure and cover predictors, coefficients of variation were used in preference to mean values, as they gave a better representation of patchiness of the sward structure. Invertebrates <2 mm in length were discounted from the analyses as they were thought to be nutritionally unimportant. Mean biomass data was scaled to represent g/m^2.

<u>Fine Scale ('Hot' and 'Cold' Spots):</u>

Data collected on the trophic links between vegetation structure, invertebrate abundance and bird foraging were from matched pairs of 'hot' (foraged in) and 'cold' (non-foraged in controls) spots, sampled on the same date and within the same treatment and broad habitat type (crop or margin). A matched pair of 'hot' and 'cold' spots was given a unique identifier, which was included as a fixed effect in the models. Random effects models were not used in these analyses as factor levels of the identifier had uniform variance. Most models were constructed using a binary response variable (1 = forage, 0 = non-forage location) but some of the larger datasets were also analysed using Poisson errors, to determine whether locations with multiple foraging visits differed from those with no, or only a single, visit. For Poisson models, the number of foraging visits was the response variable.

Two sets of models were run, the larger (173 matched pairs) containing predictor variables on vegetation structure (at percentage covers at ground and at the canopy levels) only. For a subset of 61 matched pairs, data were also available on vegetation height (mean and standard deviation), percentage weed cover and the abundance of invertebrate food groups (which were reclassified as 'present' or 'important' [see Wilson et al. 1996] in the diet of the bird species foraging in that location). All predictors were also modelled as squared terms, to investigate the possibility of quadratic relationships. Data were also collected on invertebrate biomass and percentage bare soil but these were not modelled as they were highly correlated with invertebrate abundance and percentage weed cover respectively. Percentage data were arcsine transformed.

Data were collected from within the entire treatment (crop and margins) but the number of matched samples from margins was small (particularly from 2004, when the margin vegetation was still immature and unscarified). Therefore, after initial t-tests determined that responses to predictors were broadly similar between the crop and the margins, the data were lumped. Foraging data were collected for a variety of passerine species, for which the treatment areas were expected to be potentially beneficial. The larger structural dataset was analysed for (i) all species, or subsets of (ii) skylark, (iii) largely insectivorous species and (iv) largely granivorous species using matched foraging locations. The smaller food resource and structure dataset was analysed using matched foraging locations of (i) all species and (ii) skylark (the predominant foraging species) only.

7.4 RESULTS

7.4.1 Agronomy

Crop rotations were predominantly winter cropped, and first and second winter wheats were the most common crops. A range of break crops was grown including winter oilseed rape, winter and spring barley, beans, linseed, set-aside, peas, onions and potatoes. All crops received usual farm inputs and nitrogen.

Winter wheat plant populations were assessed in the spring and ranged from 75-313 plants/m². Fertile tiller numbers ranged from 123-700 /m².

Some weed problems were encountered in the undrilled patches (UP) due to lack of competition from growing crop. Black-grass and cleavers were noted as a problem in UP and in some cases it was necessary to spray out the UP with glyphosate late in the season to prevent seed return.

Margins were generally problem free for the duration of the experiment. Docks, thistles and bristly ox-tongue did occur in several margins and were controlled by spot treatment of fluroxypyr and clopyralid.

7.4.2 Margin vegetation

Irrespective of year, values of bare ground were similar between seed mixes, with mean values ranging between 5% and 7%. Prior to the yearly application of the scarification treatment, values of bare ground in 2004 were negligible at 1%, but in years 2005 and 2006, mean values ranged from 8% to 10%. Values of coarse grain vegetation structure were greater in plots sown with the TG mix (35.6 cm) compared to the FG mix (30.0 cm) and prior to the scarification treatment values were 41.9 cm, compared to 19.6 cm in 2005 and 36.9 cm in 2006, indicating a high variability between years. Percentage litter cover tended to increase with time, providing 3.8% cover in 2004, compared to 5.8% in 2005 and 20.2% in 2006. The difference between seed mixes was minimal, with a 9.4% cover in plots sown with the FG mix and 10.5% for the TG mix. Values of Simpson's unbiased diversity were similar across years, ranging between 0.88 and 0.89. Diversity was also similar between seed mixes with a value of 0.89 in plots sown with the FG mix, compared to 0.88 in plots sown with the TG mix.

7.4.2.1 Comparisons between Experiment 2.0 and Experiment 3.0 field margin vegetation attributes

Field margins established for Experiment 2.0 using the FG and TG seed mixes that were also managed with scarification had greater values of bare ground compared to the scarified margins of Experiment 3.0. Mean values were 19% for the FG mix and 24% for the TG mix, compared to 8% - 10% for Experiment 3.0. Prior to implementation of the scarification treatment on the Experiment 2.0 and 3.0 margins, values of bare ground were also greater in the Experiment 2.0 margins, with mean values ranging from 9% to 13%, compared to negligible values with Experiment 3.0. Under the treatment of scarification, values of Simpson's Diversity were greater for the Experiment 2.0 margins, being 0.90 in plots sown with the FG mix and 0.91 in plots sown with the TG mix, compared to 0.89 and 0.88 for the FG and TG mixes sown in Experiment 3.0. Values of coarse grain vegetation structure were generally lower in the Experiment 2.0 margins, with a value of 28.0 cm for the TG mix and 20.6 cm for plots sown with the FG mix. This contrasts with 35.6 cm and 30.0 cm for the TG and FG Experiment 3.0 margins

7.4.3 Within crop vegetation

7.4.3.1 Comparison of the effect of TG and no margin

For all variates analysed, except desirable weeds, there was a significant effect of distance from the cultivated edge. All weeds and arable species were both present at much higher cover values immediately adjacent to the cultivated edge (0 m) and there was no difference between weed cover at 2 m and at greater distances from the crop edge (Table 7.14 & Figure 7.7). Similar results were recorded for undesirable species, however there was an interaction between distance and presence of a sown margin, with higher cover of undesirable species immediately adjacent to the cultivated edge where no margin was sown (Figure 7.8). This suggests that a sown margin reduces the impact of undesirable species at the crop edge.

As would be expected, crop cover was lower and bare ground higher at the field edge (Table 7.14). Results suggest that the impact of distance from the cultivated edge on crop cover extended further than for weeds to 2 m.

Table 7.14 Effect of distance from cultivated margin on percentage weed cover (backtransformed means).

	Distance from cultivated edge (m)								
	0	**1**	**2**	**4**	**8**	**16**	**32**	***F***	***P***
df = 6; n = 1176									
All weeds	15.3	1.8	0.8	0.8	0.6	0.3	0.5	92.32	<0.001
Arable species	9.7	1.6	0.8	0.7	0.6	0.3	0.5	55.05	<0.001
Crop	36.7	55.7	59.8	65.4	68.0	69.9	65.0	47.36	<0.001
Bare ground	31.5	28.2	25.4	20.5	17.1	17.2	20.7	18.58	<0.001

Note interaction between patch and sample date (F = 6.23; P = 0.013) and margin and sample date (F = 4.86; P = 0.028) for all weeds but no effect of any of these variables as a main factor.

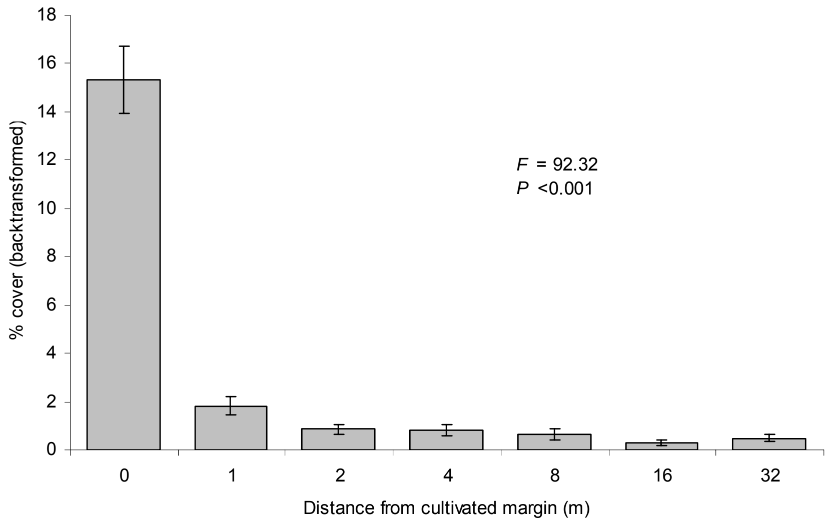

Figure 7.7 Effect of distance from the cultivated edge on all weeds. (Error bars = SEMs).

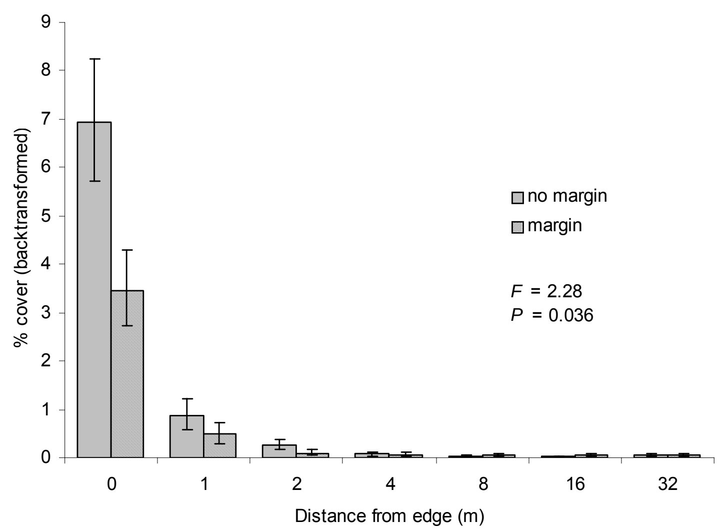

Figure 7.8 Effect of distance from the cultivated edge and presence of a sown margin on cover of undesirable species. (Error bars = SEMs).

There was an effect of sample date for undesirable species and bare ground, with a slight decrease in cover between June and July (Table 7.15). As would be expected, sample date had the opposite effect on crop cover with higher cover recorded in July, although there was an interaction between sample date and presence of patches for arable species and crop cover (Appendix 2, Table 7.A2). None of the samples coincided with undrilled patches, and since weeds are not mobile, this interaction is likely to be a random effect.

Table 7.15 Effect of sample date on percent cover of undesirable species and bare ground (backtransformed means).

	Sample date			
	June	**July**	***F***	***P***
df = 1; n = 1176				
Undesirable species	0.45	0.33	5.07	0.025
Bare ground	24.5	21.0	32.33	<0.001

7.4.3.2 Comparison of the effects of TG and FG margins

Analysis of the effect of margin type on the adjacent weed flora (between 0 and 4 m) indicated that there was a significant effect of distance from the cultivated edge for all variates analysed (Table 7.16 & Figure 7.9) but no effect of margin type on the weed cover. There was a significant effect of sample date for crop and bare ground with greater crop cover and lower bare ground at the second sample date (23.9% in July, cf. 27.5% in June, F=14.68; P<0.001). However, there was an interaction between presence of patch, margin type and sample date for crop cover (Figure 7.10).

Table 7.16. Effect of distance from a sown margin on percent cover of vegetation and bare ground (backtransformed means).

	Distance from cultivated edge					
	0	**1**	**2**	**4**	***F***	***P***
df = 3; n = 672						
All Weeds	17.4	1.3	0.6	0.6	111.93	<0.001
Desirable species	0.90	0.16	0.15	0.20	7.19	<0.001
Undesirable species	3.24	0.37	0.11	0.05	36.45	<0.001
Arable weeds	9.55	1.11	0.57	0.51	70.08	<0.001
Crop	35.2	54.9	61.7	66.3	44.42	<0.001
Bare ground	31.3	29.4	23.5	19.3	14.92	<0.001

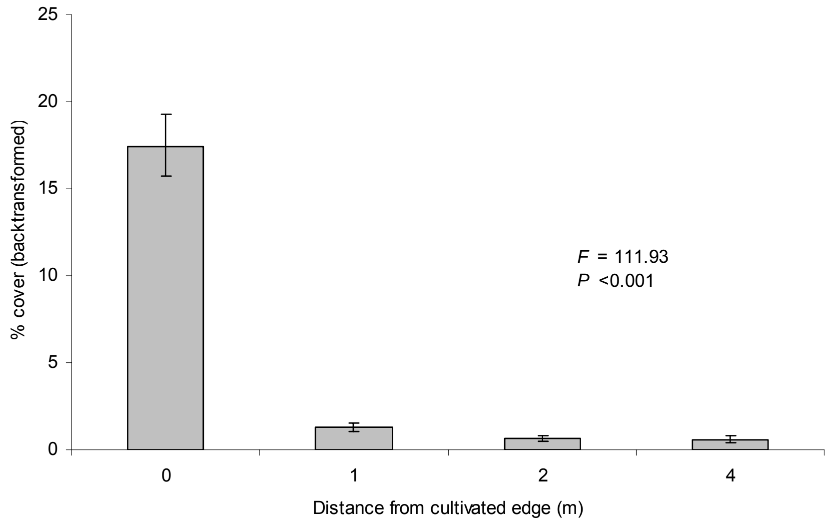

Figure 7.9 Effect of distance from a sown margin on cover of all weeds. (Backtransformed means; error bars = SEMs).

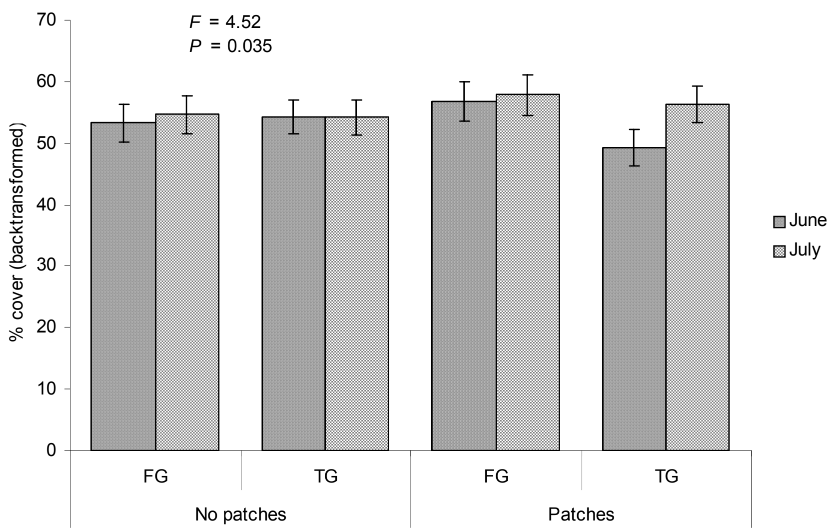

Figure 7.10 Effect of sown margin type, patch presence and sample date on crop cover. (Error bars = SEMs).

7.4.3.3 Comparison of mid field samples

Comparisons of the field centre sample (96 m) associated with the no margin and TG transects, indicated that there was no effect of main factors: margin, patch presence, sample date or year on any of the variates analysed, although for all weeds there was an interaction between patch, margin and sample date ($P = 0.042$; $F = 4.37$).

7.4.3.4 *Effect of sown margin and type of sown mix*

Vegetation structure between 0 and 4 m from the cultivated edge and weed cover in the margin adjacent to the transects (2005 and 2006 only) were analysed across all treatments.

Vegetation structure between 0 and 20 cm from ground level, at 0, 1, 2 and 4 m from the cultivated edge and on all three margin treatments (no margin, TG, FG) was analysed. Only distance from the cultivated edge was significant as a main factor, with less dense vegetation at the crop edge (Figure 7.11) although there was an interaction between patch, presence of margin, margin type and sample date (*P* = 0.022).

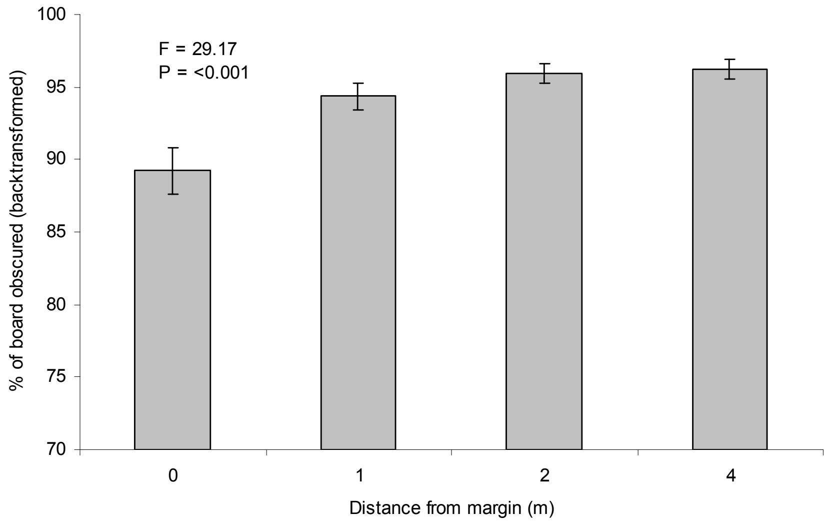

Figure 7.11 Effect of distance from the cultivated margin on crop structure between 0 and 20 cm from ground level. (Error bars = SEMs).

There were no consistent effects of treatments on the margin quadrats across the variates analysed. There was an interaction between presence of patches, presence of margin and sample date for desirable species (see Appendix 2, Table 7.A3), however the presence of patches would not affect the vegetation in the margins so this is likely to be a random effect. There was an interaction between margin type and sample date for arable species (Table 7.17). Cover of undesirable species was higher in unsown margins (Table 7.18) and cover of bare ground decreased between June and July (Table 7.19).

Table 7.17 Effect of sown margin and sample date on percent cover of arable species in the margin adjacent to the crop (backtransformed means).

	No margin	**TG**	**FG**	***F***	***P***
df = 1; n = 168					
June	32.0	16.6	29.1	5.17	0.027
July	37.5	20.7	22.4		

Table 7.18 Effect of margin presence on percent cover of undesirable species in the margin adjacent to the crop (backtransformed means).

	No margin	Margin	*F*	*P*
df = 1; n = 168				
Undesirable species	22.2	13.0	4.31	0.047

Table 7.19 Effect of sample date on percent cover of bare ground in the margin adjacent to the crop (backtransformed means).

	June	July	*F*	*P*
df = 1; n = 168				
Bare ground	31.5	26.7	4.39	0.04

7.4.4 Within crop invertebrates

Due to operational problems, a full complement of sites was not sampled over the three experimental years; sites sampled are summarised in Table 7.20. Two sites were excluded to balance the data sets for analyses, crucially these were sites which also had some changes to the original design. At CH (Lincolnshire) the control field was moved in the second sampling year, at PB (Scotland) no 96 m samples were collected. The three data sets (pitfall, Dvac and sweep samples) were analysed separately and the results are reported by sample collection method; transect analysis and mid-field analyses are also reported separately.

Table 7.20 Within crop invertebrates: Sites sampled

Site	Cluster	2004	2005	2006
BX	CA		✓	✓
GK	CA	✓	✓	
UW	CA	✓		✓
BE	LI	✓		✓
CH	LI		✓	✓
CG	LI		✓	
RA	EA	✓		✓
DH	EA		✓	✓
BM	EA		✓	✓
HF	EA		✓	
PA	SC	✓		
PB	SC		✓	✓
OE	SC			✓
ME	SC	✓	✓	
TF	SC	✓	✓	

7.4.4.1 Ground active invertebrates (pitfall traps)

Transect: 1-32m into the crop

There were no main effects of year (in the site stratum), undrilled patches or margin presence on any of the composite groups. For field staphylinids there was an interaction between patch and margin; in fields with no patches the presence of a margin led to an increase in abundance, in contrast, in fields with patches the presence of a margin appeared to reduce abundance (Figure 7.12). However, this group was comprised of only of *Philonthus cognatus* and abundance was very low, consequently this group is of minimal importance in terms of providing a food resource for birds.

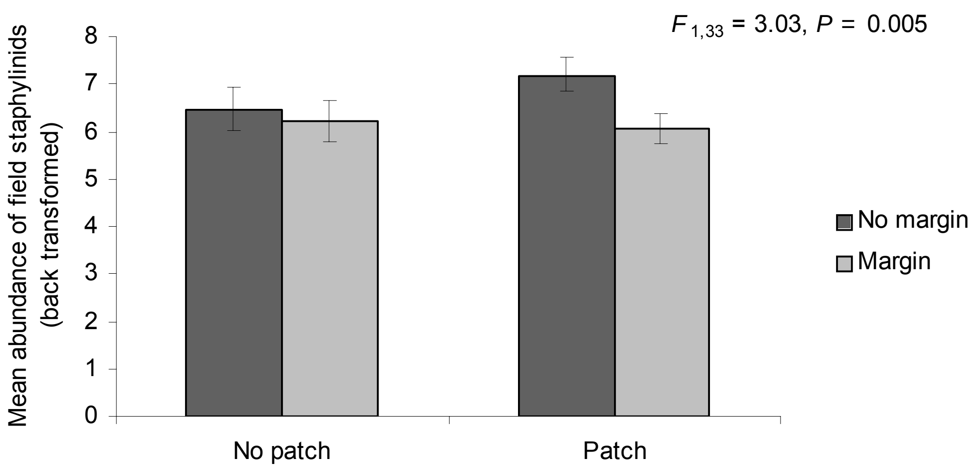

Figure 7.12 Interactive effect of undrilled patch and margin presence on field staphylinids.

The seed mix of the margin affected only one composite group, the seed eating carabids; there was a greater abundance along the transect leading from the fine grass mix (Figure 7.13). However, overall abundance of the group was again low.

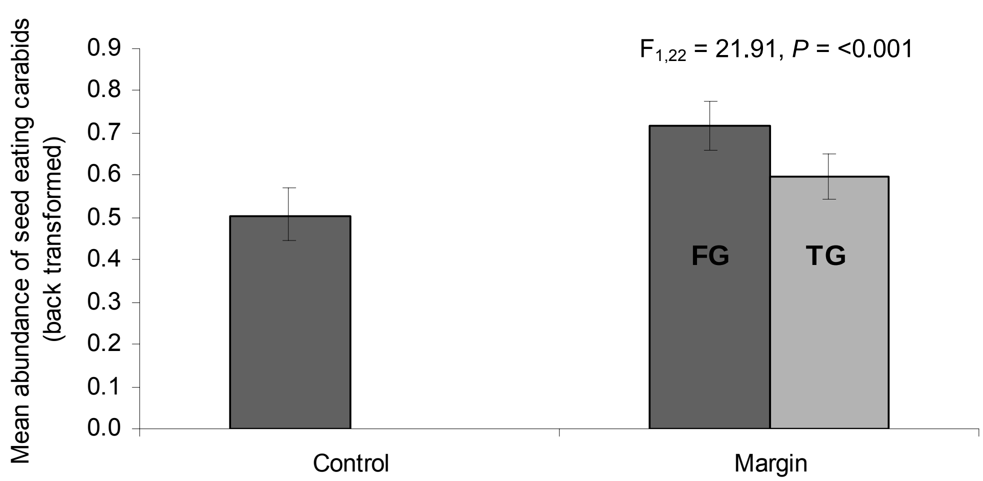

Figure 7.13 Interactive effect of seed mix on abundance of seed eating carabids.

Most composite groups (with the exception of boundary carabids) varied with position along the transect, although this was frequently confounded by an interaction with margin presence, sample date or both. The seed eating carabids and boundary staphylinids were affected by position, independently of other factors. Fewer seed eating carabids were collected away from the edge (Figure 7.14), whereas the abundance of boundary staphylinids increased with distance in to the field (Figure 7.15).

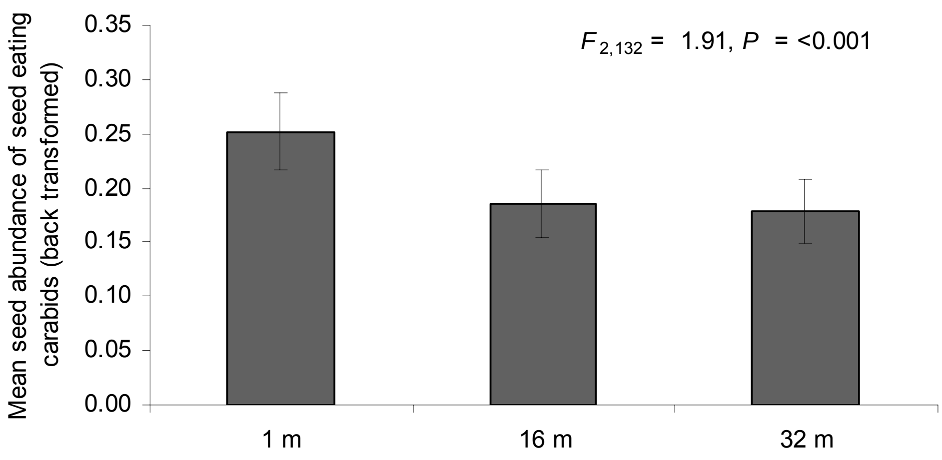

Figure 7.14 Effect of distance from the crop edge on seed eating carabids.

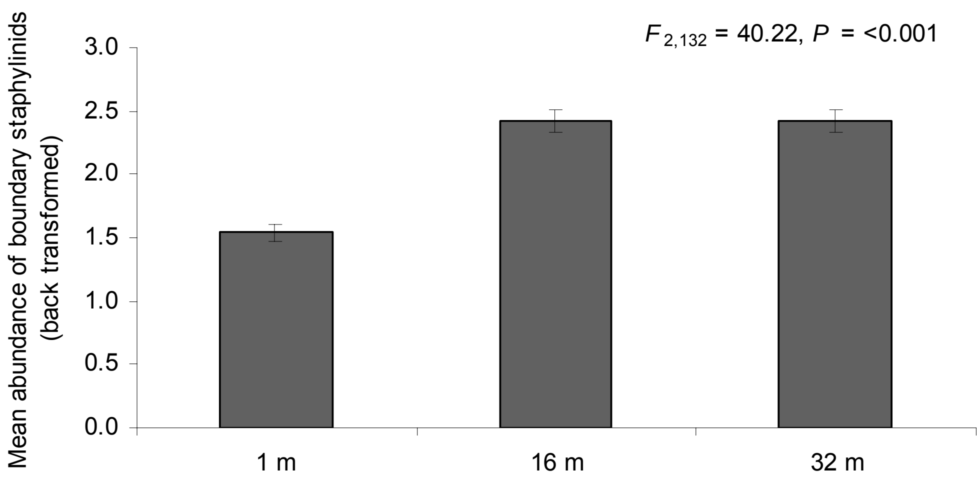

Figure 7.15 Effect of distance from the crop edge on boundary staphylinids.

For total invertebrates (Figure 7.16) and field staphylinids (Figure 7.17) there was an interaction between margin presence and position. In both cases, in fields with no margins, the abundance of invertebrates increased away from the edge, however, in fields with margins, there was no difference in abundance between different positions along the transect.

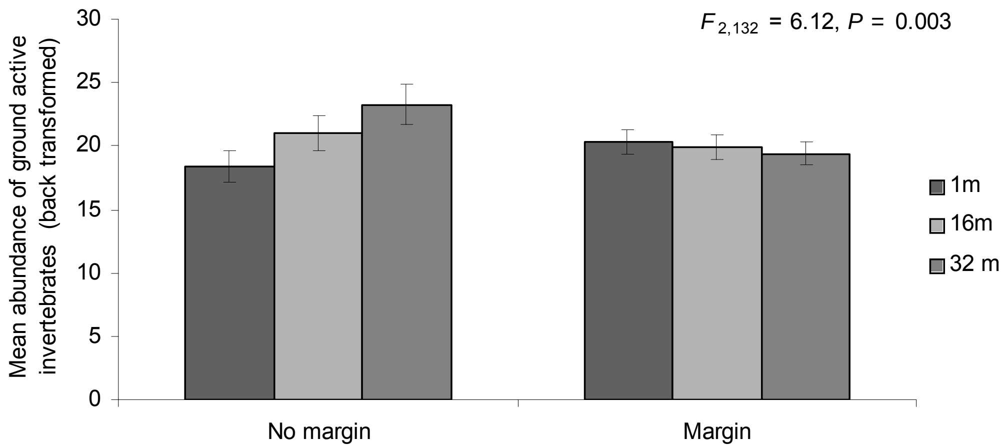

Figure 7.16 Interactive effect of margin and distance from the crop edge on total invertebrates.

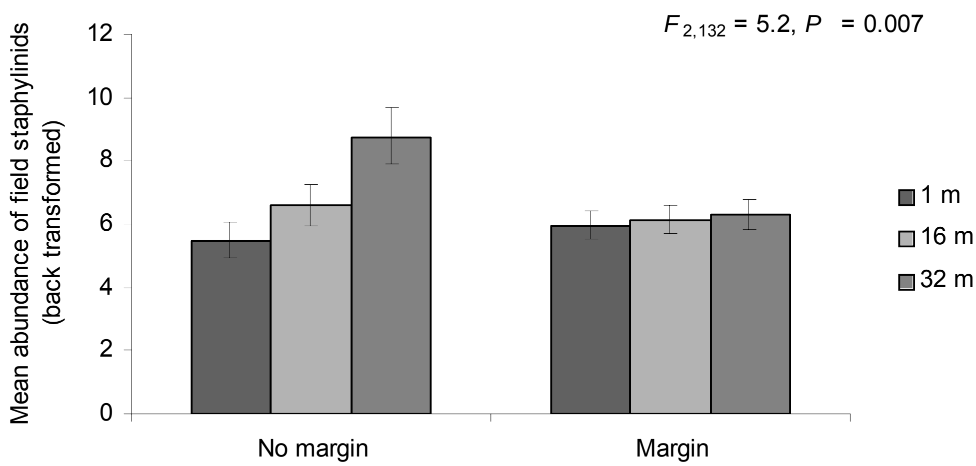

Figure 7.17 Interactive effect of margin and distance from crop edge on field staphylinids.

Carabids (both boundary and field) and predators responded to transect position but the results were further complicated by interactions with both margin presence and sampling date (details in summary tables, Appendix 3). Further analysis of this relationship has not been pursued.

There was a significant difference in the abundance of total invertebrates, boundary and field staphylinids between sampling dates, independently of all other factors. Total invertebrates (Figure 7.18) and boundary staphylinid abundance (Figure 7.19) were greater in early June, but field staphylinid (Figure 7.20) abundance was higher in July.

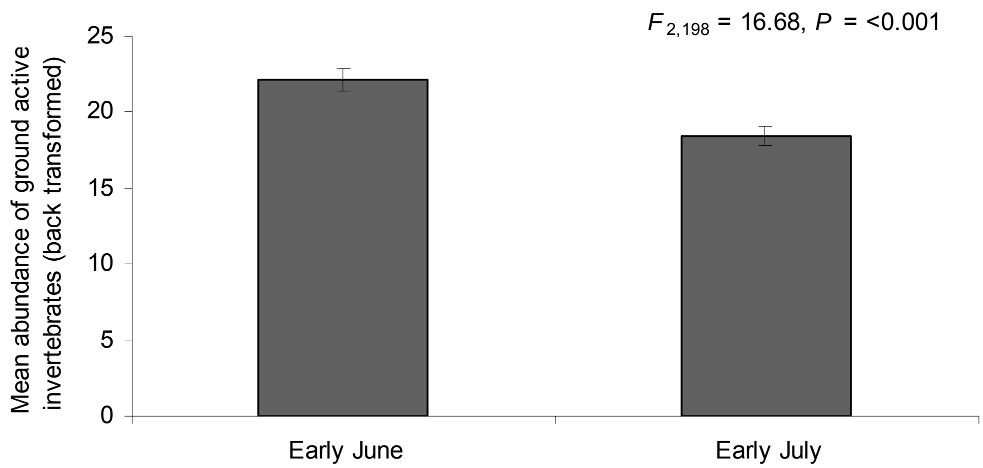

Figure 7.18 Effect of sampling period on total invertebrates.

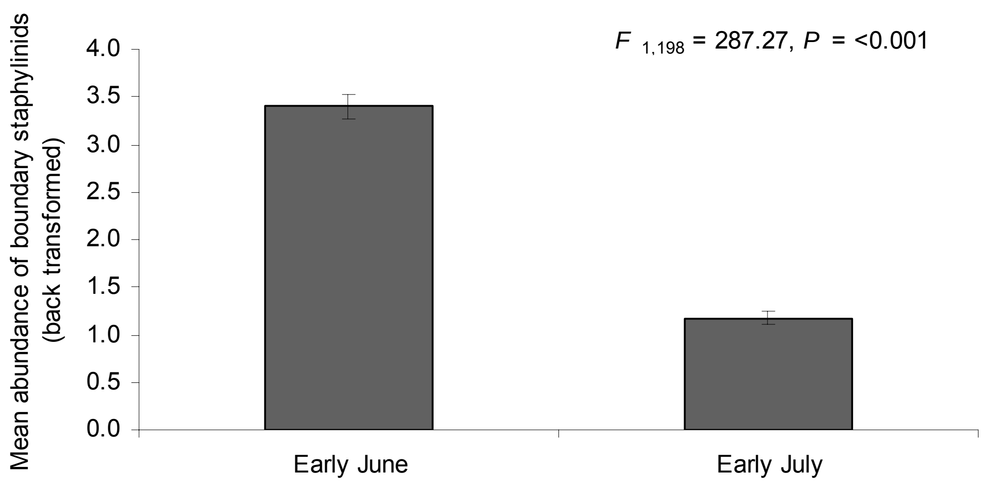

Figure 7.19 Effect of sampling period on boundary staphylinids.

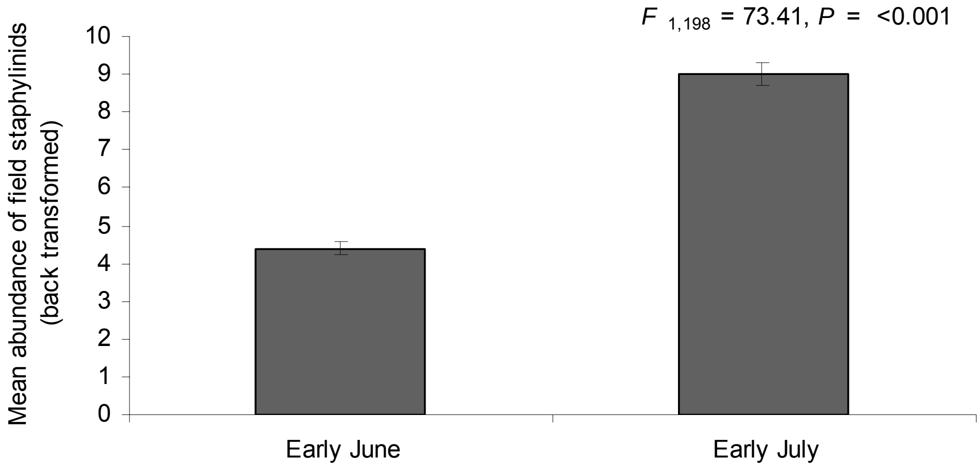

Figure 7.20 Effect of sampling period on field staphylinids.

Mid-field samples (96 m)

There were no significant main effects of year (site stratum), undrilled patch or margin. However there was a significant interaction between undrilled patch and margin presence for three groups: seed eating carabids (Figure 7.21); boundary carabids (Figure 7.22) and field staphylinids (Figure 7.23). In fields without patches there was a greater abundance of seed eating carabids and of boundary carabids where a margin was present. In contrast, in fields with patches there was a greater abundance of invertebrates where there was no margin. The trend was different for the field staphylinids. In fields with patches there were fewer invertebrates where margins were present.

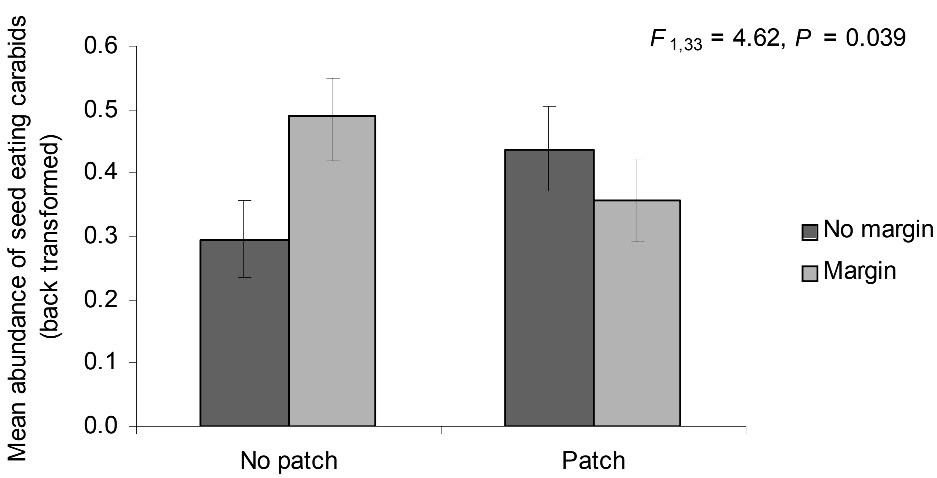

Figure 7.21 Interactive effect of margin and patch on seed eating carabids.

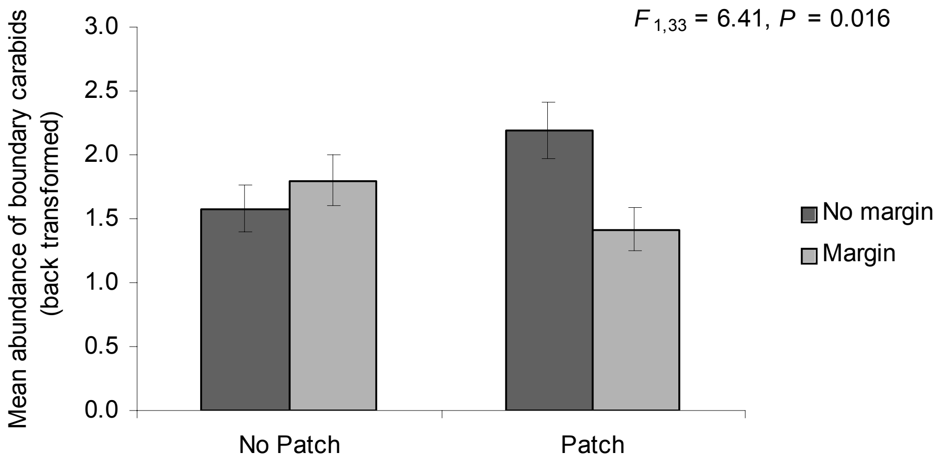

Figure 7.22 Interactive effect of margin and patch on boundary carabids.

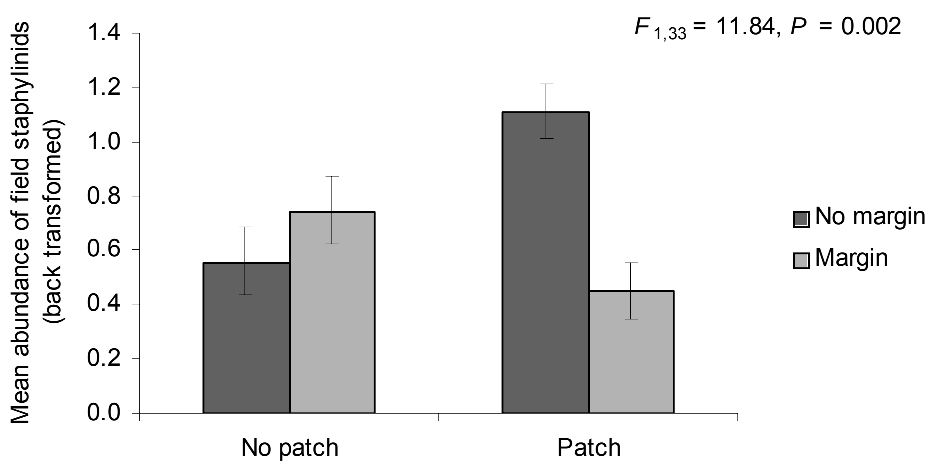

Figure 7.23 Interactive effect of margin and patch on field staphylinids.

7.4.4.2 Crop dwelling invertebrates (Dvac suction samples)

Transect: 1-32 m into the crop

There were no significant main effects of year (in the site stratum), undrilled patch or margin presence nor was there any interaction between the two experimental treatments. There was a three-way interaction between undrilled patches, margin and margin type for the 4FI (Figure 7.24). Where there were no undrilled patches, fields with fine grass margins had a higher 4FI than those fields with tussocky grass margins. The reverse was true in fields when patches were present.

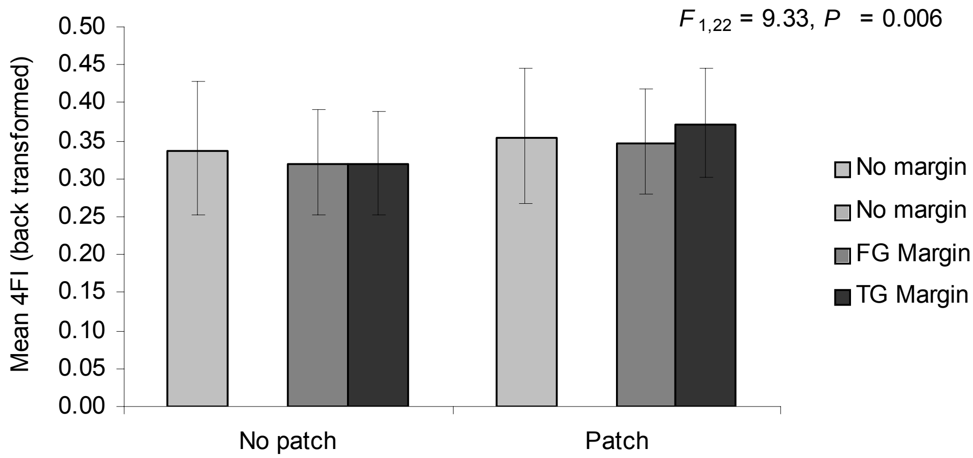

Figure 7.24 Three-way interaction (Patch*margin*margin type) effect on 4FI (4 food index, suction sample).

The abundance of invertebrates sampled from different positions in the field did not vary for all groups and had no independent effect. In all cases, where there was an effect of position, there was also an interaction with another factor. In the case of 4FI, this interaction was with the presence of a margin. In the absence of a margin the 4FI was highest at the field edge, lowest at 16m and intermediate at 32 m (Figure 7.25). In fields with margins, 4FI was highest at the field edge but fell with distance from the margin. Overall level of 4FI was low.

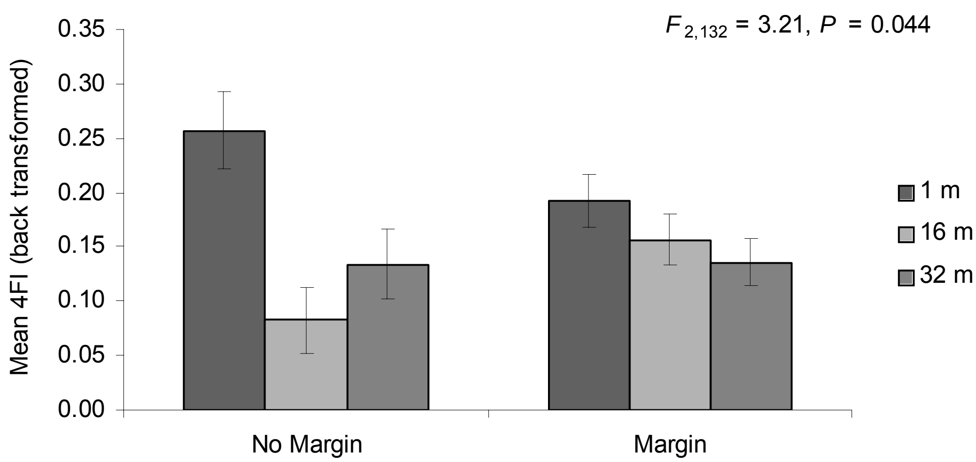

Figure 7.25 Interactive effect of margin and distance on 4FI ((4 food index, suction sample)

In the cases of SFI (Figure 7.26), YHI (Figure 7.27) and total crop active invertebrates (Figure 7.28) there was an interaction between the presence of margin and sampling date. The trend is the same in all cases; they were lower in early June and highest at the edge of the crop. In early July, they were highest at 16 m.

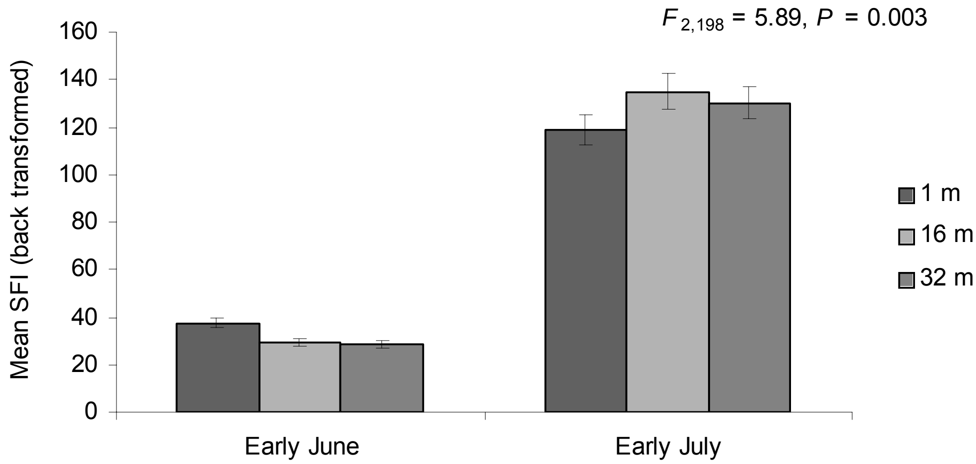

Figure 7.26 Interactive effect of sample date and position on SFI (Skylark food index, suction sample).

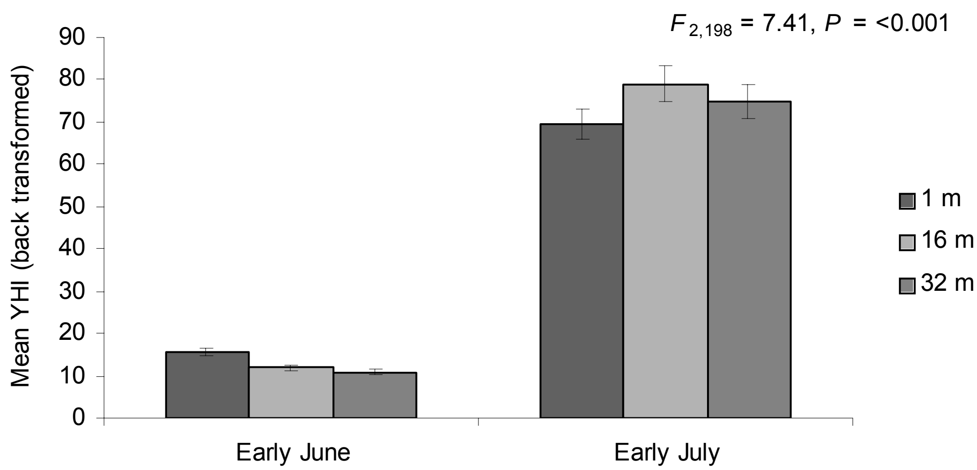

Figure 7.27 Interactive effect of sample date and position on YHI (Yellowhammer index, suction sample).

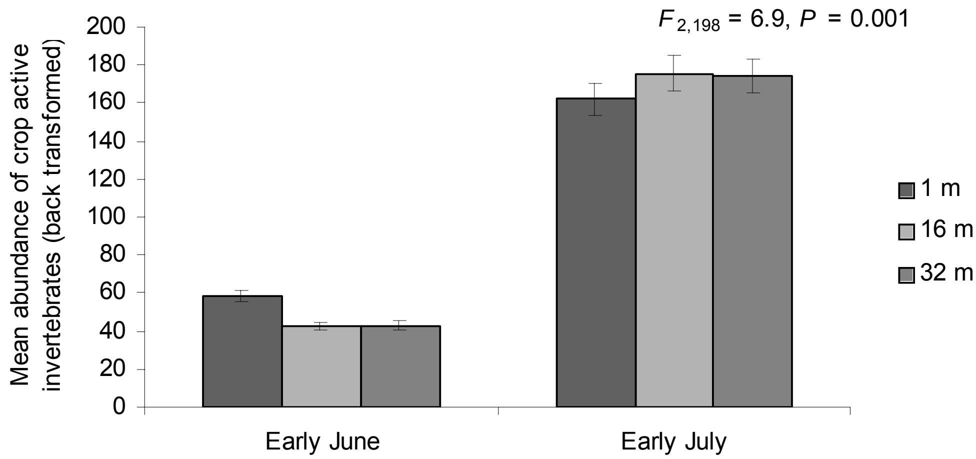

Figure 7.28 Interactive effect of sample date and position on total crop active invertebrates (suction sample).

Mid-field samples (96 m)

The SFI (Figure 7.29) and total crop active invertebrate abundance declined over the three years of study (Figure 7.30).

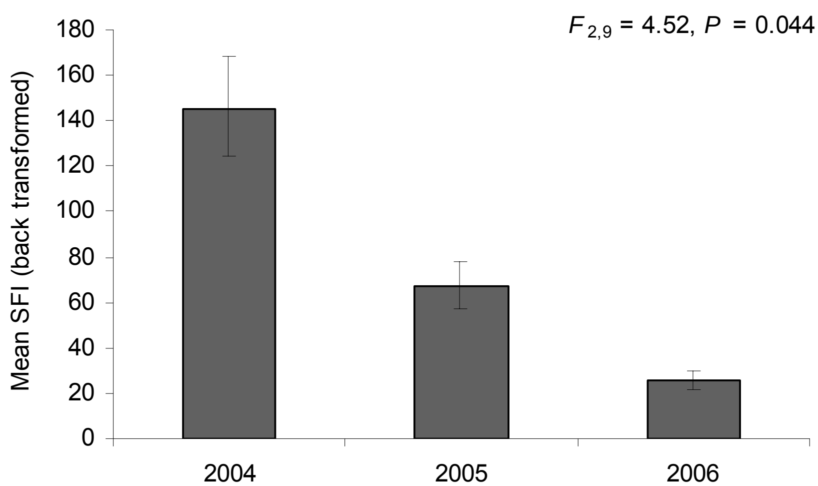

Figure 7.29 Difference in SFI (skylark food index) between years at 96 m (suction sample).

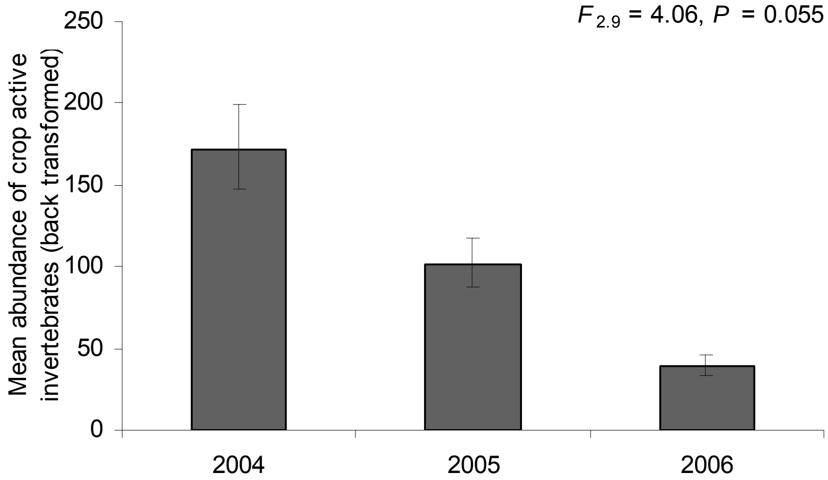

Figure 7.30 Difference in abundance of crop active invertebrates between years at 96 m (suction sample).

There were no main effects of undrilled patches or margin presence, although there was an interaction between patch and margin for SFI (Figure 7.31), YHI (Figure 7.32) and total crop active invertebrates (Figure 7.33). The same trends occurred for all three groups; in fields without patches the presence of a margin leads to an increase in the abundance of these groups, however, the combination of patches and margins led to a reduction of these groups.

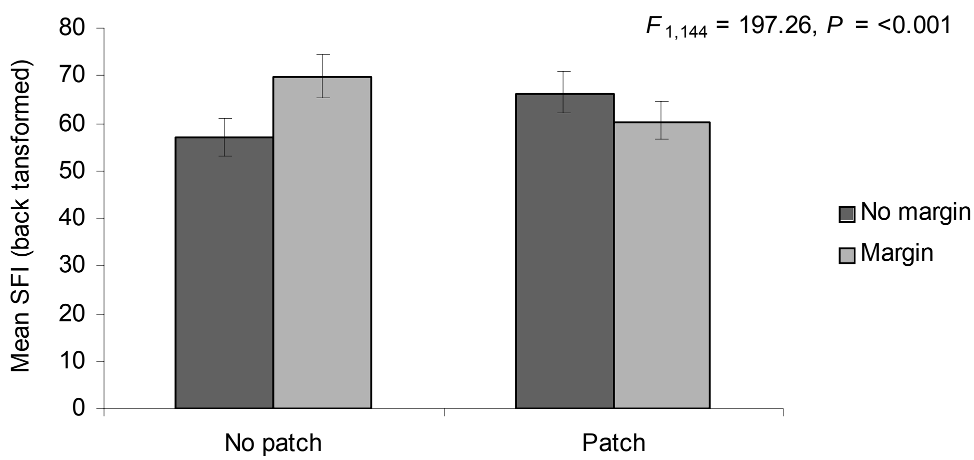

Figure 7.31 Interactive effect of patch and margin at 96 m on SFI (Skylark food index) (suction sample).

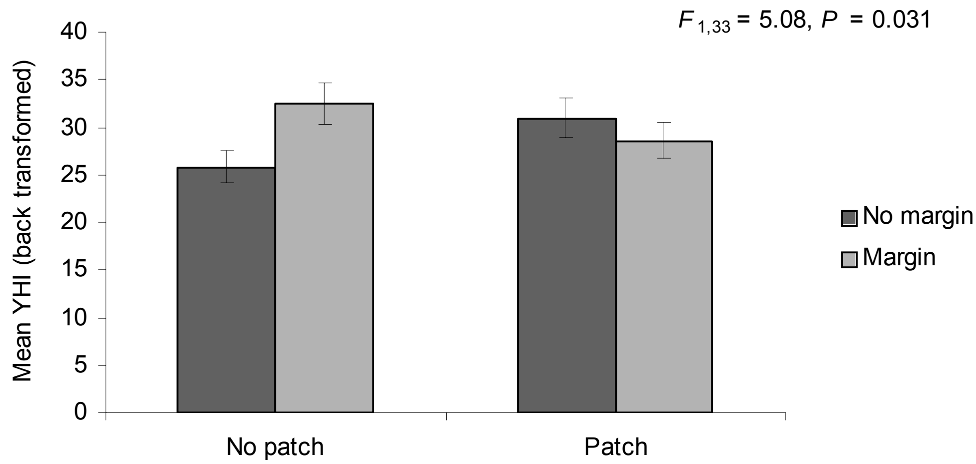

Figure 7.32 Interactive effect of patch and margin at 96 m on YHI (Yellowhammer index) (suction sample).

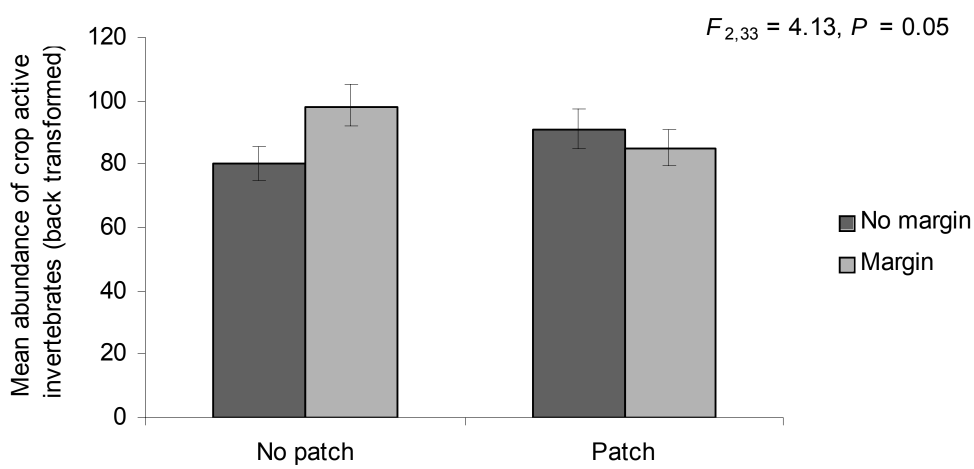

Figure 7.33 Interactive effect of patch and margin at 96 m on total crop active invertebrates (suction sample).

CFI (Figure 7.34), SFI ($F_{1,44}$ = 197.6, P =<0.001), YHI (Figure 7.35) and total crop active invertebrates ($F_{1,44}$ = 206.59, P = <0.001) all increased between early June and early July, indicating greater food resources for farmland birds later in the season.

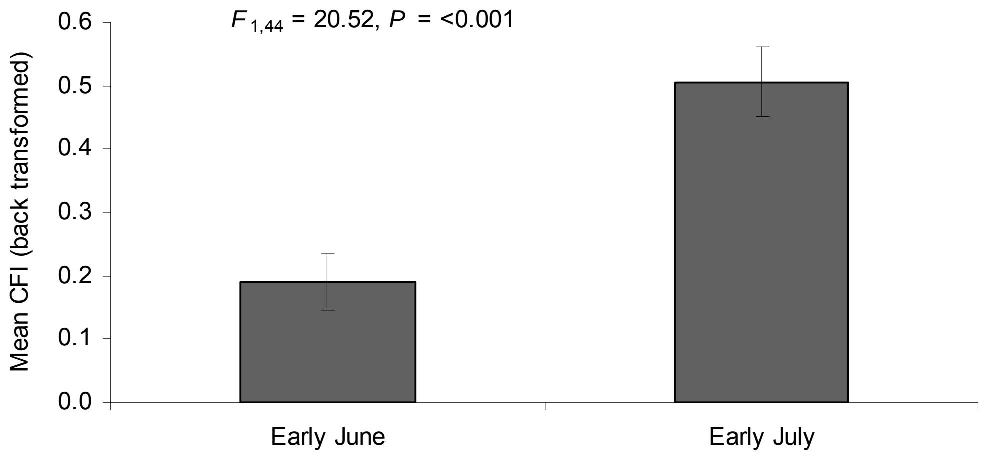

Figure 7.34 The effect of sample date on the CFI (Chick food index), (suction sample).

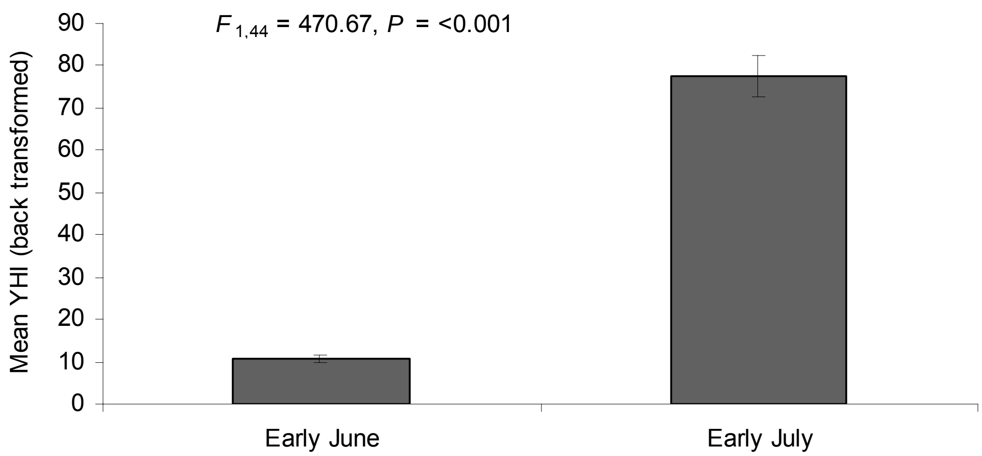

Figure 7.35 The effect of sample date on the YHI (Yellowhammer index) (suction sample).

Differences in this stratum were restricted to sampling date for all groups except 4FI where there was a three-way interaction between patch, margin and sampling date. Although it is important to be conservative when interpreting such interactions it is interesting to note that in this case the treatment supporting the greatest number of invertebrates was that of patch and margin combined when sampled in July (Figure 7.36).

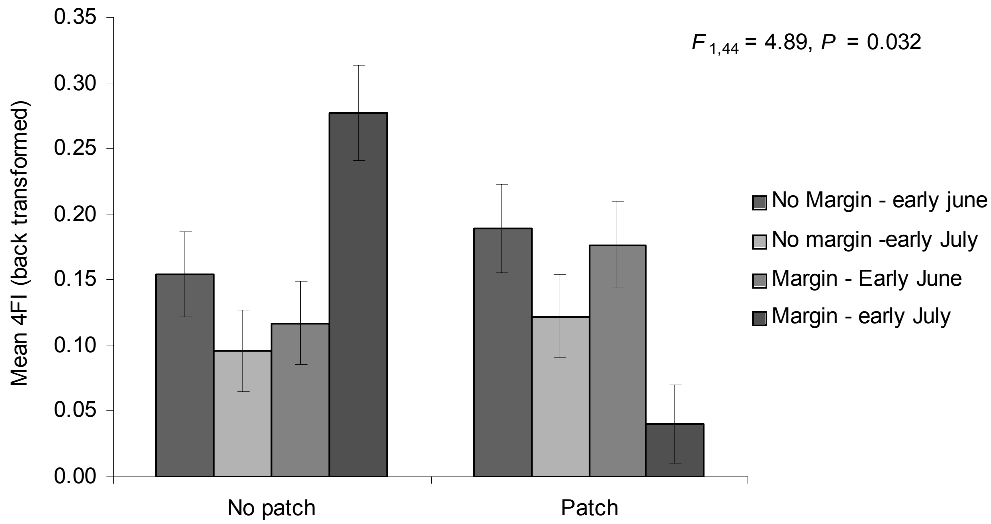

Figure 7.36 4FI (4 food index) (suction sample): Three way interaction (patch*margin*sample date)

7.4.4.3 Crop dwelling invertebrates (sweep net samples)

<u>Transect: 1-32 m into the crop</u>

Fewer invertebrates were captured with sweep nets than were captured with the Dvac suction sampler. There were no main effects or interactions between the experimental treatments. The abundance of all groups varied according to the sampling location along transects, however, with the exception of 4FI there was an interaction between position and margin presence. 4FI was highest at the crop edge and declined with distance into the crop (Figure 7.37).

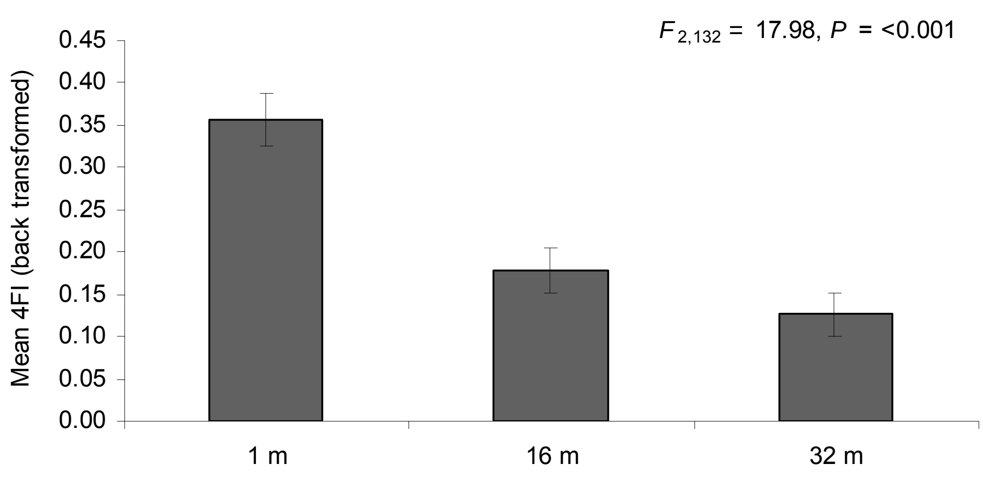

Figure 7.37 The effect of position on 4FI (4 food index) (sweep net sample).

For other groups, CFI (Figure 7.38), SFI ($F_{2,132}$, = 5.05, P = <0.001), YHI ($F_{2,132}$ = 4.61, P =<0.001) and total invertebrates (Figure 7.39) there was a similar trend in that invertebrate abundance declined away from the field edge. However, for the CFI where there was a margin present their abundance was lower at 1 m and at 16 m compared to where there was no margin. For the YHI they were only lower at 1 m whereas the total invertebrates were higher at 16 m and 32 m when a margin was present.

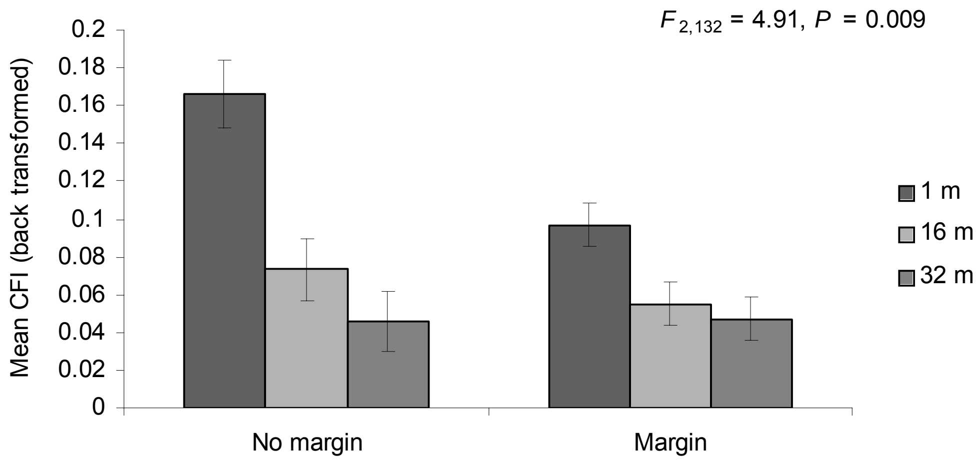

Figure 7.38 Interactive effect of margin and distance on CFI (Chick food index) (sweep net sample).

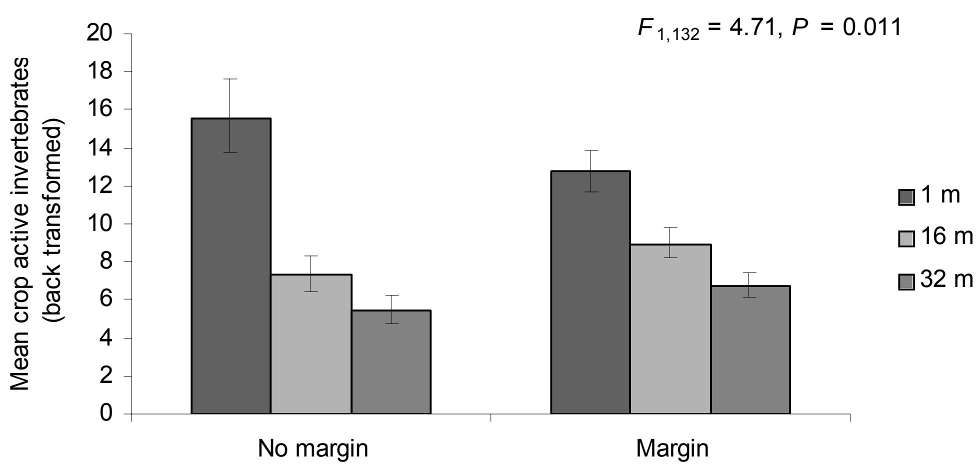

Figure 7.39 Interactive effect of margin and distance on total crop active invertebrates (sweep net sample).

Mid-field samples (96 m)

The only significant difference was between years (in the site stratum). CFI ($F_{2,9}$ = 4.93, *P* =0.036), SFI (Figure 7.40), YHI (Figure 7.41) all declined sharply over the three years of the experiment.

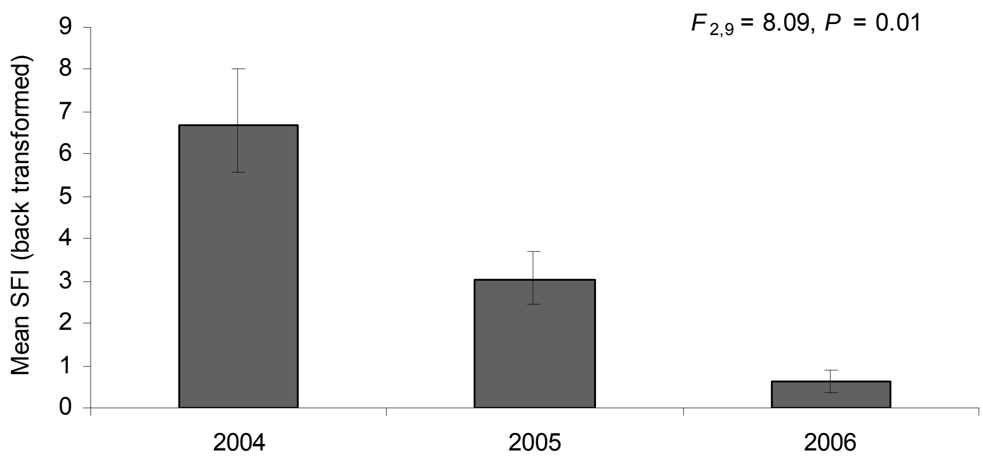

Figure 7.40 Effect of year on SFI (Skylark food index) (sweep net sample).

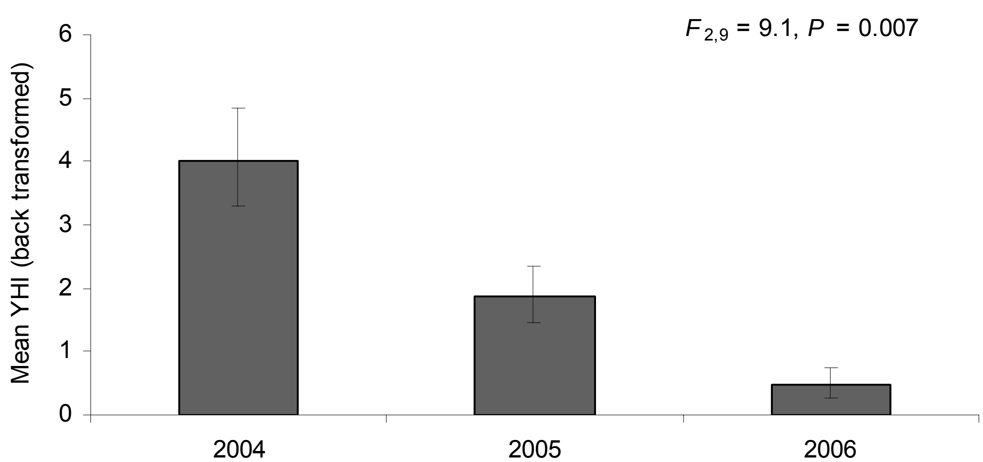

Figure 7.41 Effect of year on YHI (Yellowhammer index) (sweep net sample).

7.4.5 Birds

7.4.5.1 Bird data from mapping methods

The data in Table 7.21 and Table 7.22 show that there was a statistically significant effect of ‘treatment’ on the breeding distribution and densities of all species/species groups (showing also the affects for year, boundary characteristics and adjacent field types). In Table 7.22 and Figure 7.42 and Figure 7.43 (a-e) the data include combined field and boundary counts of bird registrations. In Figure 7.43 (f & g), the data include field counts only, with sufficient data available for field species (skylark and yellow wagtail) and boundary species groups (insectivores and buntings) only. The model structure for these analyses is given, with selected effects only (Table 7.21).

Territory distribution: T2 was always associated with the highest breeding territory densities (Table 7.21). In addition, for all species and species groups, except skylark and yellow wagtail, T3 was associated with the second highest territory densities. Together these results imply that birds were responding to treatments containing field margins, but especially to T2, which combined field margins with UP. Apart from skylark and yellow wagtail, T1 and T4 were associated with relatively low breeding densities (Figure 7.42).

Bird densities: For each species group/model combination, the full content of predictor variables are summarised in Table 7.23. The data in Table 7.22, with selected model variables, show that there was a statistically significant effect of 'treatment' on the distribution of bird densities in wheat crops, for all species/species groups. As with breeding territories (Table 7.21), there were consistently higher relative densities of birds on T2 and consistently low relative densities on T1 (except for the 'control' group, 'woodland'). Usually, T3 was associated with the second highest territory densities, but this varied with the combination of species versus the number of experimental sites analysed. As with breeding territories, the results indicate that birds were responding to the treatment containing both field margins and UP. T2 also consistently supported the highest densities of birds, on the core 14 field sites, where T3 was again second or equal second (Table 7.22).

Although the factor 'year' was a significant effect in all models, with significant annual variation in bird numbers on the experimental sites, there was no consistent direction of change across species groups in the use of treatments between years. There were small relative seasonal increases in the use of T2 and T3 (both with field margins) for buntings, but overall, very few significant interactions between treatments and other variables were detected. Exceptions, for probing species, gleaning species and BAP species for the full 26 sites suggest a relative seasonal increase towards late summer, in the number of birds using T2 in particular. There was also a main effect of 'season' that indicated a significant increase in buntings using treatments T2 and T3 towards late summer.

<u>Species and species group accounts</u>

Skylark: Significant overall effects were detected for treatments on both skylark territories and densities in wheat crops (Table 7.21 and Table 7.22). In both cases, the highest concentrations were on T2 and to a lesser extent on T4, across all sites and on the core 14. Skylark territories were 1.9 times higher on T2 than on the control treatment (T1) and registration densities 1.6 times higher on T2 than T1.They imply an effect of UP but especially in association with field margins. There were significant year effect for territories and registrations but not in the same direction and generally differences between years showed no overall direction of response. There was no significant effect of season and no significant interaction between season and treatment, but there were expected boundary effects (Table 7.23).

Yellow wagtail: There were no significant effects of treatments on yellow wagtail territories (Table 7.21), but the direction of the effect implied densities over five times higher on T2 than the next most closely associated treatment (T4). These results imply an effect of UP, especially in association with field margins. There were also significant effects of treatments on bird densities (Table 7.22), although the direction of effects was different to territories in that the margin treatments, T2 and T3, supported the highest densities of birds (Table 7.22). The densities on T2 and T3 were 2.5 times higher than on treatments T4 or T1 (Figure 7.43a), implying positive effect of margins. There were significant year effects for registration densities, a significant effect of season but no significant interaction between season and treatment. There were significant effects of adjacent crops on their distribution in the treatment wheat fields (Table 7.23).

Insectivores: There were strong overall significant effects of treatment on the distribution of breeding territories (Table 7.21) and registration densities (Table 7.22). The highest densities in each case were associated with T2 in particular, followed by T3. Territory densities were 1.3 times higher in T2 than in T1, while densities (crop and boundary counts) in T2 were precisely 2 times higher than T1. For crop-only registration densities, treatments T2 and T3 were again associated with the highest densities. T3 was more prominent than with the crop & boundary counts. The results imply an effect particularly of field margins influencing the distribution of insectivorous species in the crop itself. Other significant factors were year (no consistent directional effect) and expected positive effects of boundary characteristics. There was no significant interaction between treatments and seasonal effects.

Finches & tree sparrow: There were significant effects of treatments on territories and registration densities, with birds being particularly associated with T2 and to a lesser extent T3. The pattern of distribution across treatments was similar to insectivorous species, but showed an even stronger affiliation to field boundaries (although the densities of birds were much lower in the present group: Figure 7.43b). Very few birds were recorded in the crops themselves and so no crop-only analysis was possible. There was also only a weak effect of year and no significant effect of season but, expectedly, significant boundary effects (Table 7.23).

Buntings: There was no significant effect of treatments on bunting territories but a significant effect on registration densities, with birds being particularly associated with T2. The pattern regarding the other treatments was equivocal. A large enough sample of buntings was recorded in wheat crops to enable an analysis (Figure 7.43g) showing a stronger association with T2 and T3 – both with field margins. Among the buntings, yellowhammer, as one of the few individual species that was numerous enough analyse independently also showed a significant difference in the density distribution between treatments, again with densities highest on margin treatments T2 and T3 (Table 7.22).

Woodland species: There was a significant effect of treatment on this group, across all 26 sites, but the pattern was in contrast to all the other species or species groups analysed. Highest densities were recorded from treatments T4 and T1 with additional year, season and boundary effects (Table 7.22, Table 7.23). This group was considered least likely to respond to treatment effects and so the contrasting response, compared to other species, indicates that the response by other target species was unlikely to be a random effect.

Probers: There was a significant effect of treatment on the density distribution of registrations for this group, favouring T2 then T3 and T4 over T1 (Figure 7.43c). The density of birds in T2 was 6.4 times higher than on the control. For this group there was significant interaction effect of treatment and season showing higher densities of birds on treatments T2 and T3 in late summer (thus a relative increase on these two treatments – suggesting added benefits of the margin treatments as crops mature) and in late summer when soil invertebrates are more difficult to access..

Gleaners: There was a significant effect of treatment on the density distribution of registration, with highest densities being on T2, followed by T4. The density of birds recorded on T2 was 5.1 times higher than on T1 (Figure 7.43c).

BAP species: This species group comprises a broad mix of boundary-based passerines, but also turtle dove, grey partridge and skylark that will range further into fields. There was a particularly strong response to T2 for bird densities, with little distinction between the other three treatments T1, T4 and T4 (Table 7.22). Densities on T2 were 2.8 times higher than on T1. There was also a small but significant relative increase in the proportion of birds using treatment T2 in contrast to T1 and T3 in later summer (Table 7.22).

FBI passerine species: The population trends of these species contribute to the Farmland Bird Index and as a group include a broad range of insectivorous and seed-eating passerine species. They, include three cardueline species but not song thrush or, in this analysis, non-passerines (in contrast to the BAP species above). On the core 14 sites and on all sites, the group showed a significant response to treatments with highest densities of registration on T2 and lowest densities on T1 (Table 7.22). The difference between T2 and T1 was 1.8 times higher in T2. On the core 14 sites, there was also a small but significant relative increase in the proportion of birds using treatment T2 in later summer (Table 7.22).

For the winter (Table 7.25), in three models, 'winter period' and 'hedges' were consistent significant predictors of bird numbers in margins. There were always more birds present in November than in January and more birds on margins with an adjacent hedgerow. The presence adjacent stubbles only significantly affected (increased) seed eating passerines (SEP) numbers on margins. In the ALL-species and GRAN models, 'year' and 'management' were significant, with twice as many birds being present: (a) on cut margins than on uncut margins and (b) in the second winter compared to the first. 'Seed-mix' was the only significant predictor of bird counts, but its interaction 'year' was significant for SEPs – with numbers increasing more in the fine grass mix than in the tussock grass mix between winters. Significant interactions included: (a) 'year and period' (where ALL-species and SEPs retained a greater percentage of the November counts into January during 2005/06 than during 2004/05), and, (b) 'management and period' (where the ALL-species group retained a greater percentage of the November counts into January on the cut treatment). For SEPs, January counts on cut treatments almost doubled, while those on uncut margins were just 6% of the November counts.

Table 7.21 Bird territories on core 14 sites (except yellow wagtail). GLMM analyses in relation to experimental treatments with Poisson error terms, log (area) offset and random effects for site and siteXfield. This table shows fixed effects, model structure and content. Bird species groups are defined in Appendix 1. The direction of a fixed effect is shown as positive (+) or negative (-), or for 'year' and 'treatment', by the arrangement of parameter values. N/e = variable not included in the model. Probabilities (*P*) are: **P* ≤ 0.05, ***P* ≤ 0.001, ****P* ≤ 0.0001, ns = not significant. The dispersion factor (χ^2/df.) shows an approximation to Poisson, ideally approaching '1'.

Species/ Group	**Skylark**		**Yellow wagtail (8 sites of occurrence)**		**Insectivores**		**Finches & tree sparrow**		**Buntings**		**FBI**		**BAP**		**Yellow wagtail (5 breeding sites)**	
N (territories)	92		41		1002		587		206		840		477		22	
Dispersion (χ^2/df.)	0.82		0.57		1.43		1.5		1.11		1.46		0.94		0.48	
Predictor variables:	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**
Year	06<04<05	*	04<05<06	ns	05<06<04	**	06<05<04	***	06<05=04	ns	04<05<06	ns	06<05<04	***	06<05<<04	***
Treatment	1=3=4<<2	*	1<3<4<<2	ns	1=4<<3<2	ns	4=1<3<2	***	4=<1<<3<2	**	1<3<4<<2	ns	4=<1<3<2	***	1=3=4<2	*
Boundary type	-	*	+	***	N/e		-	*	+	***	+	***	+	*	+	***
Boundary length	N/e		N/e		-	ns	+	*	+	ns	N/e		N/e	**	N/e	
Boundary width	N/e		N/e		-	ns	N/e		N/e	***	N/e		N/e	***	N/e	
Boundary height	N/e		N/e		N/e		N/e		N/e	***	N/e		N/e	***	N/e	
% adjacent gr	+	ns	-	ns	N/e		-	ns	+	ns	-	ns	+	ns	N/e	
% adjacent sc	+	*		ns	-	ns	-	*	+	ns	-	ns	-	*	+	ns
% adjacent osr	+	*	-	ns	+	ns	+	ns	+	ns	-	ns	-	ns	+	ns
% adjacent wc	+	*	-	ns	-	ns	-	ns	+	ns	-	ns	-	ns	+	ns

Table 7.22 **Bird registrations (densities) –** Model 1: all 26 sites included, except for yellow wagtail); Model 2: core 14 sites (except yellow wagtail). GLMM analyses of bird territories in and around winter wheat in relation to experimental treatments. Bird species groups are defined in Appendix 1. This table shows a relevant selection of fixed effects and interactions (see Table 7.23 for complete model content and effects). See Table 7.21 for information on model structure and keys to the direction of fixed effects, significance and the dispersion factor.

Model 1 – all 26 sites

Species/Group	**Skylark**		**Insectivores**		**Finches & tree sparrow**		**Buntings**	
N (per visit)	224		780		590		415	
Dispersion (χ^2/df.)	1.10		2.64		3.26		1.64	
Predictor variables	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**
Year	04<05< 06	***	05<06<04	***	05<06< 04	*	04<05< 06	**
Season	Early=late	ns	Early<late	ns	Early<late	ns	Early=late	ns
Treatment	1<3=<4<2	*	1<<4<3<<2	***	1<<4<3<2	***	1<<4=3<<2	***
Treatment X Season		ns		ns		ns		ns

Model 2 – core 14 sites

Species/Group	**Skylark**		**Insectivores**		**Finches & tree sparrow**		**Buntings**	
N (per visit)	141		376		304		236	
Dispersion (χ^2/df.)	1.03		2.29		2.46		1.67	
Predictor variables	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**
Year	04<05= 06	***	05<04< 06	***	04=05= 06	ns	04<05= 06	***
Season	Early=late	ns	Early<late	ns	Early=< late	ns	Early=late	ns
Treatment	1=<3<4<<2	**	4<3=1<2	**	4<1=<3<2	***	4<3=1<<2	***
Treatment X Season		ns		ns		ns		ns

Model 1 (continued) – all 26 sites (similar effects on core 14 for yellowhammer).								
Species/Group	**Yellow wagtail (core 8 sites of occurrence)**		**Yellowhammer**		**Woodland species**		**Probers**	
N (per visit)	39		348		356		623	
Dispersion (χ^2/df.)	3.62		1.72		3.2		4.55	
Predictor variables	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**	**Effect**	**P**
Year	04<05<06	***	05<06<04	*		***	05<04<06	*
Season	Early<late	*	Early=<late	***		***	Early=<late	*/ ns
Treatment	1<4<2=<3	**	4<1<<3<2	***	2<3<1<4	***	1<<4<3<2	***
Treatment X Season	No effect	ns	Margin relative densities on T2 by June/July	ns	No effect		Increase on T2 & T3 by June/July	***

Model 1 (continued) - all 26 sites.						
Species/ Group	**Gleaners**		**FBI species**		**BAP species**	
N (per visit)	674		875		446	
Dispersion (χ^2/df.)	3.14		2.11		2.61	
Predictor variables	**Effect**	**P**	**Effect**	**P**		**P**
Year	05<06< 04	***	04<05=<06	***	04<06=<05	*
Season	Early< late	***	Early<late	**	Early=late	ns
Treatment	1<4<3<2	***	1<3=4<<2	**	1<3=<4<<2	**
Treatment X Season	Relative incr. on T2 by June/ July	***	Small % increase on T2 by June/July	ns	Decrease on T1 and T3, increase on T2 by June/July	**
Model 2 (continued). Core 14 sites only.						
N						
Dispersion (χ^2/df.)			2.72		2.61	
Predictor variables			Effect	P	Effect	P
Year			04<05<06	***	04<05<06	***
Season			Early<late	**	Early=late	ns
Treatment			4=<3=<1<<2		1<3=<4<2	***

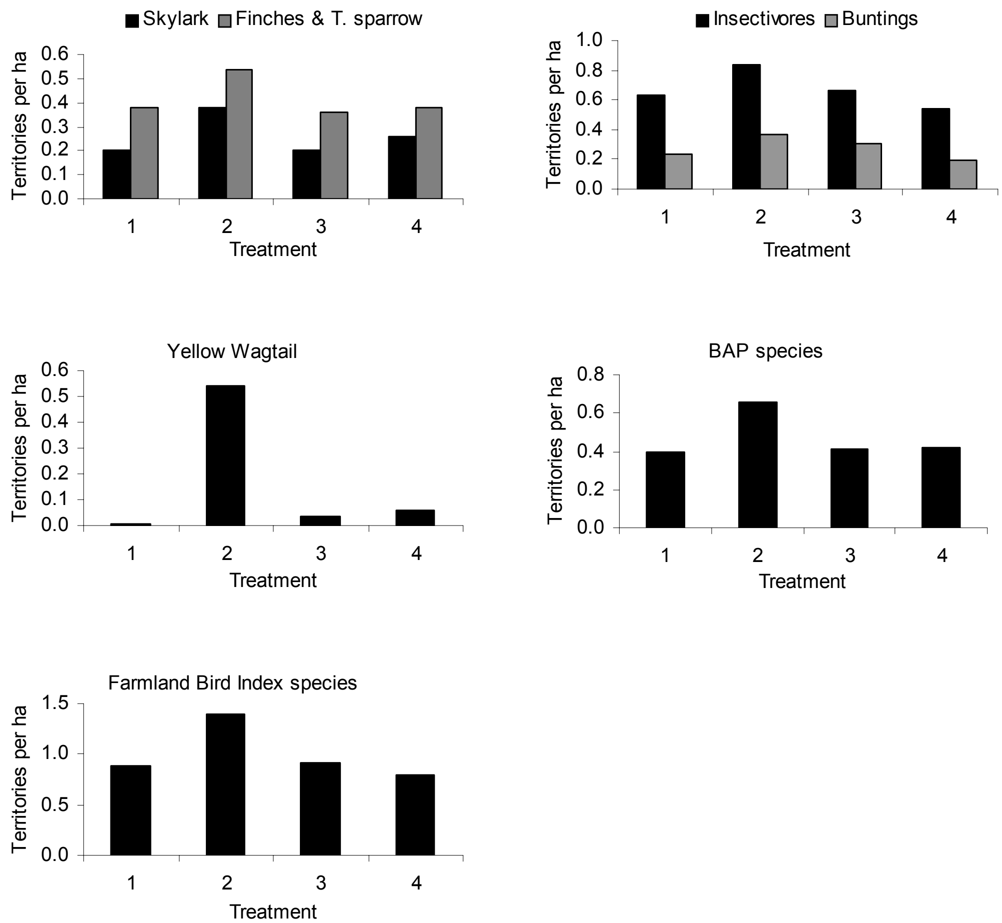

Figure 7.42 The distribution of bird territory densities per ha, for two species and five species-groups by treatment over combined years 2004, 2205 and 2006. For statistical details, see Table 7.21. For species-group definitions, see Appendix 1.

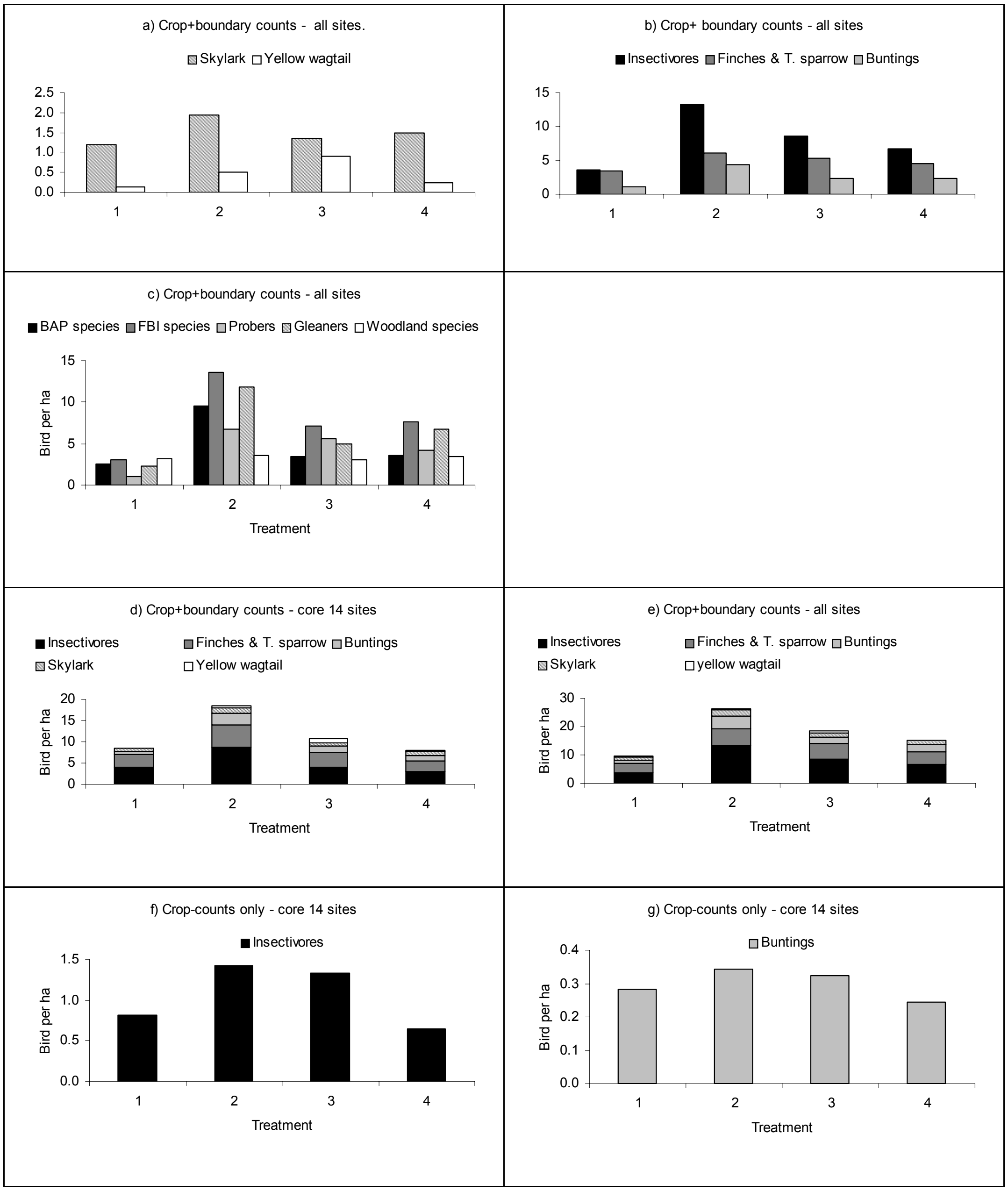

Figure 7.43 Bird registration densities for two species and five species-groups by treatment over combined years 2004, 2205 and 2006. For statistical details, see Table 7.22. For species-group definitions, see Appendix 1. In (d) and (e) the figures show densities summed across mutually exclusive species groups: (d) for all SAFFIE sites and (e) for the core 14 sites.

Table 7.23 (a: all sites) A summary of the GLMM variables included in the analysis of bird densities for the species or species groups found in Table 7.21. Bird species groups are defined in Appendix 1. n/e = variable not included in the model. Total N = the total available sample size of birds summed over the three years - 2004 to 2006. See Table 7.21 for explanation of model structure, dispersion factor and probabilities of significance (*P*) codes.

Model effects	**Skyl**	**Inse**	**F&S**	**Bunt.**	**BAP**	**FBI**	**Prob**	**Glean**	**Woo**	**Ywa**
All sites (except for yellow wagtail)										
Total N (per visit)	224	780	590	415	446	875	623	674	356	39
Dispersion	1.1	2.5	3.3	1.65	2.64	3.1	4.1	3.2	3.2	1.6
Year	***	***	*	**	***		***	***	***	***
Season	***	ns	ns	ns	*	***	***	***	***	*
Treatment	***	***	***	***	***	***	***	***	***	**
Boundary type	***	***	***	***	***	*	***	***	***	***
Boundary length	ns	***	ns	***	***	ns	***	**	**	n/e
Boundary height	ns	***	***	*	***	ns	**	***	n/e	n/e
Wet ditches	n/a	ns	n/e	***	n/e	n/e	n/e	n/e	n/e	ns
Adjacent habitat type	*	ns	*	ns	*	ns	ns	ns	n/e	***
% adjacent habitat type	*	ns	**	ns	**	***	***	**	n/e	***
Treatment x Boundary type	*	**	n/e	***	**	***	***	***	n/e	n/e
Treatment x %adjacent habitat	*	***	***	*	***	***	***	***	n/e	n/e
Treatment x Season	ns	ns	ns	ns	**	**	***	***	n/e	ns

Table 7.24 (b: – core sites) A summary of the GLMM variables included in the analysis of bird densities for the species or species groups found in Table 7.21 Bird species groups are defined in Appendix 1. n/e = variable not included in the model. Total N = the total available sample size of birds summed over the three years - 2004 to 2006. See Table 7.21 for explanation of model structure, dispersion factor and probabilities of significance (*P*) codes.

Model effects	**Skyl**	**Inse**	**F&S**	**Bunt**	**BAP**	**FBI**	**Prob**	**Glean**	**Woo**	**Ywa**
Core 14 sites All 14 core sites										
Total N (per visit)	141	376	304	236	135	164	132	143		
Dispersion	1.03	2.2	2.46	1.68	2.1	3.9	3.64	2.61		
Year	***	***	ns	***	***	***	***	***		
Season	***	ns	**	ns	***	**	*	*		
Treatment	**	***	***	***	***	***	**	**		
Boundary type	***	***	***	ns	***	**	***	***		
Boundary length	ns	ns	ns	***	***	**	n/e	***		
Boundary height	ns			*	ns	**	n/e	*		
Wet ditches	n/e	n/e	n/e	***	n/e	n/e	n/e			
Adjacent habitat type	ns	***	ns	ns	ns	**	***	***		
% adjacent habitat type	ns	*	ns	ns	ns	***	***	***		
TreatmentX Boundary type	ns	ns	n/e	n/e		***	***	***		
TreatmentX %adjacent habitat	ns	ns	***	**	ns	***	***	***		
Treatmentx Season	ns	ns	ns	ns	ns	ns	ns	ns		

Table 7.25 Bird use of 6m grass margins during the winter on 10 East Anglian farm sites. Significance tests for fixed effects and the least squares means & 95% confidence intervals for factor-levels (for tests significant at P<0.05, only) from three GLMMs with Poisson errors and random effects for site and siteXfield: (i) all bird species, (ii) primarily granivorous species (galliformes & seed-eating passerines), (iii) primarily seed-eating passerines (skylark, finches, sparrows, buntings). Interaction terms 'mixXperiod' & 'cutXmix' were included but were not significant in any of the models. Probabilities are represented as: *P =< 0.05, **P < 0.01, ***P < 0.001, <***P <0.0001.

Model	**All Species**			**Granivores**			**Seed-eating Passerines**			**Probing Insectivores**		
Type 3 Tests Fixed Effects	**DF**	**F**	**P**	**DF**	**F**	**P**	**DF**	**F**	**P**	**DF**	**F**	**P**
Least Squares Means Factor-levels	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**
year	1	11.72	0.0007	1	7.56	0.0071	1	ns (main term retained in MAM due to significant interaction)		1	12.72	0.0004
2004/05	0.93	0.59	1.47	0.40	0.22	0.72				0.02	0.00	0.08
2005/06	2.10	1.45	3.03	0.86	0.52	1.42				0.13	0.04	0.44
period	1	14.87	0.0001	1	26.41	<0.0001	1	20.69	<0.0001	1	9.84	0.002
November	2.01	1.40	2.87	0.95	0.59	1.52	0.54	0.27	1.07	0.09	0.03	0.29
January	0.97	0.64	1.48	0.36	0.21	0.62	0.19	0.09	0.39	0.03	0.01	0.11
management	1	8.99	0.0030	1	4.82	0.0316	1	ns (main term retained in MAM due to significant interaction)		1	7.38	0.007
No cut	0.93	0.56	1.53	0.41	0.22	0.77				0.03	0.01	0.10
Autumn cut	2.10	1.46	3.02	0.83	0.50	1.39				0.10	0.03	0.33

Model	All Species			Granivores			Seed-eating Passerines			Probing Insectivores		
Type 3 Tests Fixed Effects	**DF**	**F**	**P**	**DF**	**F**	**P**	**DF**	**F**	**P**	**DF**	**F**	**P**
Least Squares Means Factor-levels	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**
mix	1	ns		1	ns		1	ns (main term retained in MAM due to significant interaction)		1	ns	
FG												
TG												
hedge	1	20.57	<0.0001	1	12.60	0.0013	1	4.83	0.0355	1	9.26	0.0025
No hedge	0.69	0.39	1.23	0.29	0.14	0.61	0.19	0.07	0.48	0.01	0.00	0.08
Adj hedge	2.83	2.08	3.85	1.18	0.74	1.91	0.54	0.26	1.13	0.29	0.16	0.51
stubble	1	ns		1	ns		1	14.14	0.0002	1	4.01	0.0460
No stubble							0.17	0.08	0.37	0.03	0.01	0.12
Adj stubble							0.57	0.27	1.22	0.08	0.02	0.26
managementXperiod	1	8.42	0.0040	1	ns		1	26.88	<0.0001	1	17.36	<0.0001
none Nov	1.79	1.04	3.06				0.94	0.38	2.31	0.09	0.02	0.38
none Jan	0.48	0.25	0.93				0.06	0.02	0.17	0.01	0.00	0.03
cut Nov	2.26	1.51	3.38				0.31	0.13	0.71	0.09	0.02	0.30
cut Jan	1.96	1.30	2.95				0.57	0.26	1.25	0.12	0.03	0.41

Model	All Species			Granivores			Seed-eating Passerines			Probing Insectivores		
Type 3 Tests Fixed Effects	**DF**	**F**	**P**	**DF**	**F**	**P**	**DF**	**F**	**P**	**DF**	**F**	**P**
Least Squares Means Factor-levels	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**	**Estimate (no./100m)**	**Lower 95%CI**	**Upper 95%CI**
yearXperiod	1	4.17	0.0422	1	ns		1	4.70	0.0310	1	31.62	<0.0001
04/05 Nov	1.62	0.97	2.70				0.51	0.20	1.26	0.06	0.02	0.24
04/05 Jan	0.54	0.30	0.97				0.09	0.04	0.23	0.04	0.01	0.14
05/06 Nov	2.49	1.67	3.73				0.57	0.24	1.34	0.12	0.03	0.43
05/06 Jan	1.76	1.14	2.72				0.37	0.16	0.85	0.02	0.01	0.10
yearXmix	1	ns		1	ns		1	6.28	0.0128	1	ns	
04/05 FG							0.16	0.06	0.40			
04/05 TG							0.30	0.12	0.74			
05/06 FG							0.53	0.22	1.26			
05/06 TG							0.40	0.16	0.96			

7.4.5.2 *Data from nest observations*

The quality of available habitat around the treatments, year and treatment type were significant determinants of skylark nest density on occupied sites (Table 7.26).

Table 7.26 Skylark nest density on occupied sites. Type 3 tests of fixed effects, direction of relationships and significant differences from GLMM MAM. Poisson error term, log(area) offset and random effects for site and siteXfield. Boundary dropped as *ns*. Result from full model similar.

Effect	**DF**	**F Value**	**Pr > F**	**Direction of relationship (factor levels = greatest first)**	**Significant differences between factor level**
Adjacent habitat quality	1	13.93	0.0004	+	
Year	2	9.41	0.0002	2005, 2006, 2004	2005>2006=2004
Treatment	3	3.81	0.014	T2, T4, T3, T1	T2>T3= T1

Skylark nest densities were greatest on T2, being significantly higher than those found on T3 and T1 (Figure 7.44, Table 7.26).

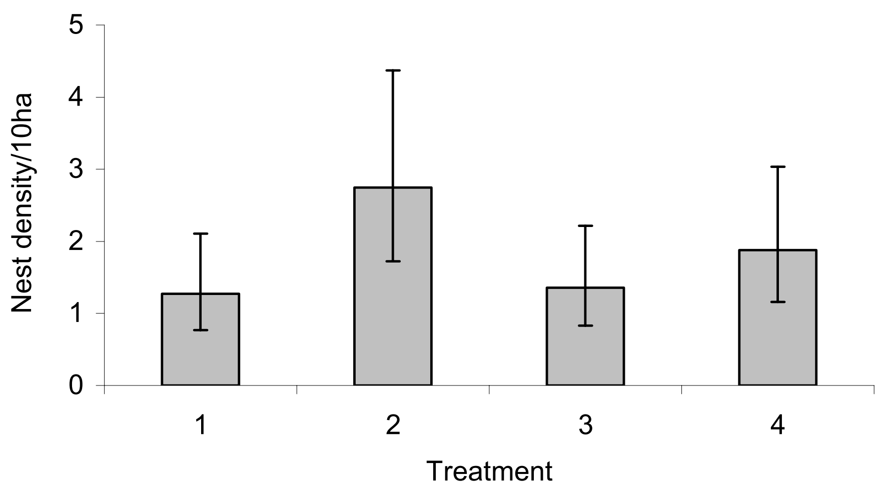

Figure 7.44 Back transformed means and 95% CI from GLMM of skylark nest densities per treatment on occupied study sites.

The two treatments with UP held significantly greater densities of skylark nests than the two treatments without UP (Table 7.27).

Table 7.27 Skylark nest density in relation to presence/absence of UP on occupied sites. Type 3 tests of fixed effects, direction of relationships and significant differences from GLMM MAM. Poisson error term, log(area) offset and random effects for site and siteXfield. Result from Full Model similar, except boundary structure also significant (-ve relationship).

Effect	**Num DF**	**F Value**	**Pr > F**	**Direction of relationship (factor levels = greatest first). [Nests/10ha]**
Adjacent habitat quality	1	7.19	0.0102	+
year	2	4.29	0.0191	2005>(2006=2004)
UP	1	5.99	0.0179	UP [3.21] > no UP [2.25]

Skylark brood condition had a markedly positive relationship with nestling age, as measured by the covariate 'tarsus length' (F = 60.9, df = 1 P <.0001). The interaction between year and treatment was significant (F = 2.50 df = 5 P < 0.0417) but three of the seven significant factor-level contrasts were between different treatments in different years and therefore not ecologically meaningful. Broods in T1 were of significantly better condition than those in T2 in 2005 but the reverse was true in 2006. However, the other significant factor-level contrasts related to variability between years in T1. Here, brood condition was significantly better in 2005 than in 2004 and 2006. This could suggest that brood condition in non-experimental wheat is more susceptible to natural stochastic processes, such as the weather, than when the vegetation is manipulated to enhance foraging opportunities. Interestingly, 2005 had the fewest, shortest periods of cool, wet weather out of the three years. Year was marginally non-significant in the full model but was significant in the MAM, with broods in 2005 having the best body condition. The lack of consistent treatment effects on body condition is unsurprising, given the proximity of the treatments to one another. This meant that adults breeding in treatments with less favourable foraging habitat had only a short distance to fly to treatments that provided greater availability of chick food.

Using data from 18 English sites for which nest data available, in the full model treatment was a significant predictor of skylark brood reduction (partial and complete nest content) resulting from abandonment and starvation. The greatest reduction was in T1 and the least in T4, with intermediate levels of loss (not significantly different from any other treatment) in T2 and T3. It was uncertain why starvation was apparently somewhat higher (although non-significantly so) in T2 than T4, although some abandonment's may have been due to predation, or disturbance by predators, of the female parent (see below). Treatment was not significant in the reduced model (P = 0.08).

Analysis of nestling stage reduction by abandonment and starvation (partial & complete nest content) for all passerine nests (many of which were of ground-nesting species), showed rates of loss were highest, but non-significantly so, on non-UP treatments. No measured predictors significantly explained nestling stage reduction in insectivore, seed-eater or yellowhammer nests.

The individual components of skylark breeding productivity are summarised in Table 7.28. Daily failure rate (DFR) were greater in the treatments with margins, particularly T2. Treatment was a borderline significant predictor of DFR (P = 0.057) but only in the MAM. Out of 161 nests for which exposure days could be calculated, 69 failed, 59 of those through predation (see below), one was destroyed by machinery and nine were abandoned or the whole brood starved. Unlike Experiment 1.1, there was no indication of differences in the number of chicks reared per nesting attempt between T1 and T4 but the greater number of nesting attempts in T4 meant that the number of chicks reared per unit area was, again, much greater (Table 7.28).

The poor productivity in T2 and T3 resulted from high levels of nest predation. Adjacent habitat, boundary and year were not significant predictors of daily predation rate (DPR), although there was some yearly variation (2004 = 7%; 2005 = 5%; 2006 = 3%). Treatment was the only significant predictor of nest DPR ($F = 3.51$; $df = 3$; $P = 0.0225$), being much greater on T2 than on both the non-margin treatments (T1 and T4) and intermediate on T3 (Table 7.28). As few skylark nests were lost to causes other than predation (most of those being in poor weather early in the 2006 breeding season), DFR were similar to the DPR (Table 7.28).

Table 7.28 The individual components of skylark breeding productivity. Data from 18 English sites in winter wheat during 2004-06.

Trt't	**Nests/ 10ha**	**Mean clutch size**	**Mean initial brood size**	**Brood size post-partial reduction**	**Mean DFR**	**Mean OSR**	**Chicks/ nest – all data**	**Chicks/ 10ha – all data**	**Mean DPR**	**Chicks/ nest – excludes non-predated failures**	**Chicks/ 10ha – excludes non-predated failures**
1	1.27	3.62	3.45	3.04	0.037	0.45	1.3	1.7	**0.029**	1.6	2.04
2	2.75	3.74	3.67	3.44	0.098	0.15	0.4	1.0	**0.107**	0.3	0.79
3	1.36	3.37	3.26	2.89	0.060	0.29	0.7	1.0	**0.062**	0.7	0.96
4	1.88	3.56	3.19	3.10	0.038	0.44	1.3	2.5	**0.032**	1.5	2.85
2>50 m	2.75	3.73	3.61	3.29	0.063	0.24	0.8	2.19	**0.063**	0.8	2.19
2>75 m	2.75	3.70	3.55	3.16	0.052	0.31	1.0	2.72	**0.052**	1.0	2.72

DFR – daily failure rate of nests
OSR – overall survival rate
DPR – daily predation rate

Table 7.29 *P* values for differences of least squares means from GLMM of skylark DPR. Binomial error term, and random effects for site and siteXfield.

Treatment comparison	Direction of estimate	Pr > |t|
1 v 2	T1 < T2	0.0112
1 v 3	T1 < T3	0.1615
1 v 4	T1 < T4	0.8530
2 v 3	T2 > T3	0.1760
2 v 4	T2 > T4	0.0170
3 v 4	T3 > T4	0.2171

A comparison of the least squares means output shows that DPR differed significantly between T2 and T1 (T1 < T2) and between T2 and T4 (T2 > T4) but not for the other factor levels (Table 7.29). Over the 22 days from first egg-laying until the young left the nest, the overall nest predation rate (OPR) for skylark nests was 46% in T1, 89% in T2, 73% in T3 and 50% in T4.

The number of chicks leaving the nest per 10 ha (excluding failures to causes other than predation), a figure that included initial clutch size, partial losses at the egg and nestling stages and the density of nesting attempts, was also lowest on T2, although this treatment had the greatest nest densities. However due to the very high predation rate, productivity was still well below that on T1 and T4. T3 also recorded low productivity per 10 ha, due to low densities of nesting attempts and nest survival, while T4 had the greatest productivity per 10 ha, due to a combination of good nest survival and high densities of nesting birds (Table 7.28).

The differences in the DPR of skylark nests in relation to distance to the crop edge were analysed separately for: (i) T2 & T3 (margins) and (ii) T1 & T4 (non-margins, with the crop edge being hedges, tracks, ditches etc.). In model (i), nest predation rates showed a pronounced quadratic relationship (with both the linear [F = 6.96, df = 1, P = 0.01] and squared [F = 6.51, df = 1, P = 0.013] terms being significant) with distance from the nearest grass margin (Figure 7.45). In model (ii), there was a non-significant negative relationship with nest distance from the nearest crop edge (Figure 7.45).

A comparison between T2 (whole area), T2 (crop centre at two distances from the margin (i) >50 m [T2>50] and (ii) >75 m [T2>75]) and T4, revealed that DPRs of nests in T2 as a whole were 1.7 times higher than in T2>50 and double those in T2>75. The DPR in T2>50 was nearly double that in T4, while in T2>75 it was 1.6 times higher. However, the numbers of chicks leaving the nest per 10ha in T2>75 m were nearly equal to T4, due to the greater density of nests (and a slightly greater mean brood size) in T2. For T2>50, the number of chicks leaving the nest per 10 ha was 0.6 less than T4, although it was slightly better than for T1, the conventional wheat control (Table 7.28).

In an attempt to establish the identity and foraging behaviour of nest predators during 2006, cameras filmed 41 nests of three ground-nesting species. Twenty-nine of these were skylark nests, of which 15 fledged successfully; eight were predated; three lost complete broods to starvation during cold, wet weather; and three clutches of eggs were abandoned, also during poor weather. Of the 12 nests of the other two ground-nesting species (yellow wagtail and yellowhammer) filmed, six fledged, one was predated, one complete brood starved and four were abandoned). No nests were considered to have been abandoned due to placement and operation of cameras, as all parents resumed incubation/brooding/ feeding once the units had been set up and comparison with a small subset of nests that were monitored without camera deployment revealed no difference in daily survival rates (Table 7.30).

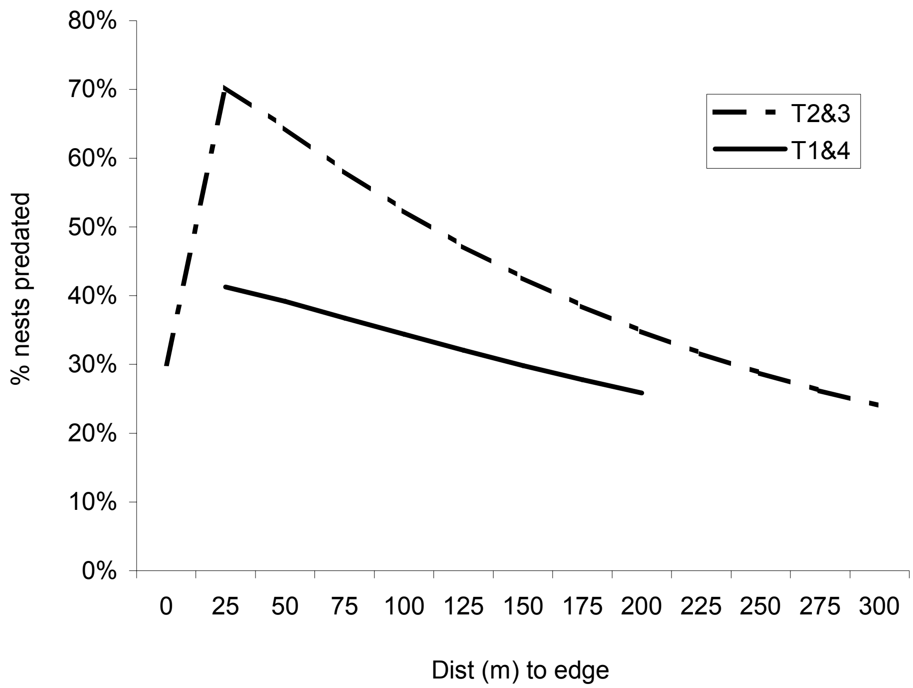

Figure 7.45 Rates of skylark nest predation (number of nests predated/number of nests successful) from two separate GLMMs: (i) in relation to distance from the nearest grass margin (T2 & T3) and (ii) in relation to distance from the nearest crop edge without a grass margin (T1 & T4)). In (i) there was a significant quadratic relationship. In (ii) there was a non-significant negative relationship. Binomial error term and random effects for site and site x field.

All filmed nest predations of ground-nesting birds were mammals: five badger *Melus melus*, two weasel *Mustela nivalis* and single stoat *Mustela erminea* and brown rat *Rattus norvegicus*. Treatment T1 had two nests predated, T2 four nests, T3 two nests and T4 one nest (Table 7.31). At a further two nests (one yellowhammer and one yellow wagtail), incubating females were flushed by unidentified large predators and did not return to the nest subsequently. There was no difference in predation rates between the egg and nestling stages.

Badgers were active both on treatments with and without margins and throughout the field, predating nests from the edge up to 120 m into the crop. At night, mice spp. and rats were filmed in close vicinity to several incubating or brooding skylarks but in no case did the females leave the nest or show agitation and the rodents made no attempt to predate the nests. However, in two cases, mice nibbled cold eggs in abandoned nests and a rat predated a brood of nestlings 80 m into the crop, after flushing a female skylark from the nest at dawn. The three instances of predation by small mustelids were in fields with margins. Both occurred in the evening before the onset of darkness and within 10 m of the field boundary in treatments with grass margins.

One further nest was abandoned after a skylark was seen to remove three of the four eggs (when the nest was unattended) and then subsequently removed nest material (when the returning female attempted to incubate the remaining egg). Such behaviour has not previously been verified for this species.

In addition to the filming at nests, approximately 1000 hours of camera deployment at 17 locations on linear features (tramlines and grass margins) potentially used as predator access routes, recorded mice spp., brown rat, red fox *Vulpes vulpes*, badger and domestic dog *Canis lupus familiaris*. Mice, rat and badger were recorded in tramlines over 50 m from the crop edge. Potential food for mammalian predators included: common pheasant *Phasianus colchicus*, red-legged partridge *Alectoris rufa*, brown hare *Lepus europaeus*, muntjac *Muntiacus reevesi*, mice spp. and brown rat.

Table 7.30 Summary of nests filmed. Outcome codes: F = fledged, P = predated, AP = abandoned on eggs after female flushed by predator, AW = abandoned on eggs in poor weather, S = brood starved. Cluster codes: CA = Cambridgeshire; EA = East Anglia; HE = Herefordshire; LI = Lincolnshire.

Species*	Cluster	Hours Filmed	No. Nests	Outcome	Nests T1	Nests T2	Nests T3	Nests T4
S	HE	1383	6	2F, 3P, 1AW	3	2	1	0
S	CA	960	4	2F, 2S	1	0	0	3
S	LI	2438	14	7F,4P, 2AW, 1S	4	4	1	5
S	EA	808	5	4F, 1P	0	4	1	0
YW	CA	840	3	2F, 1AW	0	1	1	1
YW	LI	479	1	1F	0	0	0	1
YW	EA	855	5	2F, 2AW, 1AP	1	2	0	2
Y	CA	816	3	1F, 1P, 1AP	0	0	3	0
Totals		8723	41	21F, 9P, 2 AP, 6AW, 3S	9	13	7	12

*Species: S = skylark, YW = yellow wagtail, Y = yellowhammer

Table 7.31 Summary of predations filmed.

Predator	Nest spp*	Nest Stage	Cluster	Treatment	Time	Distance From Boundary
Badger	S	Egg	HE	T1	03:30	100 m
Badger	S	Egg	HE	T1	24:30	50 m
Badger	S	Egg	HE	T2	22:10	120 m
Badger	S	Egg	EA	T2	00:05	0 m (in margin)
Badger	S	Chick	LI	T3	21:58	90 m
Stoat	S	Chick	LI	T2	19:48	10 m
Weasel	S	Chick	LI	T2	19:01	2.5 m (in margin)
Brown Rat	S	Chick	LI	T4	04:38	80 m
Weasel	Y	Chick	CA	T3	17:10	0 m (in margin)

*Species: S = skylark, Y = yellowhammer

In contrast to the ground-nesting birds, the DPR for birds nesting in hedges next to margins (T2 & T3 combined) was the same as that of birds nesting in hedges in non-margin treatments (0.038). Differences in DPR between the four individual treatment levels were also trivial and insignificant (T1 = 0.042; T2 = 0.038; T3 = 0.040; T4 = 0.036). Presence of a margin was also a non-significant predictor of DPR for a suite of low nesting species (yellowhammer, reed bunting, common whitethroat and meadow pipit) and yellowhammer alone.

Finches & bunting nest density had a positive relationship with amount of surrounding spring cropping, as did insectivore nest density. Insectivore nest density also varied with treatment: T2>T3 and T1, while T4>T1. Yellowhammer nest densities varied significantly only with year (Table 7.32).

Breeding yellow wagtails were present on only a small number of sites; hence, sample sizes were relatively small, with nest data from 25 nests from five sites (in the East Anglia, Cambridgeshire and Lincolnshire site clusters). When modelled as a 4-level factor, treatment was not a significant determinant of nest density. However, nest densities varied significantly with the interaction term (UPXtime) between UP presence/absence and the numbers of years UP were present in the experimental design (F = 4.83 df = 1 P = 0.0375) (Table 7.32). The highest nest densities occurred in crops where UP were present for a second year. In the second year of experimental management, nest density was significantly greater in crops with UP than in crops without UP (P = 0.04). For crops with UP, nest density was significantly greater in the second year of experimental management than in the first year (P = 0.01), suggesting some element of continued concentration into a more favourable habitat, perhaps by returning birds that had previously bred or reared in these treatments. Between first and second years of experimental management, two sites showed increased nest density (with all increases occurring on UP treatments) and the remaining three sites gained nesting YW on the treatments, when previously they had been absent. Of the latter, two had nests in the UP treatments while the third site had a nest in a split-field close to an adjacent UP treatment. Of 12 nests in treatments with UP where the distance to the nearest UP was recorded, one was within an UP, six were within 25m and 11 were <50 m. No nests were located in grass margins (even at sites away from tall boundary features).

Table 7.32 Results from GLMM analyses of Daily predation rate (DPR) (Binomial error terms) and nest densities (Poisson error terms and log[area] offset) of species (or species-guilds) other than skylark. Boundary index and amount of other adjacent habitats were not significant in any model. * = significant at $P \leq 0.05$; * = significant at $P \leq 0.01$. Random effects for site and site x field included in all models.

	Significant predictors				
Model	**Treatment**	**Year**	**Adjacent cropping**	**spring**	**UPXtime interaction**
DPR Hedge-nesting spp					
DPR low-nesting spp					
DPR yellowhammer		* (MAM only)			
Finch and bunting nest density			** +ve		
Insectivore nest density	* T2>T3, T1 T4>T1				
Yellow wagtail nest density					* Greatest in UP in second year

7.4.6 Trophic links

7.4.6.1 Trophic links on treatment fields

<u>Effects of invertebrate densities and vegetation characteristics on birds</u>

The association between bird densities on treatment fields and invertebrate densities is summarised in (Table 7.33). Generally, bird-invertebrate links were weak. Significant effects of 'all invertebrates combined' were detected for insectivorous bird species and for yellow wagtail. For skylarks, there was a non-significant positive association only (Table 7.33). For the seed-eating species (finches & tree sparrow and buntings), the association with invertebrates was positive for finches but negative for buntings. Treatment effects were still significant and consistent with the main bird-only analysis (Table 3). There were no significant interactions between predictor variables (such as between treatments and invertebrate densities). The implication is that for the seed-eating species, at least, in-crop variation in invertebrate densities was not enough to directly determine their occurrence in SAFFIE wheat crops. For insectivores, where an effect was identified, it was not sufficient to suggest that invertebrates were the main cause of significantly different densities of birds between treatments. Meanwhile the treatment effects themselves were consistent, suggesting a larger field-scale affect of UP.

When vegetation characteristics were added to the models, most of the bird relationships with invertebrates lost their significance and were generally negative. The proportion of bare ground present was the most consistent positive variable apart from the difference between treatments (T1 to T4). For the seed-eating finches, tree sparrow and buntings this relationship with bare ground was statistically significant. Other vegetation characteristics, such as weed cover sometimes had a positive effect, but sometimes a negative effect (Table 7.34). Apart from the presence of UP, crop conditions and structure was not expected to vary significantly between treatments as crop conditions *per se*, were expected to be broadly similar between fields.

The response of birds to the differences between treatments was stronger than for other in-field characteristics. The results suggest that, at the whole-field scale birds were responding mainly to the availability of bare ground, but especially at the larger scale of availability as provided by UP. Once in the field, fine-scale effects are more likely to be influential (see 7.4.6.3).

7.4.6.2 Trophic links on field margins

The association between bird presence/absence on SAFFIE margins, vegetation characteristics and invertebrate densities are summarised in

Table 7.35 (as univariate tests for association) and Table 7.36 (as multivariate regression models). For the regression analysis, only binomial models (reflecting presence/absence on small plot areas) provided good fits to the data. The in-field nesting species, skylark and yellow wagtail (combined), were an exception, where Poisson models provided a better analysis.

In Table 7.35, univariate tests are given for skylark and yellow wagtail (combined) and the boundary-base species (all other small (non-corvid) passerines). For both groups two general factors emerged as being particularly important. These were: 1) the proportion of litter cover present and 2) the abundance of invertebrates, especially beetles or spiders (perhaps reflecting a connection between the two). There was a weak but positive association with Heteroptera (true bugs) but the association between birds and Auchenorrhyncha (leaf hoppers) was significantly negative (perhaps reflecting denser sward conditions favoured by this invertebrate group).

The multivariate analysis is shown in Table 7.36 for 'all species' recorded using margins and for various species groups, showing different 'best fit' model combinations. Consistent significant effects were detected for 'year' throughout the analysis (all model combinations), with densities in 2004 being significantly lower than in either 2005 and/or 2006. Effects of the 'seed mix' on birds was always positive towards a higher occurrence of birds on the fine grass mix rather than the tussock mix, but the difference was generally not significant (only significant when few other variables were included in the models: i.e., models 4 and 5).

Among the vegetation characteristics only (model 6), heterogeneity in vegetation height, vegetation species diversity (Shannon index) and percentage litter cover were significant (or close to significant) and positive, but the effect of heterogeneity in litter cover was negative with respect to bird presence/absence (Table 7.36). The direction of these effects was consistent across the analysis, though not always significant. The implication is that birds were responding to heterogeneous swards with litter cover – perhaps harbouring invertebrates or improving bird access.

Among invertebrates, the abundance of beetles and of spiders was always positive and, generally, one or other was significant (even in combined models with vegetation characteristics: model 1 or model 8). At the same time, the Heteroptera and the specifically the Auchenorrhyncha were not significant effects. The Auchenorrhyncha were negatively associated with birds, also in combined models

(models 1, 6 and 8). Models including spiders, either by mass or by number, tended to cause other variable effects to decline in significance, even including beetle abundance (models 1, 7 and 8). Thus, in combined vegetation and invertebrate models, invertebrate variables tended to dominate (especially spiders: compare model 6 with models 1 and 8). The implication is that the birds were responding to invertebrate abundance, moderated though vegetation characteristics that either supported higher abundances of invertebrates (perhaps the litter layer) or increased access for birds to these invertebrates (heterogeneous swards).

Skylark and yellow wagtail: For this group bird densities (Poisson model) were most strongly associated with total beetle abundance (Table 7.35 and Table 7.36) as well as patchiness in bare ground, and a significant, positive and confounding effect of % litter cover (Table 7.36). There was no significant effect of margin seed mix or a year effect. Generally, both the univariate and multivariate data suggest a response to beetle densities (possibly associated with the litter layer) and patchy bare ground, offering foraging access.

Insectivores: For the insectivorous group, the main effect was vegetation composition and litter cover (negative effect of heterogeneity in litter cover) and especially heterogeneity in vegetation height. Beetle and spider abundance were positive but there was no significant effect. The implication is that heterogeneous vegetation characteristics and a litter layer were most important in determining their presence in margins.

Finches & tree sparrow: For seed-eating species, factors indicative of vegetation heterogeneity were positive (species richness and heterogeneity in vegetation height) though not statistically significant in the presence of invertebrate components such as beetle or spider abundance. There was a significant effect of beetle abundance but a stronger over-riding effect of spider abundance, both likely to be associated with litter cover (non-significant positive effect). The implication is that these species are responding to invertebrate abundance, modified though sward composition, which either improves foraging access and/or invertebrate abundance/availability.

Table 7.33 A summary of bird registration densities in and around winter wheat, in relation to experimental treatments and invertebrates abundance. Models are repeated measures, Poisson error GLMMs with random effects for site and site x field. Data are from all 15 sites where invertebrate and vegetation sampling was carried out in crops, between 2004 and 2006. The table summarises model combinations for species or species groups. All models include controls for 'year' and adjacent habitat and boundary types (effects not shown). Bird species groups are defined in Appendix 1.

	Species or species groups						
	Skylark		**Insectivores**			**Finches & tree sparrow**	
N (per visit)	131		482			334	
Dispersion (χ^2/df.)	1.10		2.64			4.15	
Predictor variables	**Effect**	***P***	**Effect**	***P***		**Effect**	***P***
Treatment	1<4=3<2	*	1<4<3<2	*		1<3<4<2	***
Total invertebrates	+	ns	+	*	Dvac	+	ns

	Yellow wagtail (7 sites where species occurred & invert. sampling was carried out)			**Buntings**		
N (per visit)	28			265		
Dispersion (χ^2/df.)	1.47			1.62		
Predictor variables	**Effect**	***P***		**Effect**	***P***	
Treatment	1<4<3<2	**		1<4<3=2	**	
(Total invertebrates)	+	*	Dvac	-	ns	Dvac

Table 7.34 Invertebrate and vegetation characteristics. Models are repeated measures, Poisson error GLMMs with random effects for site and siteXfield. Data are from all 15 sites where invertebrate and vegetation sampling was carried out in crops, between 2004 and 2006. The table summarises model combinations for species or species groups. All models include controls for 'year' and adjacent habitat and boundary types (effects not shown). Bird species groups are defined in Appendix 1.

	Species or species groups							
	Skylark		**Insectivores**		**Finches and tree sparrow**		**Buntings**	
N (per visit)	131		482		334		265	
Dispersion (χ^2/df.)	7.3		8.7		89.8		39.1	
Predictor variables	**Effect**	***P***	**Effect**	***P***	**Effect**	***P***	**Effect**	***P***
Treatment	1<4=3<2	*	1<4<3<2	***	1<4<3<2	**	1<4<2<3	**
Total invertebrates		ns	-	**	-	***	-	***
All weeds	-	0.06	-	*	+	***	-	ns
Bare ground	+	ns	+	ns	+	***	+	***

Table 7.35 Spearman rank correlations between abundance, for field nesting species (skylark & yellow wagtail) and boundary-based species and vegetation or invertebrate characteristics on SAFFIE field margins. The bird data used include June and July counts only, to match the invertebrate and vegetation sampling period.

	Skylark & yellow wagtail N=196	**Variable**	**Boundary-based species N = 286**
Spearman rank univariate tests:			
Years 2002-2006	**Effect**	**Variable**	**Effect**
	Rho = 0.02 ns	Veg height variance	Rho = 0.02, ns
	Rho = -0.08, ns	Plant species diversity	Rho = 0.05, ns
	Rho = 0.09, ns	%Bare ground	Rho = 0.02, ns
	Rho = 0.15*	Bare ground variance	Rho = 0.02, ns
	Rho = 0.28***	%Litter cover	Rho = 0.10, P = 0.09
	Rho = -0.20**	Litter variance	Rho = -0.14 *
	Rho = 0.31***	Total beetle abundance	Rho = 0.20***
	Rho = 0.22**	Mass beetles	Rho = 0.13*
	Rho = 0.13*	Total spiders	Rho = 0.11*
	Rho = 0.20**	Mass spiders	Rho = 0.15**
	Rho = 0.20**	Larvae abundance	Rho = 0.02, ns
	Rho = 0.09, ns	Total Orthoptera	Rho = 0.04, ns
	Rho = 0.14*	Heteroptera	Rho = 0.06, ns
	Rho = -0.20**	Mass Auchenorrhyncha	Rho = -0.11*

Table 7.36 Effects on the presence or absence of birds on field margins. This is a summary of mixed-model regression analyses on birds using SAFFIE field margins, in June and July, in relation to vegetation and invertebrate characteristics. GLMMs included binomial error terms and random effects for site and siteXfield. Data were taken from 16 farm sites on which both bird and invertebrate/plant data were gathered between 2004 and 2006. The tables show fixed effects, with controls for location and sample year. The direction of an effect is either positive (+) or negative (-), or for 'year' and 'seed mix', by the order in which the parameter values were arranged.

All species combined									
	Model 1			**Model 2**		**Model 3**		**Model 4**	
N	2029			2030		2110		2111	
Dispersion (χ^2/df.)	0.95			0.96		0.96		0.97	
Predictor variables:	**Effect**	***P***	***P***	**Effect**	***P***	**Effect**	***P***	**Effect**	***P***
Year	04<06<=05	**		04<06<=05	***	04<06<=05	***	04<06<=05	***
Margin mix	Tussock<Fine	ns		Tussock<Fine	ns	Tussock<Fine	ns	Tussock<Fine	*
Year* margin mix		ns			ns		ns		ns
Total beetles	+	*	ns	+	**	+	**	+	**
Litter cover	-	ns		+	ns	+	ns		
Veg. species diversity	+	ns		+	*	+	*		
Vegetation height var.	+	ns		+	ns				
Total spiders or mass	+		**						
Bareground	+	ns							
Auchenorrhyncha	-	ns							
Heteroptera	+	ns							
Total beetlesXmix		ns							

Cont'd…….

All Insectivores, finches & tree sparrow & buntings combined									
	Model 5		**Model 6**		**Model 7**			**Model 8**	
N (observations)	2111		278		265			267	
Dispersion (χ^2/df.)	1.01		0.91		1.01			0.95	
Predictor variables:	**Effect**	***P***	**Effect**	***P***	**Effect**	***P***		**Effect**	***P***
Year	04<06<=05	***	04<05<06	**	04<05<06	*		04<06<=05	ns
Margin mix	Tussock<Fine	*							
			Vegetation only data						
Litter cover			+	Ns				+	ns
Litter variance			-	*				-	ns
Veg. species diversity			+	*				+	*
Vegetation height var.			+	0.08				+	ns
Bareground			-	ns				-	ns
					Invertebrate only data				
Total beetles					+	*	ns		
Total spiders (or mass)					+		**	+	***
Auchenorrhyncha					-	ns	ns	-	ns
Heteroptera					+	ns	ns	+	ns

Cont'd……

Species or species group	Insectivores		All finches, tree sparrow & buntings			Finches & tree sparrows		Skylark & yellow wagtail (Poisson model)		
N (observations)	80		184			84		78		
Dispersion (χ^2/df.)	0.96		1.2			0.98		0.70		
Predictor variables:	**Effect**	***P***	**Effect**	***P***		**Effect**	***P***	**Effect**	***P***	
Year	05<04<06	*	04<05<06	**	*	04<05<06	*			
(Margin mix)	Tussock<Fine	ns	Tussock<Fine		ns	Tussock<Fine	ns			
Total beetles	+	ns	+	*	ns	+	ns	+		ns
Litter variance	-	0.06							**	ns
Litter cover			+	ns	ns	-	ns	+		**
Veg. species diversity	+	ns	+	*	*	+	*	-		ns
Vegetation height var.	+	*	+	ns	ns	+	ns	+	ns	ns
Total spiders	+	ns			**	+	**		ns	ns
Bareground	-	ns	-	ns	ns	+	ns	variance: +	ns	

7.4.6.3 Trophic links at the fine-scale:

Results from the fine-scale structural dataset suggested that skylarks, insectivores, granivores and passerines generally all selected foraging locations that were more open than the paired non-foraged in controls. Openness at the canopy was very highly correlated with openness at ground level, resulting in one or both variables being non-significant when both were included in the same model. When the least significant predictor was removed, vegetation that was more open at ground level was a significant predictor of foraging for all species combined, insectivores and granivores, while a more open canopy was a significant predictor of skylark foraging. In univariate GLMs, canopy openness and openness at ground level had a significant positive relationship (or, in the case of insectivores, had a markedly significant positive component of a quadratic relationship) with foraging presence/absence or the number of foraging events (Table 7.37). In Poisson errors models, there were similar positive relationships with increasing numbers of foraging visits.

Table 7.37 Vegetation structure predictors of passerine foraging. Significance levels and direction of relationship from univariate binomial GLMs. [1] indicates effects retained in MAM when both (highly correlated) variables originally included in the same model. See Table 7.21 for probabilities of significance (*P*) codes.

	All species		**skylark**		**insectivores**		**granivores**	
Variable	**sig**	**relation**	**sig**	**relation**	**sig**	**relation**	**sig**	**relation**
Canopy openness	***	=ve	**	+ve [1]	ns but retained	-ve	**	+ve
CanopyXCanopy					*	+ve		
Ground-level openness	***	+ve [1]	**	+ve	**	+ve [1]	**	+ve [1]

For a subset of matched pairs (n=61), the structural data were augmented by further variables (vegetation height, weed and invertebrate food) that potentially predicted passerine foraging patterns. In these analyses, openness of the vegetation again had significant positive relationships (or significant positive components of quadratic relationships) with presence/absence of foraging for all species and skylarks only, as did vegetation height standard deviation, a measure of patchiness of sward height. (Table 7.38). Variables representing weed or invertebrate food did not differ between foraged-in and non-foraged in locations, or with increasing number of foraging visits, and were generally scarce in both ‘hot’ and ‘cold’ spots.

Table 7.38 Expanded set of predictors of passerine foraging. Significant effects (with significance levels and direction of relationship) from binomial GLM MAMs. See Table 7.21 for probabilities of significance (*P*) codes. Due to very high correlation in the two original variables, here vegetation openness is represented by a single variable: the mean score from the one canopy and the four ground level measurements. % weed cover, abundance of invertebrates (I) present and (ii) important in the diet and vegetation height and their quadratic terms were not retained in the MAM.

	All species		**skylark**	
variable	**sig**	**relation**	**sig**	**relation**
Vegetation height SD	**	+ve	**	+ve
vegSDXvegSD	*	-ve		
openness	ns but retained	-ve	**	+ve
openness X openness	*	+ve		

7.5 DISCUSSION

7.5.1 Agronomy

The results from this experiment show that Intensive arable farming can be manipulated to benefit wildlife whilst maintaining high levels of production. Inclusion of a margin equivalent to 4% of the field size and two UP per hectare had no detrimental effects on production in terms of weed, pest and disease levels.

7.5.2 Birds

One consequence of adopting progressively intensive methods of arable faming in Britain has been a general and widespread loss of ecological heterogeneity at varying scales (e.g. Benton et al. 2003). This has included a loss of complexity within and around arable crops, for non-cropped habitats and within crops. A loss of both spatial and temporal complexity has been achieved through large-scale developments in pest control technology and machinery creating larger expanses of uniformity (O'Connor & Shrubb 1986, Chamberlain et al. 1998). Modern agriculture also extends the period during which land is managed, so creating greater uniformity over time. For most bird species, opportunities and options to breed and forage are severely reduced, sometimes with severe and long-term impacts on breeding populations in the UK (Siriwardena et al. 1998) or Europe in general (Donald et al. 2006).

The discovery of the importance of vegetation structure, particularly the unfavourable tall and closed nature of the sward structure of winter-cereals, suggested that measures to increase access to the sward might benefit many passerine species. These species utilise arable land for nesting or foraging (e.g. Donald et al. 2001b, Wilson et al. 2005). Among farmers, there is a common consensus that the economics of field management are such that attempts to create in-field complexity are unlikely to be accepted as practical options for modern farmers who try to increase the levels of biodiversity on their farms. Yet, for birds, the SAFFIE experiments have demonstrated that effective methods of increasing bird numbers and population size in and around wheat crops are possible.

Thus, the findings of both SAFFIE Experiments 1.1 and 2 supported the conclusions of Donald et al. (2001b) & Wilson et al. (2005) and it was therefore hypothesised that combining, in the same field, manipulations within crop and in the margin vegetation could provide additional benefits to birds. This could arise through increased access to nest-sites and/or food over a wider area and a greater range of vegetation types. In addition by delivering more abundant food over a wider area, due to the potential of margins to provide a source from which plant or invertebrate food could colonise the cropped area. This in-field and margin combination was tested in SAFFIE Experiment 3, along with other novel research elements not originally included in the project proposal e.g. investigations into the relative importance of the factors influencing foraging site selection, use of margins during the winter months and the identity of predators of ground-nesting birds.

7.5.2.1 Bird territories & individual counts during the summer

For bird species such as common whitethroat and yellowhammer, that typically nest within hedgerows on farmland, adjacent field margins are an obvious addition for creating a reservoir of invertebrate food and cover for nests. In grassland systems, field margin management has been shown to affect the distribution of breeding bird territories located in adjacent hedges. This effect was especially apparent for species with small territories, such as dunnock, where a high proportion of their foraging range incorporates the field margin itself (Report for BD1444 - PEBIL). However, the SAFFIE data indicate that a combined effect of UP and field margins, was particularly affective in increasing the numbers of many bird species using wheat fields, and in affecting positive change in the numbers of breeding territories and nesting attempts associated with wheat fields. This response was consistent also for Farmland Bird Index species and, importantly, for the sub group of Biodiversity Action Plan species. The latter species being those for which farmland recovery in their populations is most needed.

For birds that range from the nest site in order to acquire their food from nearby crops or non-cropped habitats, then an interaction between the condition of those neighbouring habitats and the condition of the field margin itself might be expected. SAFFIE experiments subsequently demonstrated that a simple combination of in-field management techniques and field margin management was enough to effect significant increases in the numbers of birds that were supported or associated with wheat fields. In crops, ground access was the dominant factor linked to higher numbers of foraging and breeding birds. Skylarks foraged for longer in such fields, so reducing flight times and foraging distances, while increasing foraging efficiency when provisioning young. For other species, weak links to in-field invertebrates or weed populations emphasised the importance of access through the canopy for foraging individuals, via the UP. For field margins, the association between invertebrates and birds was much stronger than in crops. However, a non-vegetative component was identified, that once again underlined the importance of access to birds attempting to forage there. The combination of a margin ‘reservoir’ of food alongside improved access probably underpinned the relative ‘attraction’ of treatment 2 to birds in general.

Overall, for field margins, the responses by boundary-based species to their management within the SAFFIE project suggested that conditions in margins could be tailored and improved to exceed the ‘performance’ of a standard implementation of seed mix and autumn cutting regimes (see section 7.4.6). For birds, management should encourage a strong 'ground dwelling' invertebrate population alongside structurally diverse swards that allow superior access to margins for foraging birds in both summer and winter. In this way, the SAFFIE data were encouragingly supportive of ongoing, intensive studies of margin manipulations to improve foraging access for birds, where significant benefits have been demonstrated (Douglas in prep).

For crops, the SAFFIE data were in themselves significant because of the enormous scale at which winter wheat is grown in the UK. The results suggest that relatively simple measures can help to increase the populations of large numbers of birds across the wider countryside. This scale of change is imperative if national population trends to be positively enhanced in future. Almost all species groups responded in a way that contrasted with the 'woodland' species. The woodland group are species encountered in hedgerows, like tits, some warblers, treecreeper and great spotted woodpecker) that were least likely to responded to the SAFFIE treatments and especially to the in-field treatments. They acted as a control for observer biases in counting effort between treatments and their contrasting responses to other 'farmland' species groups indicated that the difference between treatments displayed by the farmland species was unlikely to be random or a function of observer biases.

The response by farmland species to treatments was most likely a genuine affect of the in-field/margin combination treatments and greater access into the crop. By combining crops and non-cropped areas in strategic fashion, this would allow for flexible and effective management for biodiversity around crops. Such conditions would procure an 'integrated ecology', with year-round benefits for birds that require breeding sites, and access to summer and winter food (see also 0).

SAFFIE research has demonstrated that the precise implementation of management combinations for birds, needs to be carefully considered to guard against potentially serious interactions that lead to excessive rates of predation on nest contents in crops (see 7.5.2.2).

7.5.2.2 Factors affecting nest predation

Despite the positive effects on territories, bird and nest densities of bird species (including skylark) described in 7.4.5.1 and 7.4.5.2, after two years of Experiment 3 there were indications that on some treatments (notably T2) skylarks were experiencing reduced breeding success and productivity. Rates of skylark nest predation were somewhat variable with year, with highest nest predation rates occurring in cereal fields with experimental 6m grass margins. Furthermore, highest predation rates were closest to margins, within the first 50m. In fields without grass margins, the relationship between predation rate and field edge was non-significant. Within grass margins themselves, nest survival was relatively high, probably due to most nests being well concealed under dense, creeping vegetation. Variability (albeit non-significant) in skylark DPR between the two treatments with margins (T2 and T3), suggested that although the presence of grassy field margins alone may be sufficient to raise depredation rates, the highest rates of nest predation were only associated with the combination of UP and grass margins, as found in T2. As hypothesised, ground nesting and foraging birds benefited from T2, which provided greater available breeding habitat and greater abundance and/or accessibility of plant and invertebrate food over a wider area and in a greater range of vegetation types. For several species this proved to be the case, including a positive effect on densities of skylark territories (significantly greater than on any other treatment; 1.9

times so than on T1, the treatment with the lowest density) and nests (significantly greater than on T1 and T3; 1.75 times so than on T1, the treatment with the lowest density). However, the low breeding success and productivity, due to increased nest depredation, poses a potential ecological trap, as represented in Figure 7.46, as T2 has high nest density but low productivity (Battin 2004). To maximise the numbers of skylarks fledged (productivity), the desire would be to improve nest density and breeding success. This is be illustrated in the figure below where the situation represented in the top left hand corner of Figure 7.46, is moved to the top right hand corner. Some possible solutions to facilitate this are outlined in the *Recommendations* below.

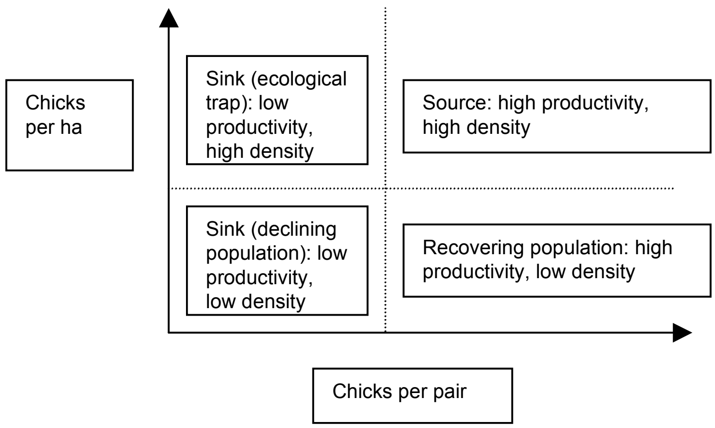

Figure 7.46 The hypothetical relationship between skylark productivity and population density.

The high nest predation rates experienced in fields with both experimental grass margins and UP are perhaps most likely a function of increased predator attraction to these sites, which are likely to offer enhanced foraging opportunities to most generalist predators. Although mammals were not directly monitored during the experiments, SAFFIE revealed that abundance of both birds and invertebrates increased in the crop adjacent to experimental margins. Other studies have shown that the presence of grass margins can greatly increase the abundance of small mammals (Shore et al. 2005). Mammalian predators may be attracted by this increased food abundance (invertebrates, small mammals or birds), and may then occur at higher densities within the adjacent crop (both badger and rodents were recorded foraging in the centre of experimental fields), resulting in increased opportunistic nest depredation by mammals. Opportunistic foragers, such as foxes and badgers, are known concentrate their efforts in response to the availability of food resources (Lucherini & Crema 1995). Although both species can rely heavily on earthworms, this food source is dependent on environmental conditions and alternative foods and foraging habitats (e.g. crops in dry weather, such as experienced during summer 2006) are readily utilised (Cavallini & Lovari 1991). Additionally, high skylark nest densities in T2 could lead to increased nest encounter rates by predators, possibly allowing individuals to develop a search image for nests and thus increasing local nest targeting.

Although birds, including various corvids and raptors, are known to depredate skylark nests (Donald 2004), the camera study strongly suggests that mammals are likely to be the main depredators. As sample sizes from the nest cameras were relatively small and originated from a single year, it was not possible to draw robust conclusions on predator activity from this study. On camera, the greatest range and encounter rate of mammalian predators occurred in, or close to, the margins. Faeces, tracks and route ways found near margins further support this pattern. It has been shown that the introduction of 6m margins into arable fields increased the small mammal biomass at the field edge by up to three times compared to standard field edges (Shore et al. 2005) but this study recorded only one depredation by a rodent. At night, rodents were also recorded visiting deserted nests with abandoned eggs and empty nests that had previously been depredated but when they encountered nests with incubating females, no attempts were made to depredate the nests, suggesting that parent birds are often capable of repelling small mammals. This study found that larger predatory mammals, which may be tracking dispersing invertebrates or small mammal populations, caused the majority of nest depredations. Stoat, weasel and red fox, the latter not recorded depredating nests in this study but a known depredator of skylark nests elsewhere (Tryjanowski 2000), were filmed only in close proximity to the margins. In contrast, badgers, the main depredating species in 2006, were active on treatments with and without margins and throughout the field, depredating nests from the edge up to 120m into the crop. Larger mammals were recorded moving along the interface between margin and crop, particularly as the margins became more overgrown. From here, they would be able to easily access the network of tramlines running across the field centre. Although Donald et al. (2002) reported greater rates of nest predation next to tramlines in conventionally managed cereal crops, in this experiment the proximity of nests to tramlines was not a significant predictor of predation. This was possibly because there was a trend for later nests to move towards UP when they are present in the crop (see Chapter 4).

Although year effects were not significant, the T2 daily predation rate was lower in 2006. Without further research, it is impossible to determine whether this was a stochastic fluctuation, due to factors such as the extreme weather conditions or low numbers of voles reported in 2006, or whether it represents a rebalancing of predator - prey populations over time in response to vegetation management. The lack of between-treatment difference in predation rates for a suite of hedgerow-nesting bird species perhaps suggests that the principle nest predators differ from those of ground-nesting birds. It is possible that avian predators, such as corvids, predate a high percentage of nests in hedgerows, as suggested by Stoate & Szczur (2002). However, data verifying the identity of predators of non-artificial nests/eggs in hedges on European farmland appears to be lacking.

Recommendations to reduce predation rates of ground-nesting passerines

Rigorous testing of UP in SAFFIE has shown they enhance skylark densities and are beneficial to breeding success (Morris et al. 2004, Donald & Morris 2005). Grass margins also benefit a range of taxa including, under certain circumstances, nesting and foraging skylarks (Edwards et al. 2001, Wilson 2001). SAFFIE has demonstrated synergistic effects of combining the two management practices in the same field. For many species the effect was positive but skylarks suffered very high rates of nest predation, resulting in productivity per unit area falling below even the low level found in conventional wheat crops. If the level of predation observed in SAFFIE were repeated, wide-scale implementation of the same combination of options, EF8 (Skylark Plots) and EE3 (6m grass buffer strips, which differ only slightly from the SAFFIE grass margins), side by side in the same field throughout England via ELS has the potential to negatively impact the skylark population. This is contrary to the objectives of the scheme and option EF8, which were designed to benefit widespread but declining species such as the skylark.

One of the stated SAFFIE objectives is to 'communicate the research results … in order to facilitate the adoption of effective conservation measures'. Advice or mitigation should therefore be provided for placement of these options in agri-environment schemes to benefit key crop nesting species, such as the skylark.

One potential solution to the predation problem would be to advocate that grass strips and UP are not placed in same field in ELS agreements. However, for many other species this would not be desirable, as SAFFIE results suggest that the synergistic effect of combining the two management options is beneficial in the vast majority of cases.

Another possible solution may be a zone of separation between UPs and grass margins. In SAFFIE, productivity per unit area, of nests more than 50 m from the margin, was better than conventional wheat; at distances of more than 75 m from the margin it was similar to the high levels on fields with UP without margins. However, such zones of separation have yet to be tested experimentally and this should be a priority before it can be recommended with confidence for ELS management guidelines.

There may also be some possible disadvantages with such a zone of separation. It is possible that it could discourage some hedgerow species that appear to benefit from the combination of UP and margins from foraging in UP. However, 50–75 m is well within the core foraging range of most bird species. A zone of separation could also reduce colonisation of UP by invertebrate food. However, the value of UP as foraging areas is believed to be due primarily to provision of access to food via the short sparse swards, rather than as centres of food abundance per se (see 7.4.6.3, Morris et al. 2004). High densities of UP could concentrate skylarks in the crop-centre, potentially attracting higher densities of mobile predators to these areas. Donald (2004) documents such an example in set-aside, although it is doubtful whether winter wheat crops, even with favourable management, would support such high densities of skylarks or other bird species.

It is possible that reductions in predation could also be attempted through predator control. However, with data from a limited sample gathered during a single breeding season, it is still uncertain whether the predators identified in this study would necessarily be the same in the majority of situations. Even if this is found to be the case, unless undertaken by a special licence, current legislation in Great Britain prohibits the killing of badgers, the chief nest-predator in 2006. Others, such as stoat and weasel, are difficult to control effectively without substantial and continual effort by experienced gamekeepers: a resource no longer available to many arable farmers, including most of those taking part in SAFFIE.

Ultimately, if the numbers of ELS agreements containing UP remain low (currently they are in <3% of agreements), then there is no prospect of wide-scale synergistic effects, positive or negative, of positioning this combination of options in the same field. However, should a revision of option funding or changes in farmer attitude lead to an increase in UP uptake, then a programme of monitoring nest predation and predators should be considered to assess effects at the wider scale and whether the suggested mitigation measures are effective.

Until further results are available to validate a zone of separation it is reasonable to recommend UP's are placed >50m from the field boundaries in wheat fields, particularly those with margins. In addition to the direct ground predation issue, skylarks are unlikely to nest within 50m from tall boundary structures.

7.5.2.3 Bird foraging in margins during winter

There was only a weak effect of the sown seed-mix on bird distributions in winter. Factors or co-variables not directly related to the establishment and management of the margins, such as year, month and presence of adjacent hedges were generally strong and consistent predictors of bird counts. As in summer, margin management had an effect on determining bird numbers while margin seed mix was relatively unimportant. In 2005/06, the greater number of birds present in January compared to January 2004/05 probably relates to margin age, and bird resource accumulating between years (D Westbury, S Harris & V Brown, unpublished data). The significant interaction between year and seed mix, for seed eating passerines (SEPs), suggests that the compositional properties of margins may also mature, since between the two winters, SEPs showed a greater increase in the fine grass mix (the forbs component being relatively slow to seed) than in tussock grass. As expected, November counts were greater than those in January, as some depletion of the food-resources is expected during winter. The scale of the decrease, in bird counts, over the two-month period (between 52-65%), suggests that depletion of resources was considerable, especially for SEPs. Higher bird densities in margins by hedgerows were also expected, as most species use hedgerows as cover from predators between foraging bouts.

The main or interaction terms of management had an effect on densities in all models, but contrary to our predictions, that not cutting in autumn would leave more seed available for foraging birds, densities on the no-cut treatments for the ALL-species and GRAN-species models were lower than in the autumn-cut treatments. The sample size of the autumn cut treatments in winter 2005/06 was low (three sites, 24 replicates), compared to the no-cut treatment (seven sites, 56 replicates) but cut treatments still held higher counts of birds, such as thrushes & starling (ratio = 125:60) and gamebirds (ratio = 113:43). For birds that glean food off low vegetation or probe the soil for it, low cut swards probably improve access, which may be as important as food abundance per se. Even for SEPs, the highly significant interaction between management and winter-period, indicated that densities per 100 m were almost nil on the no-cut treatments in January, while those on the cut treatment actually rose slightly from November (although only to around half a bird per 100m). This suggests that access to food was important to some SEPs, such as buntings, which feed primarily on the ground for seeds produced from tall or low/prostrate vegetation.

In conclusion, relatively cheap but effective solutions for farmland birds may be achieved by focusing attention on margin management. Management that promotes access to short, open swards is likely to benefit the widest range of farmland bird species. Investigations into the proportion of habitat required to maintain or diversify invertebrate populations relative to that required to promote bird access are of future interest.

7.5.3 Trophic links

Generally, there was a strong response by most farmland species or species groups to the combined effects of in-field and field margin management. The consistently stronger association with T2 rather than to T3 (margins only) indicated that crop-access was probably the major influence.

The link between vegetation structure and foraging for farmland birds was known from previous studies (see Wilson et al. 2005 for a summary). For skylarks foraging in set-aside, Henderson et al. (2001) suggested an optimal vegetation height of around 20cm, with patches of bare earth. This study found no significant relationship between mean vegetation height and foraging for skylark or any other group studied Openness and variability in height (patchiness) of the sward were both significant predictors of foraging and it is quite possible that the relationship with vegetation height recorded in some studies is a surrogate for unmeasured variables, such as sward heterogeneity. In this study, there was a general preference for greater diversity in height. This probably represents selection of locations with more open areas, for greater access and/or foraging opportunities, but also with sufficient taller vegetation to provide cover from predators, a microhabitat for invertebrate food and/or a source of grass seed or wheat grain.

Due to their highly correlated nature, at the fine-scale, it proved difficult to quantify the importance of openness of the canopy (providing an access point for many species) compared to openness at the ground level (which may aid movement, detection of food and capture of mobile invertebrate prey). Other than for skylark, the MAMs retained the latter measure, suggesting that openness at the ground level may be the more important measure for most species. However, in reality both measures are probably important (as suggested by consistent significance in univariate tests). For skylark, relationships with sward openness and variation in height were strongly positive and linear. This suggests that skylarks forage in very open swards with a greater variance in height, than other passerine species, where the relationships were curved; although with strong positive components. This may be due to some insectivorous species studied benefit from a degree of vegetation cover: either because a large amount of food is taken by gleaning, e.g. common whitethroat, or captured when perching on (or on foraging flights from) plants, e.g. yellow wagtail.

At the field-scale, it is important that neither the vegetation characteristics nor invertebrate densities in crops were as strong or as consistent in determining the distribution of birds in crops as was the difference between SAFFIE treatments (T1 to T4).

This suggests that birds at the whole-field scale, were mainly responding primarily to large-scale availability of bare ground (UP or otherwise) and secondarily to smaller-scale subtleties in vegetation characteristics. Birds foraging at identified locations within crops showed stronger links to fine-scale differences in vegetation type or invertebrate numbers. For boundary-nesting bird species, attracted primarily to the likely benefits provided by field margins for food and cover, the addition of adjacent access areas to the ground for foraging purposes within crops is a significant, biologically meaningful requirement of their foraging ‘territories’. These features are undoubtedly missing from large areas of arable farmland.

Field margins: Field nesting species such as skylark and yellow wagtail also benefit from field margins in open landscapes (more typical of SAFFIE sites in Lincolnshire and Essex) as nesting and foraging locations. However, unlike skylarks, yellow wagtails are reported to generally avoid field edges, even where there is no vertical boundary structure (Gilroy 2007) and no yellow wagtail nests were found in the SAFFIE margins. It is likely that there would also be some movement of invertebrates into adjacent crops from margins, even though there was not sufficient variation to pick up links to bird densities at the field-scale, in this study.

In margins, there were far stronger links to invertebrate densities, than in crops. invertebrate densities were higher in field margins and, importantly, the spatial link between recorded bird locations in margins and invertebrate sampling at the field-scale was closer. there was greater variability in vegetation and invertebrate characteristics due to the twin margin-treatment regimes of seed mix and management. Birds in margins were most strongly associated with beetles and spider abundance (consistent with bird-diet studies; e.g., Holland et al. (2006), and very weakly linked to other species groups (e.g., Auchenorrhyncha), which despite their abundance, appear to be under-selected in bird diets (e.g., Holland et al. 2006). this reflects behavioural differences between invertebrates groups and their ease of capture for bird predators, and/or it reflects their choice of habitat higher in the grass/flower canopy. By contrast, important invertebrate groups are influenced by structural complexity in margins (as with some common Lycosidae as well as ground [carabid] beetles), preferring a 'sunlight' element of bare ground or litter, alongside vegetation for breeding and cover. Certainly for birds, a bare ground/litter component to margins was the strongest, positive 'vegetation' effect on their presence there. This finding is consistent with the in-crop analysis and further emphasises the need for foraging access for birds that use either crops or field margins. Some previous studies have also reported positive relationships at the fine-scale between birds foraging in arable habitats and abundance of invertebrate foods. For example, Morris et al. (2002) showed that increased regularity of yellowhammer foraging in the crop was positively related to the abundance of invertebrate chick-food. This was not detected in this study, in which invertebrate numbers in the crop were low compared to the above study, in which some fields were organically managed. Where food abundance is generally low (as will be the case in many arable habitats), providing a patchy and more open sward to permit adequate access to the available food is clearly an important factor for many farmland passerines. The results from the fine-scale foraging analysis support the conclusions of Experiment 1.1 that providing access to food in the crop, through measures that deliver a more open and variable sward structure (such as UP), should be beneficial, even if they do not significantly increase the amount of food present.

7.5.4 Within crop vegetation

The analysis of the TG treatment vs no margin and comparisons of the two sown margin types indicate that by far the most important factor for the weed flora and crop was distance from cultivated margin. However, this effect was limited to the area close to the edge of cultivation; for weed variates the effect extended to 1.5 m and for crop cover to between 2 and 4 m. This rapid decline of total weeds is consistent with other studies (Marshall, 1989, Wilson & Aebisher, 1995), but suggests that the effects of the field margin are only important closer to the cultivated edge than the effects described by Wilcox et al. (2000).

For all weeds, arable species and desirable species, there was no effect of sowing a margin on the weed flora, i.e. there was no difference between quadrats located at the original field boundary compared to quadrats located at 6 m from the original field margin (sampled between one and three years after margin establishment). This suggests that the impact of the margin is not a result of a historical build up of seeds in the soil at the crop edge, but an immediate impact of the adjacent margin. This effect is presumably at least in part a result of reduced crop competition at the crop edge (Wilcox et al., 2000).

For undesirable species there was an interaction between margin presence and distance from the cultivated edge, with lower undesirable weed cover where a margin had been sown (Figure 7.8). Many undesirable species are common in highly fertile, uncropped, field margins from where they can spread into the crop (e.g. *Galium aparine*, *Anisantha sterilis*) whereas many more desirable species (e.g. *Stellaria media*, *Polygonum aviculare*) are restricted to the crop area (Marshall, 1989). Many of these undesirable species have relatively little persistence in the soil (Grime et al., 1988), therefore a historical build up of seeds in the soil is unlikely. However the margins were sown with perennial species which reduced the density of undesirable species in the area immediately adjacent to the crop (Table 7.18), thereby reducing the likelihood of these species establishing in the cropped area.

The absence of an effect of margin or patch presence on weed cover in the field centre would be expected, given plants' lack of mobility and the fact that these samples did not coincide with any undrilled patches.

There were few effects of sample date on weeds, although crop cover increased and bare ground decreased between June and July. Where there was an effect of sample date, cover of weeds tended to decrease, perhaps because by July many plants had either already set seed or were starting to desiccate and therefore represented lower percent cover. However, differences were generally small and this reflects the relatively short interval between samples (3 to 4 weeks).

7.5.5 Within crop invertebrates

An outcome of increased farm size (due to 20th century intensification of agriculture) and associated economies of scale has been the removal of hedges, the simplification of rotations and the introduction of block cropping. Consequently there has been a reduction in crop diversity and a loss of non-crop habitats, both of which have contributed to a decline in invertebrate diversity on arable land (Potts, 1991; Stoate *et al*, 2002). Remaining structural heterogeneity has been shown to benefit invertebrates, particularly in the case of field boundaries. Field boundaries adjacent to crops are utilised by beneficial invertebrates for overwintering and aestivation, as foraging sites in winter and summer and also for breeding. The complexity of the habitat structure and the plant species composition will determine the range of niches and hosts available and consequently the diversity and abundance of invertebrates capitalising on the resource (Morris & Webb, 1987). Invertebrates move between the boundaries and the crop and consequently the invertebrate composition of the boundary can affect the abundance, diversity and distribution of invertebrates in the adjacent crop. Previous work has shown that the less mobile species decline in abundance with increasing distance from the boundary in to the crop, whereas more mobile species achieve a more extensive and rapid spread (Coombes & Sotherton, 1986). There are some exceptions however; some species show a greater species differentiation between uncropped and cropped areas (e.g. spiders), and consequently the presence of boundary habitats has little impact on abundances within the adjacent crop (Kromp & Steinberger, 1992; McLachlan & Wratten, 2003). Boundaries also act as refuges from the perturbations of farming practices facilitating reinvasion of areas where population reductions have occurred. Previous studies examining the effects of boundaries on invertebrates within the crop have focussed either on the influence of existing boundaries or beetle banks (reviewed by Landis et al., 2000).

Evidence that sown field margins can enhance the invertebrate fauna of the adjacent crop is scarce and most prolific for predatory invertebrates, including Carabidae and Syrphidae (Harwood et al., 1992; Kielty et al., 1992; Thomas et al., 1999, 2001; Powell et al., 2004). It is almost non-existent for most taxa important in the diet of farmland birds. Invertebrate abundance and species composition is often higher close to field margins (Moreby, 1994; Holland et al., 1999, 2004, 2005) but whether they are enhanced further by the presence of wider margins is not known. Not all invertebrates overwinter in field boundaries and some of the numerically most dominant species overwinter as larvae within fields (e.g. many species of Carabidae and Diptera) (Nielsen et al., 1994; Holland et al., 2007), although the adults may make use of margins for foraging.

Evidence, that altering the structure of the crop by introducing undrilled patches benefits birds, was found in SAFFIE experiment 1.1, however, the patches only had localised effects for invertebrates. In this study we examined whether the sown field margins and undrilled patches (in combination) could affect the abundance and distribution invertebrates. We had two focii: 1) to establish the effect of margins and undrilled patches on ground-active invertebrates according to where they overwinter; 2) to assess the effects on invertebrates important in the diet of farmland birds by using a variety of indices.

7.5.5.1 Indices

Four indices were chosen to assess the value of the combination of margins and patches for farmland birds. The SFI (skylark food index) comprised invertebrate groups we know to be part of skylark diet from faecal analysis performed for SAFFIE experiment 1.1. This information added to that which has been previously published (Holland, Hutchinson *et al* 2006). CFI (Chickfood index) is a weighted index calculated specifically to assess food resources for the Grey Partridge (Potts & Aebischer, 1991). However, as several farmland bird species have similar diets, the CFI is a robust measure of avian food resource in the breeding season. The 4FI (four food index) was developed to assess the impact of agricultural change on corn buntings and comprised key dietary components (Brickle *et. al*., 2000). Similarly, the YHI (Yellowhammer Index) was composed to assess the impact of agriculture on the breeding success of Yellowhammers (Hart *et. al*. 2006). Together, these indices well represented the effects of treatment on invertebrate food resources available to farmland birds.

7.5.5.2 Effects of sown margins and undrilled patches

The was no significant effect of either the sown margins or undrilled patches alone on the invertebrate groups collected using pitfall traps, suction sampler or sweep net, either on the transects or in the middle of the fields. Of all the invertebrate groups, the numbers of boundary overwintering Carabidae and Staphylinidae in the adjacent crop, as measured using pitfall traps, would be most expected to respond to the additional overwintering habitat provided by the sown margins. These invertebrates prefer mature tussocky grasses for overwintering which take several years to develop. Even so, previous studies of beetle banks revealed that a suitable habitat structure capable of sustaining substantial numbers of beetles can develop within two years (Thomas et al., 1991). The lack of any effect may have resulted from: a) only half the margins sown with tussocky grasses, the remainder with fine grasses that may be less suitable for overwintering; b) beetles remaining within the margins; in another study, approximately a third of the Carabidae and half the Staphylinidae measured during the winter remained within field boundaries during the summer (Thomas et al., 2000); c) beetles redistributing by the time of sampling and mixed with those originating from areas beyond the field, species capable of flight can achieve rapid coverage across the whole field (Coombes & Sotherton, 1986; Kromp & Nitzlader, 1995), masking any margin affects; d) margins supporting too few invertebrates to have any impact on field populations (Holland et al., 2006).

Some phytophagous taxa, comprising the various bird food indices, may also have been expected to be enhanced by the sown margins because more suitable vegetation would be available when compared to the narrower standard margin. None of the indices were affected by the presence of either margin or undrilled patches. It is known that the abundance of these groups within fields is highly dependent on the abundance of arable weeds (Moreby & Southway, 1998) and as the weeds declined sharply with increasing distance from the boundary this may explain why the sown margins had little impact on invertebrate distribution and abundance within the field.

7.5.5.3 Interaction between undrilled patches and margins

While the treatments had no effect independently there was a synergistic effect of the two combined. The seed eating beetles and boundary overwintering carabids along with the SFI, YHI and total crop active invertebrates collected by suction sampling were more abundant where there was a margin but no undrilled patches, however, when undrilled patches were introduced alongside margins, the abundance of these groups was limited. This suggests that the sown margins were increasing these groups within the field but that there was a restricting factor associated with the undrilled patches. Although further study would enhance our understanding, it can be hypothesised that the reduction may be due to higher predation by birds or small mammals within the fields containing the patches, their numbers also being boosted by the presence of the sown margins. It is unlikely that the presence of the undrilled patches themselves was affecting the invertebrates as in SAFFIE experiment 1.1 the undrilled patches had a negligible effect on invertebrates. The effect is not limited to sites close to the margins but extends into the field and is still evident at 96m (our mid-field sampling point).

7.5.5.4 Margin seed mix

The seed mix of the margin had very little independent effect on invertebrates in the adjacent crop. Only seed eating (ground active) beetles responded and were more abundant next to field margins, especially the fine grass mix where there was likely to be a greater abundance of food.

7.5.5.5 Effects of distance from crop edge

The numbers of boundary overwintering Staphylinidae was lowest close to the field edge, which was the opposite of the expected result, but as these invertebrates disperse in early May, any effect of the margin may have been masked by redistribution. Numbers of seed eating beetles and the 4FI that is comprised of mostly phytophagous invertebrates, declined with distance from the margin, a result that is to be expected; the food resources for these invertebrates were high within the margin and they are only likely to move and penetrate the crop if the appropriate arable weeds are sufficiently abundant, however, all weed cover declined sharply into the field. Frequently the effect of distance from the field edge was confounded by the effect of margin presence. The field overwintering Staphylinidae and total number of invertebrates collected by pitfall trapping increased with distance from the field edge when there was a margin but were more evenly distributed where there were no sown margins, possibly indicating that the margins were acting as a sink habitat. Similarly, the abundance of 4FI (suction sampling) and CFI, SFI and YHI estimated from sweep netting, was higher at 1m where there was no margin than when a margin was present, suggesting that invertebrates remained in the margin rather than dispersing into the adjacent crop.

7.5.5.6 Temporal effects

Temporal effects were expected. The field overwintering Staphylinidae were more numerous in early July than early June, whereas the reverse occurred for the boundary overwintering Staphylinidae, this difference reflecting their phenology. The total number of invertebrates collected by pitfall trapping was also higher in early June. Food resources for birds (SFI, YHI) and total invertebrates collected by suction sampling were higher in early July. There were interactions between collection date and distance from the crop edge; SFI and YHI were most abundant at 1m early in the year but by June had moved out into the crop and were more abundant at 16m, indicating that these may be more available to birds feeding in the crop at this time providing there is sufficient access. Unexpectedly, the SFI estimated from suction samples and sweep netting declined steadily each year; there were no concomitant year effects on the weed abundance and it is unclear why there should be an annual decline.

7.6 CONCLUSIONS AND KEY RECOMMENDATIONS

7.6.1 Agronomy

There were no adverse effects on weed pest disease levels from incorporating margins and undrilled patches into an arable rotation dominated by winter-crops.

7.6.2 Birds

For all species and species groups, bird densities and territories were consistently higher on T2 (between 1.3 and 2.8 times higher) than on a normal conventional crop (T1). This response was consistent also for species on the Farmland Bird Index species and Biodiversity Action Plan species, for which farmland recovery is particularly desirable. The results indicate that birds were responding to fields containing both field margins and UP.

The combination of UP and field margin resulted in the highest density of skylark nests but also the highest level of nest predation by mammalian predators. This led to an overall low level of productivity compared to the other treatments. However, if UP's are placed >50m from margins then the predation effect had much less impact.

In field margins, birds responded to higher beetle and spider abundance, to more complex swards comprising a non-vegetative, litter component – but with only weak links to seed-mix composition. In wheat crops, birds responded to the presence of UP (large-scale open ground), and bare ground at a fine-scale at foraging locations within the crop – but with only weak links to invertebrate abundance.

The effect of creating bare ground and foraging access in dense crops and field margins was the single most important management action to affect a significant increase in bird densities and breeding territories for both field and boundary nesting species. Open ground can be achieved at relatively low cost by scarification in margins, and by creating UP at the recommended rate in wheat crops. For birds, margin sward content in terms of the grass/flower mix, is best managed to encourage beetles (especially carabidae) and spiders (Arachnidae).

7.6.3 Within crop vegetation

Overall the sown margins and patches had relatively few effects on the numbers of invertebrates within the crop and, therefore, the abundance of food available to farmland birds. There was some evidence that invertebrates were remaining within the margins rather than dispersing into the adjacent crop as would be expected if the margins provided more desirable resources. Further analysis comparing the invertebrate species composition of the margins and crop may reveal whether the two were associated. The low levels of weeds within the crop may also have inhibited colonisation by phytophagous invertebrates and their associated predators. On the other hand, there was an indication that invertebrate predation may have been higher where margins and patches were present, so that the effects of the margins were obscured. The establishment of wider field margins and undrilled patches would not appear to be a suitable technique for boosting food supplies for farmland birds within crops nor predatory insects for pest control. Undrilled patches support few extra invertebrates and only occupy a small proportion of the field (see section 7.4.4), but lower herbicide inputs did have a substantial impact on invertebrates (see experiment 1.2).

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7.8 REFERENCES

Anon (2005) Entry Level Stewardship Handbook. RDS, UK.

Arable cropping and the environment – a guide" HGCA/DEFRA 2002

Battin, J. (2004) When good animals love bad habitats: Ecological traps and the conservation of animal populations. *Conservation Biology* **18,** 1482-91.

Benton, T.G., Vickery, J.A. & Wilson, J.D. (2003) Farmland biodiversity: is habitat heterogeneity the key? *Trends in Ecology & Evolution* **18,** 182-188.

Boatman, N.D., Jones, N.E., Garthwaite, D. & Pietravalle, S. (2007) Option uptake in entry level scheme agreements in England. *Aspects of Applied Biology* **81,** 309-316.

Brickle, N.W., Harper, D.G.C., Aebischer, N.J. & Cockayne ,S.H. (2000) Effects of agricultural intensification on the breeding success of corn buntings *Milaria calandra*. *Journal of Applied Ecology* **37,** 742 - 755.

Cavallini, P. & Lovari, S. (1991) Environmental factors influencing the use of habitat in the red fox*. Journal of the Zoolological Society* **223,** 323-339.

Chamberlain, D.E., Fuller, R.J., Bunce, R.G.H., Duckworth, J.C. & Shrubb, M. (2000) Changes in the abundance of farmland birds in relation to the timing of agricultural intensification in England and Wales. *Journal of Applied Ecology* **37,** 771-788.

Coombes, D.S. & Sotherton, N.W. (1986) The dispersal and distribution of predatory Coleoptera in cereals. *Annals of Applied Biology* **108,** 461-474.

Crawley, M.J. (1993) *GLIM for Ecologists*. Blackwell Scientific Publications, Oxford.

Donald, P.D., Sanderson, F.J., Burfield, I.J. & van Bommel, F.P.J. (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds 1990-2000. *Agriculture Ecosystems and Environment* **116,** 189-196.

Donald, P.F. & Morris T.J. (2005) Saving the Sky Lark: new solutions for a declining farmland bird. *British Birds* **98,** 570-578.

Donald, P.F. (2004) *The skylark*. Poyser, London.

Donald, P.F., Evans, A.D., Buckingham, D.L., Muirhead, L.B. & Wilson, J.D. (2001) Factors affecting the territory distribution of Skylarks *Alauda arvensis* breeding on lowland farmland. *Bird Study* **48,** 271–278.

Donald, P.F., Evans, A.D., Muirhead, L.B., Buckingham, D.L., Kirby, W.B. & Schmitt, S.I.A. (2002) Survival rates, causes of failure and productivity of skylark *Alauda arvensis* nests on lowland farmland. *Ibis* **144,** 652-664.

Douglas, D., Benton, T. & Vickery, J.A. (In prep) Vegetation height influences the use of field margins by foraging birds.

Edwards, P.J., Schmitt, S.I.A., Jenner, T., Cracknell, J. & Everett, C.J. (2001) Research into the value of field margins for skylarks *Alauda arvensis*. In: *The*

Ecology and Conservation of Skylarks eds. P F Donald & J A Vickery, pp. 203-207. RSPB: Sandy.

Garthwaite, D.G. & Thomas, M.R. (1999) *Arable Farm Crops in Great Britain 1998*. *Pesticide Usage Survey Report 159*. Ministry of Agriculture, Fisheries and Food, & Scottish Executive Rural Affairs Department, London.

Gilroy, J.J. (2007) Breeding ecology and conservation of yellow wagtails *Motacilla flava* in intensive arable farmland. Unpublished PhD thesis, University of East Anglia.

Grime, J.P., Hodgson, J.G., Hunt, R. (1988). Comparative Plant Ecology. Oxford University Press, London.

Hart, J.D., Milsom, T.P., Fisher, G., Wilkins, V., Moreby, S.J., Murray, A.W.A. & Robertson, P.A. (2006) The relationship between yellowhammer breeding performance, arthropod abundance and insecticide applications on arable farmland. *Journal of Applied Ecology* **43,** 81-91.

Harwood, R.W.J., Wratten, S.D. & Nowakowski, M. (1992) The effect of managed field margins on hoverfly (Diptera: Syrphidae) distribution and within field abundance. *Brighton Crop Protection Conference - Pests and Diseases* 1033-1037.

Henderson, I.G., Critchley, N.R., Cooper, J. & Frowbert, J.A. (2001) Breeding season responses of skylarks *Alauda arvensis* to vegetation structure in set-aside (fallow arable land). *Ibis* **143,** 317-321.

Holland, J.M., Winder, L., Woolley, C., Alexander, C.J. & Perry, J.N. (2004) The spatial dynamics of crop and ground active predatory arthropods and their aphid prey in winter wheat. *Bulletin of Entomological Research* **94,** 419-431.

Holland, J.M, Southway, S., Birkett, T. & Moreby, S. (2006) The relative merits of field and boundary habitats for conservation biocontrol. In: W.A.H Rossing, L. Eggenschwiler & H-M. Poehling. (Eds) Landscape management for functional biodiversity*. IOBC/WPRS Bulletin* **29,** (6), 57-60.

Holland, J.M., Hutchison, M.A.S., Smith, B. & Aebischer, N.J. (2006) A review of invertebrates and seed-bearing plants as food for farmland birds in Europe *Annals of Applied Biology* **148,** 49–71.

Holland, J.M., Perry, J.N. & Winder, L. (1999) The within-field spatial and temporal distribution of arthropods in winter wheat. *Bulletin of Entomological Research* **89,** 499-513.

Holland, J.M., Thomas, C.F.G., Birkett, T. & Southway, S. (2007) Spatio-temporal distribution and emergence of beetles in arable fields in relation to soil moisture**.** *Bulletin of Entomological Research* **97,** 89-100.

Holland, J.M., Thomas, C.F.G., Birkett, T., Southway, S. & Oaten, H. (2005) Farm-scale spatiotemporal dynamics of predatory beetles in arable crops. *Journal of Applied Ecology* **42,** 1140-1152.

Johnson, D.H. (1979) Estimating nest success: the Mayfield method and an alternative. *Auk* **96,** 651-661.

Kielty, J.P., AllenWilliams, L.J. & Underwood, N. (1992) The effects of set-aside field margins on the distribution and biocontrol potential of polyphagous predatory arthropods in arable crops. *BCPC Monograph* No. **50,** *Set-Aside*, 169-174.

King, C. (1989) *The Natural History of Weasels and Stoats*. Christopher Helm, London.

Kromp, B. & Nitzlader, M. (1995) Dispersal of ground beetles in a rye field in Vienna, Eastern Austria. *Acta Jutlandica* **70,** 269-277.

Kromp, B. & Steinberger, K.-H. (1992) Grassy field margins and arthropod diversity: a case study on ground beetles and spiders in eastern Austria (Coleoptera: Carabidae; Arachnida: Aranei, Opoliones). *Agriculture, Ecosystems & Environment* **40,** 71-93.

Landis, D.A., Wratten, S.D., & Gurr, G.M. (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Review of Entomology* **45**,175-201.

Littell, R.C., Milliken, G.A., Stroup, W.W. & Wolfinger, R.D. (2002) *SAS® System for Mixed Models*. SAS Institute, Cary.

Lucherini, M. & Crema, G. (1995) Seasonal variation in the food habits of badgers in an alpine valley. *Hystrix* **7,** 165-171.

Marchant, J.H., Hudson, R., Carter, S.P. & Whittington, P. (1990) *Population trends in British Breeding Birds*. BTO, Tring.

Marshall, E.J.P. (1989). Distribution patterns of plants associated with arable field edges. Journal of Applied Ecology **26,** 247-257.

McLachlan, A.R.G. & Wratten, S.D. (2003) Abundance and species richness of field-margin and pasture spiders (Araneae) in Canterbury, New Zealand. *New Zealand Journal of Zoology* **30,** 57-67.

Moreby, S.J. & Southway, S.E. (1999) Influence of autumn applied herbicides on summer and autumn food available to birds in winter wheat fields in southern England. *Agriculture, Ecosystems and Environment* **72,** 285-297.

Moreby, S.J. (1994) The influence of field boundary structure on heteropteran densities within adjacent cereal fields In: Boatman, N.D. (Ed) *Field Margins - Integrating Agriculture and Conservation*, 117-123. BCPC, Farnham.

Morris, A.J., Bradbury, R.B. & Wilson, J.D. (2002) Determinants of patch selection by yellowhammers Emberiza citrinella foraging in cereal crops. *Aspects of Applied Biology* **67,** 43-50.

Morris, A.J. & Gilroy, J.J. (in prep). Close To The Edge: Predation Risks For Two Declining Farmland Passerines. *Ibis*.

Morris, A.J., Holland, J.M., Smith, B. & Jones, N.E. (2004) Sustainable Arable Farming For an Improved Environment (SAFFIE): managing winter wheat sward structure for Skylarks *Alauda arvensis*. *Ibis* **146,** 155-162.

Morris, M.G. & Webb, N.R. (1987) The importance of field margins for the conservation of insects. In: Way J.M. & Greig-Smith P.W. (Eds) *Field Margins*, *BCPC Monograph no.35*, 53-65. Lavenham Press, Suffolk.

Nielsen, B.O., Nielsen, L.B., Axelsen, J. & Elmegaard, N. (1994) Winter abundance of soil Diptera larvae in arable soil. *Pedobiologia* **38,** 208-221.

O'Connor, R.J. & Shrubb, M. (1986) *Farming and birds*. Cambridge University Press, Cambridge.

Powell, W., A'Hara, S.A., Harling, R., Holland, J.M., Northing, P., Thomas, C.F.G. & Walters, K.F.A. (2004) Managing biodiversity in field margins to enhance integrated pest control in arable crops (3-D Farming Project). HGCA Project Report 356. HGCA, London.

Shore, R.F., Meek, W.R., Sparks, T.H., Pywell, R.F. & Nowakowski, M. (2005) Will Environmental Stewardship enhance small mammal abundance on intensively managed farmland? *Mammal Review* **35,** 277 – 284.

Siriwardena, G.M., Baillie, S.R., Buckland, S.T., Fewster, R.M., Marchant, J.H. & Wilson, J.D. (1998) Trends in the abundance of farmland birds: a quantative comparison of smoothed Common Bird Census indices. *Journal of Applied Ecology* **35,** 24-43.

Stoate, C. & Szczur, J. (2002) Could game management have a role in the conservation of farmland passerines?: a case study from a Leicestershire farm. *Bird Study* **48,** 279-292.

Thomas, C.F.G. & Marshall, E.J.P. (1999) Arthropod abundance and diversity in differently vegetated margins of arable fields. *Agriculture, Ecosystems and Environment* **72,** 131-144.

Thomas, C.F.G., Parkinson, L., Griffiths, G.J.K., Garcia, A.F., Marshall, E.J.P. (2001) Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats. *Journal of Applied Ecology* **38,** 100-116.

Thomas, M.B., Wratten, S.D., & Sotherton, N.W. (1991) Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: densities and emigration. *Journal of Applied Ecology* **28,** 906-917.

Thomas, S.R., Goulson, D. & Holland, J.M. (2000) Spatial and temporal distributions of predatory Carabidae in a winter wheat field. *Aspects of Applied Biology* **62,** 55-60.

Tryjanowski, P. (2002) Changes in breeding populations of some farmland birds in W Poland in relation to changes in crop structure, weather conditions and number of predators. *Folia Zoologica* **49,** 305-315.

Whittingham, M.J., Stephens, P.A., Bradbury, R.B. & Freckleton, R.P. (2006) Why do we still use stepwise modelling in ecology and behaviour? *Journal of Animal Ecology* **75,** 1182-1189.

Whittingham, M.J., Swetnam, R.D., Wilson, J.D., Chamberlain, D.E. & Freckleton, R.P. (2005) Habitat selection by yellowhammers *Emberiza citrinella* on lowland farmland at two spatial scales: implications for conservation management. *Journal of Applied Ecology* **42,** 270-280.

Wilcox, A., Perry, N.H., Boatman, N.D., Chaney, K. (2000). Factors affecting the yield of winter cereals in crop margins. *Journal of Agricultural Science* **135,** 335-346.

Wilson, P.J. & Aebisher, N.J. (1995). The distribution of dicotyledonous arable weeds in relation to distance from the field edge. *Journal of Applied Ecology* **32,** 295-310.

Wilson, J.D., Arroyo, B.E. & Clark, S.C. (1996) *The diet of birds species of lowland farmland: a literature review*. Unpublished report to the Department of the Environment and Joint Nature Conservation Committee. University of Oxford and Royal Society for the Protection of Birds, Sandy.

Wilson, J.D., Whittingham, M.J. & Bradbury, R.B. (2005) The management of crop structure: a general approach to reversing the impacts of agricultural intensification on birds? *Ibis* **147,** 453-463.

APPENDIX 1. ALLOCATION OF BIRD SPECIES INTO GROUPS FOR ANALYSIS

Table 7.A1 The allocation of bird species into groups for analysis (see definitions in 7.3.5.4) The complete Farmland Bird Index (FBI) and the full list of species currently subject to a national Biodiversity Action Plan BAP) (indicated in column 1) is greater than the number of species analysed within these sub-groups (i.e., columns FBI and BAP respectively). The sub-groups thus include species of special conservation significance (e.g. seed-eating passerines), or they excluded some relatively rare species within the dataset, where a high proportion of 'zero-counts', imposes analytical difficulties on regression models).

Species		**Insect-ivores**	**Finches & tree sparrow**	**Probers**	**Gleaners**	**Wood-land**	**FBI**	**BAP**	**Bunt-ings**
Kestrel	*Falco tinnunculus*								
Grey partridge(BAP)	*Perdix perdix*							*	
Turtle dove(BAP)	*Steptopelia turtur*								
Barn Owl(BAP)	*Tyto alba*								
GS woodpecker	*Dendrocopus major*					*			
Green woodpecker	*Picus viridus*			*					
Skylark(BAP)	*Alauda arvensis*						*	*	
Swallow	*Hirundo rustica*								
Pied wagtail	*Motacilla alba*	*							
Yellow wagtail(BAP)	*Motacilla flava*	*			*		*		
Meadow pipit	*Anthus pratensis*				*				
Dunnock	*Prunella modularis*	*			*				
Wren(W)	*Trogolodytes trogolodytes*	*			*	*			
Wheatear	*Oenanthe oenanthe*				*				
Whinchat	*Saxicola rubetra*				*				
Redstart	*Phoenicurus phoenicurus*				*				
Robin	*Erithacus rubecula*	*			*				
Blackbird	*Turdus merula*	*		*					
Song thrush(BAP)	*Turdus philomelos*	*		*				*	
Lesser whitethroat	*Sylvia curruca*					*			
Common whitethroat	*Sylvia communis*	*			*		*		
Garden warbler	*Sylvia borin*					*			
Blackcap	*Sylvia atricapilla*					*			
Willow warbler	*Phylloscopus trochilus*					*			

Cont'd……

Species		Insect-ivores	Finches & tree sparrow	Probers	Gleaners	Wood-land	FBI	BAP	Bunt-ings
Chiffchaff	*Phylloscopus collybita*					*			
Nuthatch	*Sitta europaca*					*			
Treecreeper	*Certhia familiaris*					*			
Blue tit	*Parus caerulus*					*			
Great tit	*Parus major*					*			
Marsh tit	*Parus palustris*					*			
Long-tailed tit	*Aegiathos caudatus*					*			
Carrion crow	*Corvus corone*								
Jackdaw(	*Corvus monedula*						*		
Rook	*Corvus frugilegus*						*		
Jay	*Garulus glandarius*					*			
Magpie	*Pica pica*								
Starling	*Sturna vulgaris*	*		*					
House sparrow	*Passer domesticus*								
Tree sparrow(BAP)	*Passer montanus*		*				*	*	
Bullfinch(BAP)	*Pyrrhula pyrrhula*		*		*		*	*	
Goldfinch	*Caruelis carduelis*		*		*		*		
Greenfinch	*Carduelis chloris*		*		*		*		
Linnet(BAP)	*Carduelis cannabina*		*		*		*	*	
Chaffinch	*Fringilla coelebs*		*		*				
Reed bunting(BAP)	*Emberiza schoeniclus*				*		*	*	*
Corn Bunting	*Miliaria calandra*			*				*	*
Yellow-hammer(BAP,)	*Emberiza citrinella*			*			*		*

APPENDIX 2. WITHIN CROP VEGETATION.

Table 7.A2 Effect of sample date and patch presence on percent cover of arable species and crop cover (backtransformed means).

	Patches		No patches			
	June	**July**	**June**	**July**	***F***	***P***
df = 1; n = 1176						
Arable species	2.07	1.44	0.98	1.05	10.47	0.001
Crop	57.4	62.5	59.3	61.6	4.74	0.03

Table 7.A3 Effect of margin, sample date and patches on percent cover of desirable species in the margin adjacent to the crop (backtransformed means).

Margin presence	**No margin**		**Margin**			
Date	**June**	**July**	**June**	**July**	***F***	***P***
df = 1; n = 1008						
Patches	0.37	1.70	0.49	0.54	4.28	0.043
No patches	0.25	0.24	0.43	1.29		

APPENDIX 3. WITHIN CROP INVERTEBRATE ANALYSES

Table 7.A4 ANOVA table for Pitfall data 1-32 m. A/H = Amara/Harpalus; P = Predators; BC = Boundary Carabids; BS = Boundary staphylinids; FC = Field carabids; FS = Field staphylinids; TI = Total invertebrates. * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001; ns = not significant.

Source of variation	d.f.	A/H	P	BC	BS	FC	FS	TI
SITE stratum								
YEAR	2	ns	ns	ns	ns	ns	ns	ns
Residual	9							
SITE.FIELD stratum								
PATCH	1	ns	ns	ns	ns	ns	ns	ns
MARGIN	1	ns	ns	ns	ns	ns	ns	ns
PATCH.MARGIN	1	ns	ns	ns	ns	ns	**	ns
Residual	33							
SITE.FIELD.TRANSECT stratum								
MARGIN.MTYPE	1	*	ns	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE	1	ns	ns	ns	ns	ns	ns	ns
Residual	22							
SITE.FIELD.TRANSECT.SAMPLE_NO stratum								
POSITION	2	***	*	ns	***	**	***	ns
PATCH.POSITION	2	ns	ns	ns	ns	ns	ns	ns
MARGIN.POSITION	2	ns	**	ns	ns	**	**	**
PATCH.MARGIN.POSITION	2	ns	ns	ns	ns	ns	ns	ns
MARGIN.MTYPE.POSITION	2	ns	ns	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE.POSITION		ns	ns	ns	ns	ns	ns	ns
Residual	132							
SITE.FIELD.TRANSECT.SAMPLE_NO.REPEAT stratum								
DATE	1	ns	ns	***	***	***	***	***
PATCH.DATE	1	ns	ns	ns	ns	ns	ns	ns
MARGIN.DATE	1	ns	ns	ns	ns	ns	ns	ns
POSITION.DATE	2	ns	*	*	ns	*	ns	ns
PATCH.MARGIN.DATE	1	ns	ns	ns	ns	ns	ns	ns
MARGIN.MTYPE.DATE	1	ns	ns	ns	ns	ns	ns	ns
PATCH.POSITION.DATE	2	ns	ns	ns	ns	ns	ns	ns
MARGIN.POSITION.DATE	2	ns	ns	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE.DATE	1	ns	ns	ns	ns	ns	ns	ns
PATCH.MARGIN.POSITION.DATE	2	ns	ns	ns	ns	ns	ns	ns
MARGIN.MTYPE.POSITION.DATE	2	ns	ns	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE.POSITION.DATE		ns	ns	ns	ns	ns	ns	ns
Residual	198							
SITE.FIELD.TRANSECT.SAMPLE_NO.REPEAT.*Units* stratum								
YEAR	2	***	ns	***	***	ns	***	*
Residual	322							

Table 7.A5 ANOVA table for Pitfall data 96 m. A/H = Amara/Harpalus; P = Predators; BC = Boundary Carabids; BS = Boundary staphylinids; FC = Field carabids; FS = Field staphylinids; TI = Total invertebrates. * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001; ns = not significant

Source of variation	**d.f.**	**A/H**	**P**	**BC**	**BS**	**FC**	**FS**	**TI**
SITE stratum								
YEAR	2	ns	ns	ns	ns	ns	ns	ns
Residual	9							
SITE.FIELD stratum								
PATCH	1	ns	*	ns	ns	ns	ns	ns
MARGIN	1	ns	ns	ns	ns	ns	ns	ns
PATCH.MARGIN	1	*	ns	*	ns	ns	**	ns
Residual	33							
SITE.FIELD.*Units* stratum								
DATE	**1**	ns	ns	***	***	***	*	ns
PATCH.DATE	1	ns	ns	ns	ns	ns	ns	ns
MARGIN.DATE	1	ns	ns	ns	ns	ns	ns	ns
PATCH.MARGIN.DATE	1	ns	ns	ns	ns	ns	ns	ns
Residual	116							
YEAR	2	*	ns	ns	ns	ns	*	ns
Residual	70							
Total	167							

Table 7.A6 ANOVA table for Dvac data 1-32 m. CFI = Chick food index; 4FI = Four food index; SFI = Skylark food items; YHI = Yellowhammer index; TI = Total invertebrates. * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001; ns = not significant.

Source of variation	**d.f**	**CFI**	**4FI**	**SFI**	**YHI**	**TI**
SITE stratum						
YEAR	2	ns	ns	ns	ns	ns
Residual	9					
SITE.FIELD stratum						
PATCH	1	ns	ns	ns	ns	ns
MARGIN	1	ns	ns	ns	ns	ns
PATCH.MARGIN	1	ns	ns	ns	ns	ns
Residual	33					
SITE.FIELD.TRANSECT stratum						
MARGIN.MTYPE	1	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE	1	ns	**	ns	*	ns
Residual	22					
SITE.FIELD.TRANSECT.SAMPLE_NO stratum						
POSITION	2	ns	**	ns	**	**
PATCH.POSITION	2	ns	ns	ns	ns	ns
MARGIN.POSITION	2	ns	*	ns	ns	ns
PATCH.MARGIN.POSITION	2	ns	ns	ns	ns	ns
MARGIN.MTYPE.POSITION	2	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE.POSITION	2	ns	ns	ns	ns	ns
Residual	132					
SITE.FIELD.TRANSECT.SAMPLE_NO.REPEAT stratum						
DATE	1	***	ns	***	***	***
PATCH.DATE	1	ns	ns	ns	ns	ns
MARGIN.DATE	1	ns	ns	ns	ns	ns
POSITION.DATE	2	ns	ns	**	***	***
PATCH.MARGIN.DATE	1	ns	ns	ns	ns	ns
MARGIN.MTYPE.DATE	1	ns	ns	ns	ns	ns
PATCH.POSITION.DATE	2	ns	ns	ns	ns	ns
MARGIN.POSITION.DATE	2	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE.DATE	1	ns	ns	ns	ns	ns
PATCH.MARGIN.POSITION.DATE	2	ns	ns	ns	ns	ns
MARGIN.MTYPE.POSITION.DATE	2	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE.POSITION.DATE	2	ns	ns	ns	ns	ns
Residual	198					
SITE.FIELD.TRANSECT.SAMPLE_NO.REPEAT.*Units* stratum						
YEAR	2	***	*	***	***	***
Residual	311					

Table 7.A7 ANOVA table for Dvac data 96 m. CFI = Chick food index; 4FI = Four food index; SFI = Skylark food items; YHI = Yellowhammer index; TI = Total invertebrates. * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001; ns = not significant.

Source of variation	**d.f.**	**CFI**	**4FI**	**SFI**	**YHI**	**TI**
SITE stratum						
YEAR	2	ns	***	*	*	*
Residual	9					
SITE.FIELD stratum						
PATCH	1	ns	***	ns	ns	ns
MARGIN	1	ns	***	ns	ns	ns
PATCH.MARGIN	1	ns	***	*	*	*
Residual	33					
SITE.FIELD.REPEAT stratum						
DATE	1	***	ns	***	***	***
PATCH.DATE	1	ns	*	ns	ns	ns
MARGIN.DATE	1	ns	ns	ns	ns	ns
PATCH.MARGIN.DATE	1	ns	*	ns	*	ns
Residual	44					
SITE.FIELD.REPEAT.*Units* stratum						
YEAR	2	***	ns	***	***	***
Residual	67					
Total	164					

Table 7.A8 ANOVA table for Sweep net data 1-32 m. CFI = Chick food index; 4FI = Four food index; SFI = Skylark food items; YHI = Yellowhammer index; TI = Total invertebrates. * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001; ns = not significant.

Source of variation	**d.f.**	**CFI**	**4FI**	**SFI**	**YHI**	**TI**
SITE stratum						
YEAR	2	ns	ns	ns	ns	ns
Residual	9					
SITE.FIELD stratum						
PATCH	1	ns	ns	ns	ns	ns
MARGIN	1	ns	ns	ns	ns	ns
PATCH.MARGIN	1	ns	ns	ns	ns	ns
Residual	33					
SITE.FIELD.TRANSECT stratum						
MARGIN.MTYPE	1	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE	1	ns	ns	ns	ns	ns
Residual	22					
SITE.FIELD.TRANSECT.SAMPLE_NO stratum						
POSITION	2	***	***	***	***	***
PATCH.POSITION	2	ns	ns	ns	ns	ns
MARGIN.POSITION	2	**	ns	**	**	**
PATCH.MARGIN.POSITION	2	ns	ns	ns	ns	ns
MARGIN.MTYPE.POSITION	2	ns	ns	ns	ns	ns
PATCH.MARGIN.MTYPE.POSITION	2	ns	ns	ns	ns	ns
Residual	132					
SITE.FIELD.TRANSECT.SAMPLE_NO.*Units* stratum						
YEAR	2	***	ns	***	***	***
Residual	160					
Total	377					

Table 7.A9 ANOVA table for Sweep net data 96 m. CFI = Chick food index; 4FI = Four food index; SFI = Skylark food items; YHI = Yellowhammer index; TI = Total invertebrates. * = significant at 0.05; ** = significant at 0.01; *** = significant at 0.001; ns = not significant.

Source of variation	**d.f.**	**CFI**	**4FI**	**SFI**	**YHI**	**TI**
SITE stratum						
YEAR	2	*	ns	**	**	ns
Residual	9					
SITE.FIELD stratum						
PATCH	1	ns	ns	ns	ns	ns
MARGIN	1	ns	ns	ns	ns	ns
PATCH.MARGIN	1	ns	ns	ns	ns	ns
Residual	33					
SITE.FIELD.*Units* stratum						
YEAR	2	*	ns	***	***	***
Residual	34					
Total	83					

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The SAFFIE Project Report

Chapter 8 – Cost:Benefit analysis of the best practices for increased biodiversity

(Pages 636 - 650)

Sustainable Arable Farming For an Improved Environment

SAFFIE

Enhancing Biodiversity

8 COST:BENEFIT ANALYSIS OF THE BEST PRACTICES FOR INCREASED BIODIVERSITY

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Chapter 8 contents

8.1 SUMMARY

A key objective of SAFFIE was a financial costing of the novel measures evaluated during the project. The cost:benefit analysis used in this process was unconventional, as although management incurred financial costs, some of which may be remunerable through agri-environment schemes (AES), measures of benefit (e.g. biodiversity, ascetics), were not necessarily financially tangible. The costs and benefits varied between sites and years, so some are shown as ranges rather than absolute values. We assessed the costs and benefits of within-crop measures, undrilled patches (UP) and wide-spaced drill rows (WSR), using a range of yields, crop prices and any additional costs. The key findings were:

- UP receiving ELS payments were found to be profitable under all scenarios, were generally regarded by farmers as easy to create and were beneficial to birds. Reports of pernicious weed infestations, such as black-grass were rare but UP may be unsuitable (for crops and biodiversity) in fields where herbicide-resistant weeds are a known agronomic problem.

- Despite the potential of UP to deliver a cheap but effective solution for skylarks, take-up in ELS has been poor. It is likely that they will need to be further incentivised in future AES reviews to attain a level of take-up that may be beneficial at the population level.

- WSR generally incurred minimal husbandry penalties, although some farmers reported that setting up of equipment to adjust drill row width was time consuming. However, in commercial situations, crops would invariably be sown at the same row width, negating the need for adjustments. WSR are not currently eligible for AES payments. WSR had some biodiversity benefits compared to conventionally managed wheat but were not as consistently beneficial as UP.

- Weed control strategies using mechanical methods (row spacing and hoeing between rows) did not encourage the germination of beneficial or rare plant species or associated arthropods and are therefore not recommended.

- Weed control strategies using a single application of amidosulfuron in the spring, indicated that, in some fields with low populations of pernicious weeds, there might be scope to reduce or alter herbicide use (and thus input costs) without either significantly decreasing yields or increasing non-desirable weeds.

- Field margins established with wildflowers in the seed mixes were ten times more expensive than grass-only seed mixes commonly used in AES such as Countryside Stewardship and ELS. Seeds of some wildflowers, sown at low seed rates due to their expense, also suffered from poor establishment. However, biodiversity benefits of including wildflowers in seed mixes, measured at the plant community level, are great.

- The costs of creating margins using the SAFFIE seed mixes are unlikely to be met by current AES payments for grass buffer strips. Simplification of seed mixes, via the removal of species that rarely established, could reduce the cost of establishing wildflower margins while retaining the greater biodiversity benefits. However, such calculations are still highly sensitive to the price of wheat. Additional AES payments for floristic enhancement of margins are likely to be required if take-up is to be substantially improved.

- The three margin management techniques had similar costs that were insubstantial compared to the costs of the seed mixes, although spraying with a selective herbicide incurs time penalties due to the small areas involved. Costs varied with field size and shape. The novel treatments (scarification and selective graminicide) had considerably greater biodiversity benefits than mowing; the method currently prescribed to manage margin swards in most AES.

- There was no evidence that margins encouraged weeds or diseases to spread into the crop. Additional management, e.g. spot-spraying, was occasionally required to control undesirable weeds within the margins.

8.2 INTRODUCTION

This chapter provides financial costs of the approaches used in the different parts of the SAFFIE project, and links these to the benefits, by cross-referencing to other chapters. This cost-benefit analysis is unconventional because it is not possible to attribute a financial value to the farmer of biodiversity benefits that result from novel management techniques. Thus, while novel management techniques may have a financial cost, the benefit may be measured only as a change in biodiversity.

The costs are also linked to possible income from current agri-environment schemes, with the English Entry Level Scheme (ELS), administered by the Department for Environment, Food and Rural Affairs (Defra), being used as an example. However, such schemes vary within the UK, and will change. The key information in this chapter is the cost information, rather than the income under current schemes. This cost information is now available to policy makers as they review existing schemes and plan changes.

As with more conventional cost-benefit analysis, the costs and the benefits varied from site to site and year to year. Furthermore, the novel management treatments in the SAFFIE project may be appropriate for some fields, but not for others. For example, the presence on farm of competitive weeds such as black-grass (especially if herbicide-resistant), wild oats or cleavers will influence decisions about weed control, margin management, and undrilled patches (UPs). Other sources of variability are the structure of the farming business and the characteristics of the farm, including yield potential. For these reasons, we have shown costs as ranges in some instances.

Assessment of costs associated with novel wheat crop management (e.g. UPs, wide-spaced rows (WSR), herbicide use) was relatively straightforward, and included analysis of management costs and financial implications of yield responses. Margin management techniques proved more difficult to assess in a conventional way due to the complexities of the SAFFIE experiments. In all cases, however, costs have been assessed and these can then be related to the biodiversity benefits. These costs may then be judged as giving good value, or not.

8.3 METHODS

For each experiment, the approach was to estimate additional costs to a farmer of providing the specific management system. These costs included field operations, inputs such as seed mixtures, and loss of production from UPs and grass margins where crops would normally be grown. These costs have been derived from current information on actual farm costs known to ADAS and checked against Nix (2007) where possible.

The costs cover direct costs for an operation, i.e. labour, fuel and machinery repair costs along with inputs such as herbicides, but do not include overhead costs (i.e. depreciation). Other costs, such as rent, building repairs, administration and finance are not included since these will be individual to each farm. We used the costs of operations shown in Table 8.1 for calculating costs of management techniques.

The cost of establishing and maintaining field margins, per hectare of margin, have been calculated as follows. It was assumed that the field would be cultivated before establishment, along with the cultivations for the field crop. Costs may be higher than those shown if contractors are used. Costs may also be greater if contractors are asked only to do the margins in crops that have already been drilled.

For autumn establishment, on medium to heavy land, ploughing or minimum tillage may be appropriate. For a plough-based approach, it was assumed that the land would be ploughed and pressed followed by cultivation, drilling and rolling. For minimum tillage approach, the land would be sprayed, cultivated, drilled and rolled.

For spring establishment, the work would be carried out on a drying seedbed, so calculations were made based on minimal soil disturbance, i.e. spraying off followed by light power harrowing, broadcasting and rolling.

On the income side, we used the ELS payments for relevant options, shown in Table 8.2. For comparison, SEERAD Rural Stewardship Scheme payments are given in Table 8.3.

Table 8.1 Costs of field operations for use in calculations.

Operation	Cost (£/ha)
Plough/press	35.00
Cultivate (e.g. tine/disc)	11.00
Drill	12.00
Roll	6.00
Spray application	7.50
Non-selective herbicide	10.00
Power harrow	23.00
Cutting margins (flail)	12.50
Scarification	14.00
Labour to knapsack spray UPs (4 h per 10 ha) and costs of herbicide, sprayer and truck	6.00

Table 8.2 Defra environmental payments under the ELS.

ELS option	Unit	Points	Approx £/ha
Buffer strip (6 m) on cultivated land	ha of margin	400	400
Buffer strip (6 m) on intensive grassland	ha of margin	400	400
Wild bird seed mixture	ha of margin	450	450
Pollen and nectar flower mixture	ha of margin	450	450
Skylark plots*	plot	5	5
Skylark plots*	ha (field area)	10	10

*Known as skylark plots in the ELS, but referred to as undrilled patches in this report.

Table 8.3 SEERAD environmental payments under the Rural Stewardship Scheme.

RSS option	Unit	£/ha
Management of Grass margin or Beetle bank in Arable Fields	ha of margin	619
Management of Conservation Headlands	ha of margin	80
Management of Conservation Headlands (Non Nitrogenous Fertiliser)	ha of margin	150

8.4 RESULTS

8.4.1 Wheat crop architecture

Management techniques examined were use of UPs and wide spaced rows (WSRs). The calculations were based on a ten hectare field of wheat.

8.4.1.1 Undrilled patches

It was assumed that the UPs would qualify for ELS points; hence each UP would add five points per patch or ten points per hectare. In a 10 ha field, this equates to £100 (Table 8.4).

Table 8.4 Income and costs from UPs in a 10 ha field.

Item	Income or saving (£/ 10 ha)	Cost (£/ 10 ha)
ELS income	100	-
Value of seed not sown	5	-
Crop loss	-	15–30
UP establishment at drilling	-	0
UP establishment by spraying	-	60
Total	**105**	**15–90**

The crop production loss due to the UPs was assessed at a range of yields and prices for a wheat crop. Whilst the experiments were carried out, the wheat price was at its lowest for some thirty years, but has recently recovered significantly. Agricultural commodity prices are always difficult to predict, so a range of £65/t to £95/t was used to assess the likely financial loss from UPs. Another factor is loss of yield, and in this case, values between 7.5 t/ha and 9.5 t/ha were used. For a typical 10 ha field, taken for the calculation, the cost of the crop loss from the UPs, including allowance for seed not sown, was £15/ha to £30/ha plus or minus approximately £5/ha.

In order to create and manage the UPs, there may be additional costs. The cost of creating the UPs was taken as zero, since most of the farmers simply lifted the drill out of the ground for a second or two during drilling. However, this is impractical with some drills (e.g. where the tramlining facility resets when a drill is lifted), and in such cases there is either a small additional time cost or it may be necessary to create them by spraying out patches with herbicide in winter (which although not available during SAFFIE is now allowable within ELS).

For maintenance of the patches, it was assumed that in most cases, when spraying the field, the UPs would also be sprayed. In cases where UPs become unacceptably weedy, the UPs would need to be sprayed, perhaps to control undesirable species such as black-grass, wild oats or cleavers.

For making patches by spraying a patch after crop emergence, and for controlling weeds in patches by applying a herbicide to the patch, it was assumed that a knapsack sprayer would be used. The costing took into account the time taken to prepare the knapsack sprayer, travel to the field, walk the field spraying the patches and returning to the farm plus cleaning down, a total of £40 for a 10 ha field. An additional allowance was made of £20 (per 10 ha field) for pesticide, knapsack sprayer and truck.

During the SAFFIE experiments there was only an occasional need to knapsack spray UPs. It is anticipated that the need for this would be even more unlikely if the patches were made by spraying with an herbicide after crop emergence. Farmers involved in the SAFFIE experiments said that they would prefer not to have UPs in their fields if the weed spectrum, soil type and cropping history suggested a risk of very weedy UPs, or UPs infested with herbicide-resistant weeds.

8.4.1.2 Wide-spaced rows

The crop husbandry implications of WSRs in terms of fungal diseases or weed growth were minimal in SAFFIE experiments. No site manager reported high weed growth or disease levels. There was a single report from one field where it was thought that high powdery mildew *(Blumeria graminis)* occurrence was attributed to crowding in the rows, although previous studies indicate that row width has little effect on this disease (Dr Neil Paveley, ADAS, Pers. comm.).

Setting up equipment for WSRs - adjusting drill settings or blocking off alternate coulters - for the SAFFIE experiments took and hour. However, in a commercial situation, where all wheat on a farm would probably be drilled at the same row width, there would be a relatively minor additional time or cost input.

8.4.2 Weed control strategy

Details of SAFFIE Experiment 1.2, which combined a range of herbicide treatments with three row width/cultivation treatments, are given in Chapter 5. There were eight herbicide treatments at Boxworth and seven at Gleadthorpe and High Mowthorpe. Details of the herbicides used are given in section 5.2.1. The letters ‘a’ to ‘h’ denote the treatments in Table 8.5, in the same order as in 5.2.1. Treatment ‘A’ was an untreated control, with no herbicide application. Treatments ‘B’ to ‘G’ were the same at Gleadthorpe (GT) and High Mowthorpe (HM), but different to the treatments with the same identifiers at Boxworth (BX).

Table 8.5 Costs of herbicide mixtures, excluding application costs.

Treatment	Herbicide costs (£/ha) BX 2003	Herbicide costs (£/ha) GT/HM	Application Cost (£/ha)
A	0	0	0
B	28	10	7.50
C	49	3	7.50
D	11	11	7.50
E	70	14	15.00
F	77	17	15.00
G	90	7	15.00
H	97	-	22.50

Costs of using WSRs are assumed to be zero (see 8.4.1.2), but there was a cost where mechanical weed control was also carried out. The row width/cultivation treatment had an inconsistent effect (5.2.1) on weeds. Weed cover was rarely affected and neither the more open canopy in the WSR nor cultivation in spring encouraged beneficial species to germinate. In general, the arthropod groups affected were neither important bird food species, nor were they threatened arable species. There were also yield penalties in some site/years to both WSR and cultivation between the rows. Manipulating row width/cultivation is therefore not recommended for commercial application (5.4.1), and costs are not considered further here.

There was evidence from SAFFIE Experiment 1.2 that there is scope for more selective us of herbicides within a field (see Chapter 5). Higher arthropod abundances were associated with more weeds being present as a result of a selective herbicide programme involving a single herbicide treatment when compared to sequential applications. Plots receiving a March application of amidosulfuron (treatment ‘D’, Table 8.5) often contained many arthropods important in the diet of farmland birds. The cost of this treatment was £18.50 per ha, compared with a range of £10.50 to £119.50 per ha (Table 8.5) for all herbicide treatments in this study. Thus, there is potential for decreased weed management costs with accompanying benefits for biodiversity, but only in fields without serious pernicious weeds.

8.4.3 Margin establishment and management

8.4.3.1 Seed costs

Seed costs for the mixtures tested in the SAFFIE project were:

- Countryside Stewardship (CSS) grass mix, £124/ha,
- fine grass and flower mix, £1,106/ha, and
- tussock grass and flower mix, £1,302/ha.

Mixtures including wild flowers cost around ten times as much as the CSS mix. The potential benefit of the wild flowers is more pollen, nectar and better suitability for insects. The high cost is a potential barrier to wider uptake both because some flower species establish poorly and the high seed costs of some flower species limited the percentage of their seed in the mixture.

Detailed discussion of seed mixtures and component species is given in Chapter 6, but for cost benefit analysis, it is necessary to take a broad view. Farmers may naturally take a conventional, results-orientated view, based on how many species become established and to what extent. However, some species will be early colonisers and others may be more successful later. Different species of invertebrates may benefit as the species-profile of the sward changes. In general, species will influence biodiversity if it establishes to some degree, i.e. it needs to be present in the established sward. Biodiversity benefits of individual species that have established well are difficult to quantify, as the biodiversity effects of mixtures are measured at the plant community level, not for individual species.

To take a broad view, maximum canopy cover values for each sown species at each site in SAFFIE Experiment 2 (Chapter 6) were used to identify species with very low values (less than 1% ground cover, Table 8.6). The seed of species that did not establish well varied in cost and weight of seed sown. This information was used to calculate potential savings in seed costs if poorly establishing species were not included. Seed mixture costs were decreased by from £0 to £834 per ha, from initial costs of £1,200 to £1,424 per ha, by only including successful species or excluding unsuccessful species (Table 8.7).

This indicates that savings can be made from the original seed mixtures by excluding species that failed to establish or established poorly. The biodiversity benefits shown in this work were obtained despite the poor or failed establishment of these species. These savings should be seen in the context of the figures on the bottom line of Table 8.8.

Table 8.6 Establishment of dicotyledonous plants used in seed mixes for Experiment 2 (Chapter 6), categorised as successful (>1% ground cover achieved at all sites), site-dependent (>1% ground cover achieved at least at one site), and unsuccessful (>1% ground cover not achieved at any site).

Successful	**Site dependent**	**Unsuccessful**
Achillea millefolium	*Anthyllis vulneraria*	*Lathyrus pratensis*
Centaurea nigra	*Centaurea scabiosa*	*Origanum vulgare*
Daucus carota	*Echium vulgare*	*Pimpinella saxifraga*
Dipsacus fullonum	*Knautia arvensis*	*Ranunculus bulbosus*
Galium mollugo	*Leontodon hispidus*	*Reseda lutea*
Galium verum	*Linaria vulgaris*	*Sanguisorba minor*
Geranium pratense	*Malva moschata*	
Leucanthemum vulgare	*Plantago media*	
Lotus corniculatus	*Primula veris*	
Plantago lanceolata	*Silene vulgaris*	
Prunella vulgaris		
Ranunculus acris		
Rhinanthus minor		
Rumex acetosa		
Silene dioica		
Vicia cracca		

Table 8.7 Costs of seed mixtures used in SAFFIE Experiment 2 (Chapter 6), for all species, successful species only, and successful and site-dependent species.

Seed mix and site	Costs, with savings given in brackets (£/ha)		
	All species	**Successful species only**	**Successful and site-dependent species**
Tussock grass + forbs, Boxworth, Gleadthorpe & High Mowthorpe	1,424	1,205 (219)	1,312 (112)
Fine grass + forbs, Boxworth	1,335	937 (398)	1,335 (0)
Fine grass + forbs, High Mowthorpe	1,342	508 (834)	1,335 (7)
Fine grass + forbs, Gleadthorpe	1,200	631 (569)	1,104 (96)

8.4.3.2 Establishment and management costs

Establishment and management costs are given in Table 8.8. The figures at the bottom of the table show the net gain or loss, annually and over a five-year period. Five years is the duration of the Defra ELS, and so is considered suitable over which to spread establishment costs.

For calculating the savings made by not growing a crop on the area of margin, the fixed costs deemed to be saved was 55% of all fixed costs (representing less labour, fuel and machinery repairs). This value will vary greatly depending on the farm size, soil type, farm layout and how it is farmed (e.g. using contractors, or worked by the land and machinery owner).

Loss of production was taken into account at a field yield of 9.5 t/ha, reduced by 10% near the field boundary (Cook & Ingle 1997) to give 8.55 t/ha for the area of margin.

Table 8.8 Financial cost-benefit balance of establishing and managing margins, including income from the Defra ELS.

	Cost or saving/income (£/ha of margin) at three example wheat prices		
	Wheat @ £65/t	**Wheat @ £85/t**	**Wheat @ £95/t**
<u>Cost category</u>			
Establishment (spread over 5 years)*	17 to23	17 to23	17 to23
Management	12 to 35	12 to 35	12 to 35
Yield loss	556	727	812
Total costs	**585 to 614**	**756 to 785**	**841 to 870**
<u>Savings and income</u>			
Fixed costs**	140	140	140
Variable costs	250	250	250
ELS income	400	400	400
Total savings/income	**790**	**790**	**790**
<u>Balance</u>			
Annual	176 to 205	5 to 34	-51 to -80
5 year Total	880 to 1,025	25 to 170	-255 to -400

*This cost is incurred only once, in the first year, but is presented as an annual cost of one fifth of the establishment cost, because the establishment cost is spread over five years in this analysis.
**This is 55% of the fixed costs, as not all are saved. See text for further explanation.

In Table 8.8 no allowance was made for seed costs, so the balance must cover seed costs, as well as any overheads (such as?) and/or profit to the farming business. For a farmer to break even, not covering overheads, with the benefit of current ELS payments, and at a wheat price of £85/tonne, £25 to £170 per ha of margin would be available for seed, depending on establishment and management costs. However, this range of values is highly sensitive to wheat price, and at £95/tonne the greater value of the loss of production would result in a loss of £255 to £400 in addition to the seed cost. At £65/tonne wheat price (similar to the price early in the SAFFIE project), £880 to £1,025 would be available to cover seed (assuming no overheads or profit). Seed costs of the mixtures used in the SAFFIE project in 8.4.3.1 ranged from £124 to £1,302 per ha.

The more expensive seed mixes used in Experiment 2 had various biodiversity benefits, as detailed in many sections of Chapter 6 (see sections 6.1.2 to 6.1.5 for a summary). Examples of benefits of including flowering (dicotyledonous) plants in the seed mix included:

- greater plant diversity across all sites, in all years, compared with the cheaper grass seed mix;
- the tussock grass and forbs seed mix supported nearly a third greater abundances of beetles than did the conventional countryside stewardship seed mix, and spider abundance was 82.1 % greater in the tussock grass and forbs than in the fine grass and forbs seed mix;
- increases in abundance and diversity of pollen and nectar resources, bumblebees and butterflies;
- the rare bumblebee species, *Bombus ruderatus*, utilised the margins sown with forbs in all five years at the Boxworth site.

Cutting in March, using a flail, was the cheapest margin management treatment at £12.50 per hectare (Table 8.9). Scarification (light power harrowing) would cost £14.00 per hectare and spraying with graminicide, including both the cost of the chemical and application, would be £17.50 per hectare (see Chapter 6 for details of margin management treatments). The spraying cost is high because it is for a small area compared with most spraying operations. Scarification and cutting are simpler operations that can be carried out with little time used for setting up or dropping off the machine.

Table 8.9 Establishment and management costs per ha of 6 m wide margin.

Operation	Cost (£/ha)
Establishment	
Autumn	55–65
Spring	55
Margin management	
Spraying	17.50
Scarification	14.00
Cutting	12.50

The differences between costs of management treatments are insignificant because there will be larger differences between farms in costs for the same treatment. For convenience, an average of £15.00 per hectare could be used, but in Table 8.9 the individual costs were used to illustrate differences between treatments.

A further possible margin management cost, not considered in detail here, is the cost of spot treatments for arable weeds within margins. Weeds such as thistles and docks occurred in some SAFFIE margins, and in some cases spot treatments were required (see Chapter 7, section 7.4.1).

8.4.3.3 Effect of field size

Costs were calculated per ha of margin, but the area of margin in individual fields and farms can vary greatly with field shape and size.

The relationship between size of field and margin area is not linear and Figure 8.1 shows how much margin area there could be in a given field size, assuming square fields and 6 m wide margins. In a square field of 5 ha, each side will be 224 m long and the area of margin for the whole field will be 0.52 ha. In a square field of 20 ha, each side will be 447 m long and the area of margin for the whole field will be 1.06 ha. Long narrow fields will have more margin area than square fields. For a 20 ha square field, 447 x 447 m, the margin length is 1,765 m (1.07 ha), but for a 20 ha rectangular field, 700 x 286 m, margin length is 1,948 m (1.17 ha).

The length of 6 m wide margin with an area of 1 ha is 1,667 m.

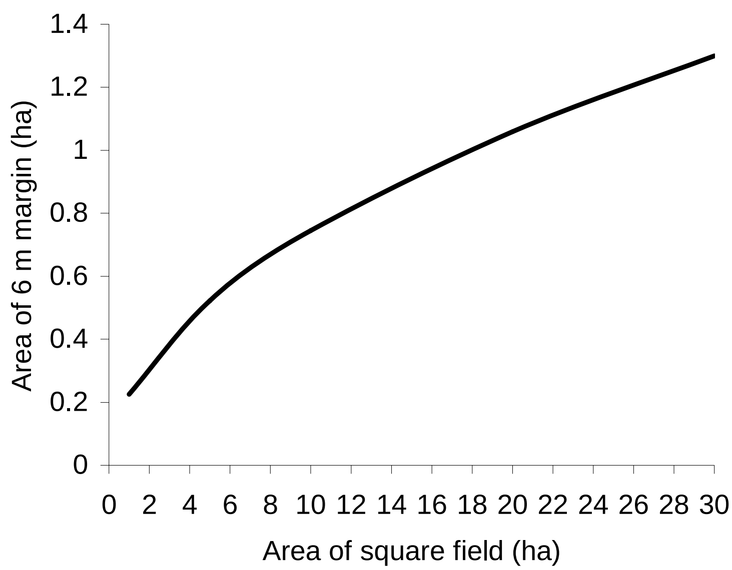

Figure 8.1 The relationship between field area and area of 6 m margin, for square fields.

8.4.3.4 Effect of margins on crop management

In addition to the costs of different margin management approaches, it is important to consider the consequences of margins for crop management. Margins could encourage crop weeds, pests or diseases; they may also encourage beneficial birds or invertebrates such as aphid predators or weed seed eaters. Costs of establishing and maintaining margins may be set against a number of potentially important considerations for crop management.

The margins contained invertebrate species likely to predate aphids at key times, especially the overwintering adults and developing spring populations. Tussock grass margins in particular provided a habitat suitable for a range of beneficial predatory invertebrates that could be helpful in controlling crop pests (see Chapter 6, section 6.4.3).

There was no evidence that margins encouraged weed species or diseases that subsequently spread into the crop. One pest that may cause some concern is wireworm. Adults (click beetles) lay eggs in grassy areas, which later hatch into larvae (wireworms) that can damage potato crops. No high populations were found within the SAFFIE margins. However, any detectable population of wireworms is a potential threat to potatoes; anecdotal evidence indicates that there is a risk from field margins and set-aside, where the soil is undisturbed for as little as 2-3 years (Hancock et al., 1992). It is possible that scarification of the margin would prevent wireworm population increase. During the spring, when soil temperatures are rising, wireworms move up through the soil profile, so may be more vulnerable to this treatment.

It is unclear whether any of these considerations would change the costs of crop management, but they should not be ignored in any future studies.

8.5 DISCUSSION

For some practices, there are currently direct financial benefits such as payments under the Defra ELS for Skylark Plots (UPs), where the financial gain could be as high as £75 to £90 per ha if the improbable task of knapsack spraying is not required.

However, for margin establishment, few may be willing to pay for costly wildflower species above the cost of cheaper margin seed mixtures. Careful assessment of the likely benefit of specific wildflower species in a seed mixture is needed in order to justify their cost. Furthermore, some farmers may wish to maximise their income from agri-environment schemes, rather than spend money on expensive seed mixtures where cheaper alternatives are allowed or do not attract a higher payment.

The seed mixtures for the margins contained a range of species that were of value to invertebrates. Seed costs vary greatly between species; primarily due to higher seed production costs (low seed productivity, difficult to grow and harvest). Seed of the lower cost species were present in greater numbers in the seed mixtures than high cost species, putting the latter at a competitive disadvantage during establishment.

To explore the scope to reduce seed costs we chose a value of 1% ground cover as a threshold for ‘satisfactory’ establishment. The biodiversity benefits reported in Chapter 6 of this report were obtained despite poor or failed establishment by some species and hence we considered it could be appropriate to omit species with less than 1% ground cover from the cost. However, in practice, species establishment and biodiversity benefits re dependant on site. It is therefore recommended that local knowledge and expert advice are used in deciding appropriate seed rates and which species to include in margin seed mixtures.

The approach of reduced herbicide inputs (8.4.2) needs careful management, and results will be specific to individual fields and will vary between seasons. This should only be considered where the weed spectrum is known to be suitable, and herbicide programmes should be planned with advice from a BASIS qualified agronomist to ensure that crop health and productivity is safeguarded.

8.6 ACKNOWLEDGEMENTS

We especially thank the host farmers for SAFFIE Experiment 3 (Chapter 7) and members of the HGCA project monitoring groups, for commenting on cost issues.

We gratefully acknowledge the help of the authors of other chapters of this report, in providing information for the analysis presented. In particular we thank Duncan Westbury (Centre for Agri-environmental Research, University of Reading) for information on species establishment. We are also grateful to Bill Parker (ADAS) for expert advice on wireworm biology.

8.7 REFERENCES

Nix, J. (2007) Farm Management Pocketbook, 37th Edition 2007, Imperial College, London.

Hancock, M., Ellis, S., Green, D.B. & Oakley, J.N. (1992) The effects of short- and long-term set-aside on cereal pests. *Set-Aside*, BCPC Monograph no. 50, 195-200.

Cook, S.K. & Ingle, S. (1997) The effect of boundary features at the field margins on yields of winter wheat. *Aspects of Applied Biology* **50,** *Optimising cereal inputs : Its scientific basis,* pp 451-466.

HGCA Project Report No. 416 June 2007 £30.00

LINK collaborative research

The Voluntary Initiative

The SAFFIE Project Report
Chapter 9 – Communications activities
(Pages 651 - 671)

Sustainable Arable Farming For an Improved Environment

SAFFIE

Enhancing Biodiversity

9 COMMUNICATIONS ACTIVITIES

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Chapter 9 contents

9.1 INTRODUCTION

In 2001 when the SAFFIE project was being instigated, the farming and crop production industry was in a state of turmoil. Wheat prices, profitability and farm incomes had plummeted. Impending CAP reforms, a greener political agenda, and the threat of a pesticide tax, all created a climate of uncertainty and in some cases despair amongst farmers. For the preceding 20 years and more, UK arable farming had increased its productivity and efficiency. Many farmers had also tried, often at their own expense, to improve farm biodiversity. This was achieved mainly through the use of grass, wildflower, and conservation field margins. However, there were limitations as to what could be achieved around the field edge (the margin area being proportionately less on large fields) and in how valuable grass dominated margins were.

At the start of the project, the majority of farmers still had to recognise the growing public need for farmers to provide "environmental goods". This has now changed thanks to the stewardship schemes introduced by CAP reform together with industry led programmes such as The Voluntary Initiative and in its own small part the awareness raising that has been undertaken through the SAFFIE project.

9.2 METHODS

9.2.1 Developing a strategy

Communicating with the industry was a specific objective of the project. A communications group was formed at the start of the project, as it was recognised that with a large consortium, specific objectives to be met and a five-year time frame communication would be important. Communication protocols and procedures together with a clear project identity were established early on. It was also recognised that there would be a need for continuous communications throughout the life of the project and therefore the communications group identified early on three potential audiences for the outputs of the project:

- Wider public and politicians
- Policy makers and researchers
- Farmers and advisers

A more detailed breakdown of these audiences is shown in the communication matrix (Table 9.1).

It was also agreed that it would be best if individual project members were to promote the project and its outputs to the audiences with which they were most familiar.

Based on these audiences the communication plans evolved during the life of the project resulting in the production of a communication matrix (Table 9.1). This shows the plans for the concluding phase of the project. BASIS and FACTS registered agronomists[1] account for the vast majority of on-farm advice relating to crop production so they were identified as the primary means of informing farmers of developments.

9.2.2 Continuous Communication

Keeping everyone informed of developments within the project has been an integral part of the work. This went through four phases:

Phase 1 — Establishment - What is the project? What is it about? Finding farm sites and communicating with over 30 farmers at the research sites

Phase 2 — Early Results - Skylark Plots work (Experiment 1)

Phase 3 — Maintaining Momentum – Keeping everyone informed of developments

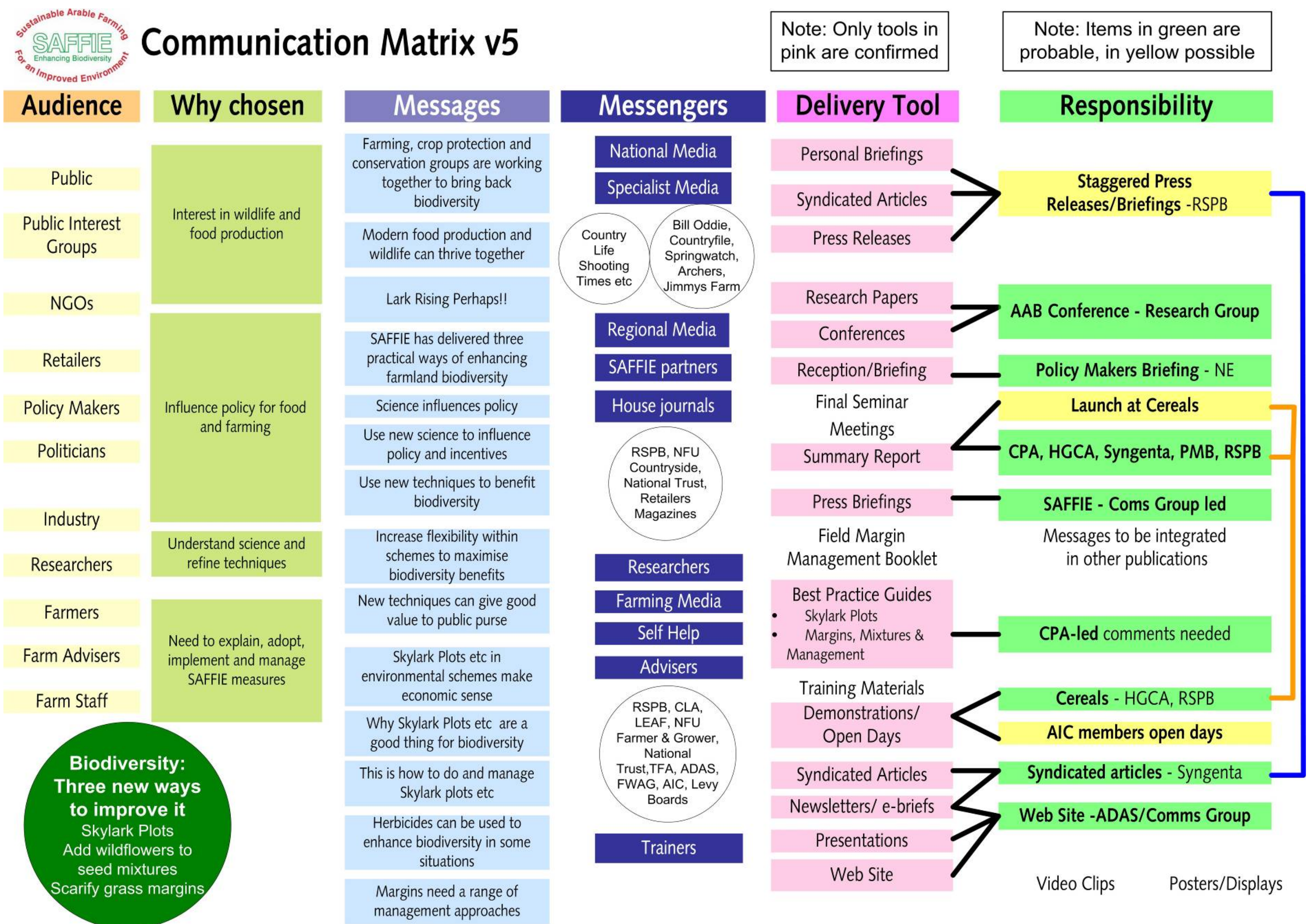
Phase 4 — Conclusion – Promotion of final results

As the project has evolved, so the volume, efficiency and focus of communication has improved. In the early days communication materials had not been fully developed, as a result it was quite difficult for agronomists to identify potential host farms and explain the requirements of such a large project. However these obstacles were overcome with individual farm visits. These visits also enabled direct feedback of farmer's concerns.

From the early days of the project there has been a web site (www.saffie.info) which has been used to include copies of relevant publications, an up to date PowerPoint® presentation of the project and other relevant information. The project was also featured on the Voluntary Initiative web site (www.voluntaryinitiative.org.uk) where it had a dedicated web page.

[1] The BASIS professional register is a scheme, which encourages continuous professional development amongst crop protection and crop nutrition (FACTS) advisors.

Table 9.1 SAFFIE Communication Matrix




Up with the Lark!

How the most beautiful sound of an English summer is making a comeback

by Graham Harvey

LYNDA LEE-POTTER IS AWAY

The promising results from the Skylark Plots work (Experiment 1.1) provided an important early platform to promote the project to both the farming and national media. It was very rewarding for the researchers and sponsors to attract such high profile coverage in the national media for this story and the RSPB's press office should be thanked for their hard work they put in to promoting this story.

In conjunction with this story, guidance on creating and managing skylark plots was published by Crop Protection Association (CPA) and RSPB and these were promoted to farmers by agronomists and conservation advisers.

"All our agronomists were briefed on Skylark Plots and the great majority of them spent some time with their customers explaining the opportunities for skylark plots on their farm," Clare Bend, Masstock

To keep agronomists and others aware of progress the CPA published a 4-page newsletter that was distributed at the 2004 Cereals event, at this event there was also a large display featuring skylark plots as well as demonstration plots showing some the field margin work.

Distributors and manufacturers also featured the skylark plots at the many open days and demonstration sites they host for farmers.

"We featured skylark plots at our Rawcliffe Bridge demonstration site. They helped encourage skylarks resulting in increased breeding territories and as the farm had no resistant blackgrass the plots were easy to manage," Graham Hartwell, BASF plc

The skylark plots research provided further evidence to Defra policy makers on the biodiversity value of this technique resulting in their inclusion as one of the in-field options in the Entry Level Scheme in 2005. This in turn encouraged distributors to incorporate the approach into the software packages they use to advise farmers

"We integrated the advice on Skylark Plots into our environmental management software which has been used on many of our client's farms," Mike Young, Farmacy

Similar activities were repeated in 2005 with a newsletter being published at Cereals 2005, this again promoted the benefit of Skylark Plots and also featured more on the herbicide programmes being tested for in-field biodiversity and the work being done on field margins. As the results on scarification of grass margins were more complex and all data had not been analysed no detailed advice it was premature to publish advice on the technique.

During 2006 project had a lower profile, as with the exception of the unexpected predator effect on skylark plots located close to grass margins (one year's results) it was felt more important to ensure all data was collated and analysed and to prepare for the release of the final results in 2007.

Presentations were given at a number of high profile farming conferences during 2006 and the latest information was incorporated into the standard SAFFIE presentation. This was promoted to distributors and agronomists via The Voluntary Initiative and SAFFIE websites. The scarification technique was also shown at some farm demonstration sites. However, results and experiences to date had been sufficiently promising for English Nature to help co-ordinate a special workshop for policy makers in May 2006 where the potential benefits of the techniques developed by SAFFIE were discussed, together with the longer-term implication for their introduction stewardship schemes.

9.2.3 Message Development

The communications group developed the key messages (see section 9.3.2) based on the findings in the research project. Headline messages were identified for target audiences and detailed advice was prepared for farmers on the new techniques in the project. All messages were checked with researchers to ensure that the advice and results had not been oversimplified.

9.2.4 SAFFIE Communication Tools and Delivery

As the project developed, a toolkit of materials was produced to support the delivery of advice and information from the project.

The toolkit included:

- Web-site
- Sustainable Arable Link Briefing sheet
- Best Practice Guides
- Newsletters
- PowerPoint® presentation
- Posters (for demonstration sites)

These materials were used to support SAFFIE promotion work at a wide range of events including:

- Cluster group meetings
- Agricultural shows – e.g. Cereals event
- Demonstration/open days organised by ADAS, HGCA, manufacturers and distributors
- HGCA Roadshows
- Conferences
- Workshops

9.3 RESULTS

Communications during the life of the research project has generated a good level of awareness of the project and its techniques. There is a much higher level of awareness of

Skylark Plots since their “launch” in 2004 and subsequent incorporation into the Entry Level Scheme (ELS). However, this awareness has still to deliver a high level of uptake. As at 4 June 2007 out of 31,037 Stewardship Scheme agreements only 483 (1.6%) farmers have included Skylark Plots, as an option. However it should be noted that number of the agreements eg coastal fen woodland are not suitable for Skylark Plots. This is not felt to be so much antipathy specifically towards skylark plots but a combination of a general reluctance by farmers to compromise field operations and to adopt in field measures and the comparative ease with which most farmers can acquire their 30 points/hectare through other better value stewardship measures.

In theory farmers can add wildflowers to grass margins in ELS, but because of the significant extra cost of seed, it is though few farmers have done so. Under the Higher Level Scheme there are 244 agreements with a specific payment for floristic enhancement.

The 6m grass buffer strips which require annual mowing of the inner 3m are a more popular option in ELS and are included in 5136 agreements (16%). With the right incentives and changes to the permitted ELS management arrangements could be enhanced by the use of a graminicide or scarification.

Data from Genrep; pers comm. Mike Green Natural England

9.3.1 Summary of outputs

As at the 31 March 2007, the SAFFIE project has been involved in or mentioned in over 180 knowledge transfer activities (Table 9.2). A full listing is included in the Appendix to this section.

Table 9.2 SAFFIE Knowledge Transfer Activities at 31 March 2007.

National Media	Regional Media	Farming Media	House Journals	Research Papers	Conferences	Demonstrations/ Open Days
22	17	54	21	18	27	23

9.3.2 Messages

9.3.2.1 Headlines

- The SAFFIE project has developed 3 practical ways to improve arable farmland wildlife
- Government policies and their administration need to encourage farmers to use these techniques
- Modern farming and biodiversity can co-exist

9.3.2.2 Three new ways of encouraging arable biodiversity

- Skylark plots can increase number of chicks raised by almost 50%
- Adding wildflowers to grass margin seed mixtures is good for bees and butterflies
- Scarifying grass margins opens up the sward and encourages annual wildflowers and beetles and helps birds to find food

9.3.2.3 Messages for Policy Makers

- The techniques developed in the SAFFIE project cost money to implement, so farmers need incentives to adopt these measures

- Stewardship Schemes need to be adapted to recognise scarification

- Existing stewardship measures need to do more to encourage Skylark Plots and Wildflowers

- Stewardship schemes need to be sufficiently flexible to allow farmers to adopt best practice

- Good science is essential. In this project we have demonstrated the importance of understanding complex interactions such as those between skylark plots, grass margins and predators. These would have been much harder and slower to find if relying on indicators and monitoring.

- Changing herbicide use in wheat can sometimes give more biodiversity than hoeing and wider row spacings; as the balance of weeds can be shifted in favour of those with lower crop competitiveness and better for biodiversity. But this is a risky strategy for farmers with a black-grass problem and there remains a strong reluctance from farmers to leave any weeds. Furthermore there is a limited range of herbicides to work with and herbicide programmes must be site-specific, therefore promoting in-crop biodiversity by other means may be more efficient

9.3.2.4 Messages for Farmers

- Biodiversity can earn you money through ELS

- Increasing biodiversity will improve farming's image

- The SAFFIE techniques are practical and easy to adopt

- Some SAFFIE techniques are low cost and recognised and rewarded through ELS

- How to create these new habitats (Advice sheets)

9.3.2.5 Messages for the Public

- Modern farming and biodiversity can co-exist

- New techniques are being developed and adopted to bring back farm wildlife

- Farmers, crop protection industry and conservation organisations are working together to find solutions

- As Skylark Plots, and other measures are adopted, skylark and other farmland birds could return to the countryside

9.4 ON-GOING AND FUTURE COMMUNICATION ACTIVITIES

As the project concluded even more was done to promote SAFFIE and its findings. Industry partners were keen to promote the findings to a wider audience, and researchers have many further opportunities to report the detailed findings at scientific conferences.

The publication of a summary report, which pulls together the main findings of the study, was a key activity for 2007. The summary was distributed to agronomists, leading farmers, policy makers, and politicians. A final re-brief to policy makers on the final results from the research was organised, so that future stewardship measures take full account of the research delivered by this project.

APPENDIX 1

SAFFIE publicity list

Refereed and edited scientific papers and abstracts

Clarke, J.H. (2002) SAFFIE - Sustainable Arable Farming For an Improved Environment - Putting the B back into Arable. Proceedings of the HGCA R&D Conference. London: HGCA. Page 15.9.

Morris, A.J., Bradbury, R.B. & Evans, A.D. (2003) SAFFIE: the effects of novel winter wheat sward management on Skylarks (*Alauda arvensis*). Proc of the BCPC International Congress - Crop Science & Technology 2003, 3B-3, 227-232.

Jones, N., Archer, L. & Boatman, N.D. (2003) Methods of determining weed seed inputs to the seedbank on arable land. *Aspects of Applied Biology* **69,** Seedbanks: determination, dynamics and management. P171-178.

Morris, Antony J., Holland John, M., Smith, Barbara & Jones, Naomi E. (2004) Sustainable Arable Farming For an Improved Environment (SAFFIE): managing winter wheat sward structure for Skylarks *Alauda arvensis*. *Ibis* 146 (s2), 155-162.

Woodcock, B., Westbury, D., Potts, S.G., Harris, S. & Brown, V.K. (2005) Field margins in arable cropping systems: invertebrate conservation and food resources for insectivorous birds. *Agriculture, Ecosystems and Environment* **107,** 255-266.

Donald, Paul F & Morris, Tony J (2005) Saving the Sky Lark: new solutions for a declining farmland bird. *British Birds* **98,** 570-578.

Boatman, N.D., Jones, N.E., Smith, B. & Holland, J.M. (in press) Putting ideas about improving ecosystem health into practice a test at a field scale: Findings from the Sustainable Arable Farming for an Improved Environment (SAFFIE) project. IX International Congress of Ecology, Montreal, August 2005.

Claire Carvell, Richard Pywell, Matt Heard & Bill Meek. The potential value of Environmental Stewardship Schemes for the BAP bumblebee, *Bombus ruderatus (Fabricius)* (Hymenoptera: Apidae). Accepted in Entomologists Gazette.

Woodcock, B.A. & Mann, D.J. (2004) The occurrence of the macropterous fly Crumomyia pedestris (Meigen) (Sphaeroceridae, Diptera) in conservation field margins, with comments on its collection and distribution in Britain. *Dipterists Digest* **11,** 103-106.

Woodcock, B.A., Westbury, D.B., Potts, S.G., Harris, S.J. & Brown, V.K. (2005) Establishing field margins to promote beetle conservation in arable farms. *Agriculture Ecosystems & Environment* **107,** 255-66.

Smith, B.M. & Jones, N.E. (2007) Effects of manipulating crop architecture on weed and arthropod diversity in winter wheat. *Aspects of Applied Biology* **81,** 31-38: Delivering Arable Biodiversity.

Henderson, I.G., Morris, A.J., Westbury, D.B., Woodcock, B.A., Potts, S.G., Ramsay, A. & Coombes, R. (2007) Effects of field margin management on bird distributions around cereal fields. *Aspects of Applied Biology* **81,** 53-60: Delivering Arable Biodiversity.

Ramsay, A.J., Potts, S.G., Westbury, D.B., Woodcock, B.A., Tscheulin, T.R., Harris, S.J. & Brown, V.K. (2007) Arable planthoppers and their responses to novel margin management. *Aspects of Applied Biology* **81,** 47-52: Delivering Arable Biodiversity.

Morris, A.J. (2007) An overview of the Sustainable Arable Farming For an Improved Environment (SAFFIE) project. *Aspects of Applied Biology* **81,** 23-30: Delivering Arable Biodiversity.

Pywell, R.F., Meek, W.M., Carvell, C. & Hulmes, L. (2007) The SAFFIE project: management to enhance the value of arable field margins for pollinating insects. *Aspects of Applied Biology* **81,** 239-246: Delivering Arable Biodiversity.

Carvell, C., Pywell, R.F. & Meek, W.M. (2007) The conservation and enhancement of bumblebee diversity in intensively farmed landscapes. *Aspects of Applied Biology* **81,** 247-254: Delivering Arable Biodiversity.

Jones, N.E. & Smith, B.M. (2007) Effects of selective herbicide treatment, row width and spring cultivation on weed and arthropod communities in white wheat. *Aspects of Applied Biology* **81,** 39-46: Delivering Arable Biodiversity.

Woodcock, B.A., Potts, S.G., Westbury, D.B., Ramsay, A.J., Lambert, M., Harris, S.J., Brown, V.K. (2007) The importance of sward architectural complexity in structuring predatory and phytophagous invertebrate assemblages. *Ecological Entomology* **32,** 302-311.

<u>Planned scientific papers</u>

Morris, A.J. et al. Skylark responses to novel management practices in winter wheat (Ex1.1) Journal of Applied Ecology.

Morris, A.J. et al. Densities of breeding and foraging bird species in relation to the provision of within-crop and field edge management in winter wheat (Ex3).

Henderson, I.G, et al. Relating foraging birds to food resources and vegetation structure in wheat crops (Ex3).

Smith, B.M. & Morris, A.J. The invertebrate diet of farmland bird nestlings: composition and selection (Ex1.1).

Morris, A.J. & Bradbury R.B. First documented evidence of egg removal by skylarks British Birds (short note).

Jones, N.E. & Smith, B.M. Effects of selective herbicide treatment, row width and spring cultivation on weeds and arthropods in winter wheat. Refereed journal.

Jones, N.E. & Cook, S.K. Impact of selective herbicides, row width and spring cultivation on weed populations and yield of winter wheat.

Smith, B.M., Jones, N.E. & Morris, A.J. Effects of manipulating crop architecture on invertebrates in winter wheat. Refereed Journal.

Smith, B.M. & Holland, J.M. The impact of margins and undrilled patches on invertebrates in winter wheat.

Smith, B.M. & Jones, N.E. Weed invertebrates associations in a cereal crop.

Conferences, workshops, demonstrations

Date	Event	Organiser	Presenter	Subject
15-Jan-02	HGCA R&D Conference 2002	HGCA	J Clarke	SAFFIE - Putting the B back into arable.
12-Jun-02	Cereals 2002			
07-Apr-03	Research Field Day with LEAF		J Clarke	SAFFIE
15-Apr-03	Research Field Day with LEAF		J Clarke	SAFFIE
11-Jun-03	Cereals 2003		Alison Riding	SAFFIE
26-Jun-03	Sustainable Arable LINK conference	LINK	P Goldsworthy	SAFFIE
01-Jul-03	HGCA Agronomy field day	HGCA	A Riding	SAFFIE: enhancing biodiversity through novel habitat management.
21-Oct-03	Create profit & sustain wildlife workshop	HGCA/RRA	J Edney	SAFFIE
19-Nov-03	BCPC Int Congress - Crop Science & Technology 2003	BCPC	T Morris	SAFFIE: the effects of novel winter wheat sward management on skylarks.
28-Nov-03	Profitable Farming, Practical Conservation conf	LEAF	S Ogilvy	SAFFIE
05-Feb-04	BOU Scientific meeting - GM crops & birds	BOU	S Ogilvy	Key drivers of agricultural ecosystems.
04-Mar-04	BES Agroecology Gp - the Spatial Distribution of Invertebrates	GCT	B Smith	Weed - invertebrate relationships within agroecosystems.
10-Mar-04	HGCA R&D Conference 2004	HGCA		LINK Poster - Sustainable arable farming for an improved environment.

Date	Event	Organiser	Presenter	Subject
27/28-Mar-04	Ecology & conservation of lowland farmland birds: the road to recovery	BOU	T Morris	SAFFIE: managing WW sward structure for skylarks.
29-Apr-04 to 08-Jul-04	Masstock Group Events	Masstock		SAFFIE
08-Jun-04	SAFFIE Science & Media Day	SAFFIE	S Ogilvy / T Morris	SAFFIE
16/17-Jun-04	Cereals 2004	RASE	numerous	SAFFIE stand.
28/29-Jun-04	BASF farmer open days	BASF	J Edney	SAFFIE skylark plot demonstration.
01-Jul-04	Agrovista/NIAB Demonstration	Agrovista/NIAB	J Edney / T Morris	SAFFIE demonstrations plots.
14-Jul-04	Rosemaund Farmers Association	ADAS	S Cook	SAFFIE update.
07/09-Sep-04	BES Annual Meeting	BES	D Westbury et al	SAFFIE: the enhancement of biodiversity in sown field margins.
07/09-Sep-04	BES Annual Meeting	BES	S Harris et al	SAFFIE: effects of field margin management techniques on vegetation architecture and the impact on invertebrate communities.
09-Sep-04	RSPB Welsh Conference	RSPB	T Morris	Mind the gap – leaving space for skylarks.
13/14-Sep-04	EWRS Weeds & Biodiversity Working Gp	EWRS	N Jones	Determination of seed return in agro-ecosystems.
Sep-04	Student visitors to HM site	Cranedale Centre	S Ogilvy	SAFFIE demonstration.
27/28-Sep-04	AAB Arable Weeds and Biodiversity Conference	AAB	N Simpson	Targeted herbicide use in winter wheat for biodiversity benefits and retention of yields.

Date	Event	Organiser	Presenter	Subject
27/28-Sep-04	AAB Arable Weeds and Biodiversity Conference	AAB	N Jones	Effects of novel crop management techniques on weeds to improve biodiversity: preliminary results from the SAFFIE project.
27/28-Sep-04	AAB Arable Weeds and Biodiversity Conference	AAB	B Smith	Weeds & invertebrates: their relationship on arable farmland.
11-Nov-04	Review of Defra's Research Programme on Farmland Conservation & Biodiversity	Defra	S Ogilvy	SAFFIE
01-Dec-04	Vegetable Consultants Association Conference	VCA	T Morris	Farmland Bird Decline: Diagnosis, Recovery & Prescriptions for growers.
16-Dec-04	University of Reading CAER Student Symposium	CAER	T Morris	Mind the gap – Manipulating vegetation structure for farmland birds.
07-Feb-05	Wildlife is the business of Farming Conference	Crops/FEC		
17-Feb-05	Conservation farm walk at ADAS High Mowthorpe	ADAS	S Ogilvy	SAFFIE margins & skylark plots and ELS options.
Feb and Mar-05	Three SAFFIE farmer days	ADAS	numerous	update of results and demo of scarification for Hereford SAFFIE farmers.
09-Apr-05	RSPB Members Weekend	RSPB	Darren Moorcroft	
15/16-Jun-05	Cereals 2005	RASE	numerous	CPA, HGCA, RSPB stands.
30-Jun-05, 07-Jun-05, 09-Jul-05	Three ADAS Open Days (Rosemaund, Boxworth and High Mowthorpe)	ADAS	S Ogilvy/T Morris/N Simpson	SAFFIE display.

Date	Event	Organiser	Presenter	Subject
03 to 06-Jul-05	Royal Show	RASE	T Morris et al.	RSPB stand (featuring ELS options & skylarks).
01-Aug-06	2006 International Ornithological Congress	IOC	T Morris et al.	Strategies for successful bird conservation in arable and grassland systems.
09-Aug-05	IX International Congress of Ecology	ESA-INTECOL	N Boatman, N Jones, B Smith, J Holland	Putting ideas about improving ecosystem health into practice a test at a field scale: Findings from the Sustainable Arable Farming for an Improved Environment (SAFFIE) project.
05-Sep-05	British Ecological Society	BES	A. J. Ramsay et al.	Boosting biodiversity of bugs in arable areas-the SAFFIE effect.
13-Sep-05	Royal Entomological Society, Annual Meeting	RES	A. J. Ramsay et al.	Boosting bug diversity in an arable and pastoral landscape.
06-Oct-05	AIC members day	CPA	P Goldsworthy, J Clarke, N Jones, N Simpson	
19-Oct-05	National Academy of Sciences (US) Workshop	National Research Council (US)	S. G. Potts et al.	Conservation of biodiversity in natural and agro-ecosystems [SAFFIE given as a case study].
25-Jan-06	HGCA R&D Conference 2006	HGCA	James Clarke (talk) Jeremy Wiltshire (posters)	Talk: "SAFFIE - research into practice and policy. Posters x2: SAFFIE: increasing skylark numbers; SAFFIE: Increasing desirable weeds.

Date	Event	Organiser	Presenter	Subject
Feb and Mar 2006	Four SAFFIE farmers' days	J Wiltshire, ADAS	J Wiltshire, T Morris, I Henderson, D Westbury, A Ramsay, B Woodcock, S Cook	
05-Sep-06	British Ecological Society	BES	B Smith	Sustainable Arable Farming For an Improved Environment (SAFFIE): Weed-invertebrate relationships in the cereal ecosystem.
23-25 -Jan-2007	Delivering arable biodiversity at: Studley Castle	AAB	A. J. Ramsay et al.	Arable planthoppers and their responses to novel margin management.

<u>Articles in trade and popular press or other media</u>

Date	Magazine/media	Publisher	Title
May-02	Fieldfare	RSPB	Spacious crops for skylarks.
09-May-02	Farmer's Weekly	FW	Barley barons are good guys after all: SAFFIE.
14-Jun-02	Farmer's Weekly	FW	Trials to make sure wildlife's gain isn't the producer's loss.
18-Jul-02	FW Interactive with Crops	FWI	Green project keeps profit up.
22-Jul-02	Farming on line		Broad & shallow? Modulated support? Env friendly? & profit too?
26-Jul-02	Farming views - Issue 4		Round the back with Digger.
26-Jul-02	Farmer's Weekly	FW	Biodiversity at no net cost.
30-Jul-02	Internal RSPB note	RSPB	Perfect patches?
16-Aug-02	AGROW No 406	PJB Pubs Ltd	UK launches new ICM research.
17-Aug-02	Arable Farming	AF	Enhancing biodiversity with SAFFIE.
17-Aug-02	Crops	Crops	Space for the songsters.

Date	Magazine/media	Publisher	Title
30-Aug-02	Farmer's Weekly	FW	In brief.
06-Sep-02	NFU Business	NFU	Cash offered for help with livestock project.
Aug/Sep-02	Grapevine	CPA	Spotlight on: SAFFIE.
Sep-02	Grow for it - Issue 18	HGCA	SAFFIE
07-Sep-02	Crops	Crops	Viewpoint
Nov-02	RSPB Newsletter - No 4	RSPB	Larks ascending.
2002	The Voluntary Initiative	CPA	For the benefit of biodiversity.
25-Mar-03	Arable Farming		Have a field day.
09-May-03	Farmers Weekly		Barley barons are good guys after all: SAFFIE.
07-Jun-03	Crops	Crops	Baring all for the birds.
Aug-03	NIAB Assoc Newsletter No 8	NIAB	SAFFIE
30-Sep-03	Arable Farming		Profit for wildlife.
Autumn-03	Reading: reading issue 34	Univ. of Reading	Saving farmland birds.
21-Nov-03	Farmers Weekly		Manage weeds effectively and boost farm biodiversity.
16-Dec-03	Arable Farming	AF	Take a LEAF out of this bestseller.
22-Dec-03	Farm Business		Bare patches in cereals are boon for birds.
Dec-03	HGCA online	HGCA	SAFFIE patches encourage wildlife.
Dec-03	LEAF E-brief	LEAF	SAFFIE patches encourage wildlife.
Winter-03	Birds	RSPB	Larks recovering.
01-Jan-04	Field Fare	RSPB	SAFFIE success for skylarks.
23-Jan-04	Farmers Weekly	FW	Crop patches help skylarks.
25-Jan-04	Fieldfare	RSPB	SAFFIE success for skylarks.

Date	Magazine/media	Publisher	Title
29-Jan-04	Oxford Nature Conservation Forum Bulletin	ONCF	SAFFIE patches encourage wildlife.
Spring-04	Birds	RSPB	Undrilled patches benefit skylarks.
01-Feb-04	BTO News	BTO	SAFFIE enhancing biodiversity.
03-Mar-04	Arable Farming	AF	Take a LEAF out of this bestseller.
03-Mar-04	Farmers Weekly	FW	Unsown patches boost biodiversity.
Mar-04	Crop Saver	CPA	Skylarks' choice.
Mar-04	DTI/LINK website	DTI	Helping skylarks to sing again.
Apr-04	FarmBird UK	FarmBird UK	How skylark plots work.
Apr/Sep-04	Researchers Web Diaries: SAFFIE	RSPB	(5 online research updates)
28-May-04	SFFFS Internal Policy Bulletin	Defra	SAFFIE research is benefiting skylarks.
07-Jun-04	BBC News website	BBC	Skylarks helped by 'crop circles'.
08-Jun-04	Shropshire Star		Crop circles boosting skylarks.
08-Jun-04	Star (Barnsley, Doncaster, Sheffield editions)		Crop circles could be skylarks' lifeline.
08-Jun-04	Express & Star (Cannock, Dudley, Kidderminster, Lichfield, Sandwell, Stafford, Stourbridge, Walsall, Wolverhampton)		Crop circles may help skylark numbers.
08-Jun-04	Ipswich Evening Star		How can this ……. save this?
08-Jun-04	Belfast Telegraph		Unplanted ground could help save skylarks.
08-Jun-04	Birmingham Post		Farmers urged to create crop circles for sake of skylarks
08-Jun-04	Fwi website	FW	Patch protection brings bird boost.
08-Jun-04	BBC1 TV breakfast news/ One O'clock News	RSPB - David Gibbons	
08-Jun-04	Anglia TV news	RSPB -Tony Morris	
08-Jun-04	BBC1 Newsround	RSPB	

Date	Magazine/media	Publisher	Title
08-Jun-04	Radio Five Live News	RSPB	
08-Jun-04	Radio Two	RSPB	
08-Jun-04	BBC Radio 4 Today/news	RSPB	
08-Jun-04	BBC Radio 4 Farming Today	RSPB	
08-Jun-04	Q103 FM Cambridge local radio	RSPB - Tony Morris	
08-Jun-04	Scotsman	RSPB	
08-Jun-04	Daily Mail	RSPB	
08-Jun-04	Times	RSPB	
08-Jun-04	BBC online	BBC	Larking with crops - could crop circles hold the clue to reversing the skylarks decline?
09-Jun-04	The Cram: BBC2 news quiz	RSPB	
09-Jun-04	Cambridge News on line	Cambridge News	Skylarks soaring thanks to trials.
10-Jun-04	Stratford upon Avon Herald		Two year experiment throws a farming lifeline to skylarks.
11-Jun-04	Farmers Weekly	FW	Project skylark.
11-Jun-04	Farmers Guardian	FG	Farmers encouraged to support the skylark.
11-Jun-04	Factiva		Farmers encouraged to support the skylark.
12-Jun-04	East Anglian Daily Times (East, Essex editions)	Unsown fields help skylarks.	12-Jun-04
15-Jun-04	Defra website	Defra	Good news for farmers and skylarks.
16-Jun-04	Western Morning News (Cornwall, Devon)		Lark-friendly fields that don't hit yields.
Summer 04	LEAF newsletter	LEAF	SAFFIE success for skylarks.
17-Jun-04	Oxford Nature Conservation Forum Bulletin	ONCF	Skylark lifeline from national farm trial.

Date	Magazine/media	Publisher	Title
28-Jun-04	Arable Farming	AF	SAFFIE plots to save the skylark.
28-Jun-04	Factiva		SAFFIE plots to save the skylark.
01-Jul-04	Anglian Farmer		Local farms are winners for wildlife.
01-Jul-04	Crop Saver	CPA	49% more chicks with UP.
01-Aug-04	LEAF IFM trainers pack	LEAF	SAFFIE
20-Aug-04	Agronomists Alliance newsletter	HGCA	SAFFIE News: Undrilled Patches Best Option.
24-Aug-04	NIAB Assoc - Email Newsletter	NIAB	Boost for skylarks.
Autumn-04	Birds	RSPB	Skylark Patches could reverse trends.
Nov-04	Conservation Science in the RSPB 2004	RSPB	Managing winter wheat for skylarks.
Dec-04	Heart of England - BBC Regional TV	RSPB - Tony Morris	
01-Feb-05	Agriculture LINK newsletter	Defra	Managing arable farming for biodiversity and profit.
18-Mar-05	Farmers Weekly	FW	Good for farms - good for birds.
April-05	Cirl Bunting Bulletin - newsletter for Devon Farmers	RSPB	Skylark plots - a novel way to save the skylark.
20-May-05	Farmers Weekly	FW	Understanding environmental schemes.
26-May-05	Hereford Times		Experts are on hand for ADAS open day.
06-Jun-05	Natural History Programme - BBC Radio 4	RSPB - Paul Donald & Tony Morris	Signs of Spring: skylarks - decline and recovery.
28-Jun-05	The Journal - First/South		Guide to field margins - help for farmers.
01-Jul-05	Hope for Farming	RSPB	RSPB farm booklet - incl 3 pages on SAFFIE skylark plots & margins.

Date	Magazine/media	Publisher	Title
01-Jul-05	Farmers Guardian (Eastern edition)	FG (E)	Field margins guide will provide growers with best options data.
11-Jul-05	Arable Farmer	AF	Guide of field margins.
02-Sep-05	Farmline.com		VI backs skylark plots, desirable weeds and scarified margins.
09-Sep-05	Farmers Guardian	FG	Saffie offers practial tips on skylark patches.
09-Sep-05	Farmers Guardian (Eastern edition)	FG (E)	Raising the profile of biodiversity.
17-Sep-05	Crops		Plotting skylark success.
2005	http://www.farmwildlife.info/default.asp		Farmwildlife.
28-Jan-06	Crops		Birds won't peck away profits if you plan with care.
10-Feb-06	Farmers Guardian (+ Eastern edition)	FG (E)	Spring cultivations increase wanted weeds.
06-Feb-06	http://www.farmwildlife.info/default.asp	T. Morris	Skylark Plots & Field Margins.
2006	2005 GCT Annual Review	GCT	Sustainable Arable Farming For an Improved Environment (SAFFIE) project.
Jan-07	ADAS Science Review 2005-2006	Jeremy Wiltshire	Sustainable Arable Farming For an Improved Environment (SAFFIE).

Other SAFFIE publications

Date	Title	Publisher
2002	Sustainable Arable LINK Programme Factsheet: SAFFIE - enhancing biodiversity.	LINK
Jun-04	CPA SAFFIE Newsletter Update.	CPA
Jun-04	CPA/VI Best Practice Guide: Undrilled Patches for Skylarks.	CPA
Jul-04	RSPB Farming for wildlife: Skylark plots.	RSPB
Mar-05	Planning your entry level stewardship application - CD ROM.	RSPB

Date	Title	Publisher
2002	Sustainable Arable LINK Programme Factsheet: SAFFIE - enhancing biodiversity.	LINK
May-05	RSPB Farming for wildlife: Skylark plots - updated version.	RSPB
Aug-05	CPA SAFFIE Newsletter.	CPA
2005	Winspear R. and Davies G. 2005. A management guide to the birds of lowland farmland. RSPB, Sandy.	RSPB

<u>Press releases</u>

Date	Title	Publisher
Jul-02	SAFFIE - enhancing biodiversity.	
May-03	Putting SAFFIE on the map.	
Dec-03	SAFFIE patches encourage wildlife.	
Jun-04	Skylark lifeline from national farm trial.	
05-Oct-04	Don't lose the plot in the haste to sow winter cereals.	RSPB
Nov-04	Arable farming - management for biodiversity & profit.	Ag-LINK
Spring-05	ELS options (several regional releases on skylark plots, margins and other ELS options).	RSPB
07-Sep-05	Sowing hope for skylarks.	RSPB
July-07 (planned)	End of project press release.	RSPB