

CHAPTER 3

How can field margin management contribute to invertebrate biodiversity?

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3.1 Introduction

More than 50% of known species are invertebrates (World Conservation Union 2010). While many of these are small, inconspicuous and less charismatic than their vertebrate cousins, invertebrates are an indispensable part of a healthy ecosystem. They are primary, secondary and tertiary consumers, nutrient recyclers, and prey items for a wide range of other taxa. Farmland invertebrates provide a range of ecosystem services such as pollination and pest control, essential for human welfare and economic prosperity. For example, production of at least one third of the world's food, including 87 of the 113 leading food crops, depends on pollination by insects, bats and birds (Klein *et al.* 2007), the value of insect pollination worldwide being estimated (in 2005) at €153 billion (Gallai *et al.* 2009).

Yet the outlook for many farmland invertebrates is bleak. How butterflies are faring provides an insight into the fortunes of the UK's invertebrates: an alarming 72% of butterfly species have decreased in abundance and 54% decreased in distribution in the ten years to 2011 (Fox *et al.* 2011). These include wider countryside species such as the small tortoiseshell *Aglais urticae* and small skipper *Thymelicus sylvestris*. The statistics for moths make equally gloomy reading; records spanning nearly four decades show two-thirds of moth species in the UK are declining, amounting to around 220 species (see Chapter 8, this volume). More than a fifth of them have plummeted by a third or more in the past decade (Conrad *et al.* 2006). Steep population declines have also been recorded for other groups,

including bumblebees (Goulson *et al.* 2008) and carabid beetles (Brooks *et al.* 2012). Many factors related to agricultural intensification are implicated in these and other invertebrate declines, including loss of forage (e.g. Carvell *et al.* 2006), loss of breeding habitat (e.g. Warren *et al.* 2001), and changes in fertiliser and pesticide use (Storkey *et al.* 2012). For example, while some of the most notorious pesticides (e.g. DDT) are no longer used, non-target invertebrates continue to be vulnerable to modern pesticides.

Neonicotinoid pesticides are currently the focus of considerable publicity. These systemic insecticides are now the most widely used pesticides in the world and are highly toxic to most arthropods (Goulson 2013). Their use is strongly implicated in bumblebee declines: colonies of the bumble bee *Bombus terrestris* exposed in the laboratory to field-realistic levels of the widely used neonicotinoid imidacloprid have a significantly reduced growth rate and an 85% reduction in production of new queens compared with controls (Whitehorn *et al.* 2012); the European Commission is now legislating to restrict the use of neonicotinoids in the EU. Neonicotinoids have been called the 'new DDT', demonstrating the old truth that those not learning from history will repeat it (Monbiot 2013¹).

Neonicotinoids persist and accumulate in soil, often leaching into water, and their effects on birds, mammals, and other taxa are not known (Goulson 2013). Other threats include fungicides. Widely used on farmland, these also affect honey bees: probability of infection by the gut parasite *Nosema* was increased where bees consumed pollen with a higher fungicide load (Pettis *et al.* 2013).

What refuges from these threats can farmland provide? One option for mitigating the impacts of farming intensification is the creation of uncropped field margins (Chapter 2, this volume). Field margins connect non-cropped habitats such as semi-natural grasslands (e.g. Sutcliffe *et al.* 2003). They are also part of wider landscape-scale matrix restoration (Donald and Evans 2006). Field margins increase resources for invertebrates through sward diversity and complex vegetation structure and can also reduce the exposure to pesticides of boundary-dwelling invertebrates, through a buffering effect. They may also provide invertebrates with a refuge from farming operations and undisturbed areas for breeding

¹ Monbiot, G. The Guardian Aug 13 2013

and overwintering, and act as sources from which overwintering invertebrates may colonise fields. In 1995, in recognition of the importance of field margins for wider biodiversity, cereal field margins were listed as a priority habitat by the UK Biodiversity Steering Group (UK Biodiversity Steering Group 1995a,b). They are now one of the most widely adopted conservation measures on farmland and are an important component of agri-environment schemes in the UK (e.g. Grice *et al.* 2006), and Europe (e.g. Kleijn *et al.* 2006).

How should a field margin be created and managed to maximise the benefit to wildlife, while at the same time accommodating the practical realities of farming? Finding practical ways to manage the uncropped edges of arable fields for biodiversity benefits was a key challenge in the mid-1980s. Two of our team, David Macdonald and Helen Smith, solicited opinions from an array of farmers and farm advisors. From this, it transpired that field margins posed many unanswered questions and that no reliable, evidence-based management prescriptions were available. In particular, the farmers asked us how could field margins be managed to foster desirable species of plants and invertebrates while allowing for the control of weeds? This question, emerging as the priority from our 'market research' became the stimulus for developing a pioneering farm-scale experiment (see Chapter 2, this volume). Our first step was to bring together a team under the Manpower Services Commission². This enabled us to transform the general conservation quality of the farm. Next, supported initially by English Nature (now Natural England) and the Co-Op Bank, we designed and established one of the largest farm-scale conservation ecology experiments in Europe. In the meantime, we formed a liaison with the Farming and Wildlife Advisory Group (FWAG) who, throughout the project, were crucial in helping communicate the concerns and interests of farmers to us, and facilitating dissemination of our research results back to farmers and the wider practitioner community.

Our hypothesis was that simple methods for restoring and managing field margins could improve habitat quality for wildlife on farmland, without resulting in the proliferation of problem weeds. Successful management for both agriculture and conservation requires

² This was a non-departmental public body created in 1973 to co-ordinate employment and training services in the UK (such as training schemes to help alleviate unemployment). It was abolished in 1988.

competing goals like these to be achieved. For example, many farmers will want to minimise weed problems and management costs, but many also want to promote game interests, or promote pollinators or aphid predators. Our experiments were primarily designed to understand the critical ecological processes important in field margin management, so that the same principles could be applied in other situations. By using a blocked design and keeping our treatments constant, we minimised sources of variation and so maximised their predictive power, providing the robust information for extrapolating to different circumstances and sites.

In the previous chapter (Chapter 2, this volume), we examined the factors that affected vegetation on the experimental margins. Here, we first look at how their botanical character affected the invertebrates that were found there. We briefly summarise the experimental design; full details are given in the previous chapter and in Smith *et al.* (1993).

3.2 Impacts of field margin management on invertebrates

We aimed to restore attractive and diverse communities on the field margins by establishing swards that imitated semi-natural grassland (typically uncompetitive and perennial species). In autumn 1987, field margins around arable fields at Wytham were extended in width from 0.5 m to 2 m by following arable strips, which were divided into 50 m long plots (Fig. 3.1). Since in many intensive arable situations the local flora is severely impoverished, we used two methods to establish our swards. Half of the plots were sown with a grass and wild flower seed mixture which comprised six 'non-aggressive' grass species and 17 forbs in a 4:1 weight ratio. We selected a complex mixture to enable us to test the responses to management of a wide range of species, all of which were common components of semi-natural grassland in the Wytham area. The remaining plots were left to regenerate naturally: a cost-free option that would be likely to result in very different sward development, and which may have been especially appropriate where conservation of the local flora is a priority. Fertilisers and pesticides were not applied to the field margin swards, other than on the tenth treatment (see below).

Both sown and naturally regenerated plots were managed in the following ways: either left uncut, or cut (with cuttings removed) in summer only, spring and summer, or spring and autumn. We predicted that mowing, and the timing of mowing, would have important consequences for plant communities, for example via differing impacts on flowering and seed production, or through competitive interactions between species (e.g. mowing, like grazing, can select for slow-growing species at the expense of more competitive ones), and on invertebrate communities, which were likely to be sensitive to vegetation structure and composition.

A ninth treatment, on unsown plots only, investigated the impact of leaving cut hay lying - advocacy of removal of cut hay has been a mantra of grassland conservation management because of its expected effect in reducing soil nutrient levels and increasing sward diversity. Finally, it was common practice in agricultural management at the time to spray field margins with glyphosate herbicide annually in late June. Our tenth treatment was left uncut and managed in this way.

[INSERT Figure 3.1 here]

Plots were monitored for plant and invertebrate diversity for up to twelve years. Here, we focus on the effects of field margin management on four important and ecologically contrasting groups of invertebrates: butterflies (Lepidoptera), spiders (Araneae), hoppers (Auchenorrhyncha), and heteropteran bugs (Heteroptera) (Feber *et al.* 1996; Baines *et al.* 1998; Haughton *et al.* 1999). We chose these groups because, between them, their ecological characteristics are such that they are representative of the wider community of farmland invertebrates.

Butterflies and moths have complex life cycles, comprising egg, larval, pupal, and adult stages. Some species live as adults for only a few days or weeks, and spend the winter in the egg, larval or pupal stage. The small skipper *Thymelicus sylvestris*, for example, hatches from its egg in late summer, spins a cocoon around itself, and overwinters as a tiny larva within

the sheath of a grass stem. It feeds during the spring, pupates in June, and emerges in July, having just a few weeks as an adult in which to lay its own eggs. By contrast, larvae of the powerfully flying peacock butterfly spend a short few weeks feeding voraciously on nettles in spring. They then pupate, emerging as adults in late summer and surviving the winter as butterflies, hibernating until warm spring days when they seek nettle clumps on which to lay their eggs. With such different life histories, butterflies need a range of resources: sufficient nectar sources to supply them with food, suitable larval foodplants (which vary according to the species), and suitable habitat, often undisturbed, for the protection and development of the immature (immobile) stages. Furthermore, around 85% of British butterflies are relatively sedentary (Thomas 1984) so these functional habitats cannot be widely dispersed. So we predicted that butterflies would respond in contrasting ways to our different management treatments and would usefully indicate responses of other pollinator groups.

Spiders (Fig 3.2) are highly successful predators and valuable pest control agents. They are often the first predators to enter a crop field after ploughing, establishing themselves before most pests have an opportunity to colonise (Sunderland *et al.* 1999) and frequently reaching high numbers of individuals (e.g. up to 1000 individuals/m², Marc *et al.* 1999) and species (~50–60 species is not exceptional, e.g. Feber *et al.* 1998; Sunderland *et al.* 1999). They have evolved the ability to withstand periods of starvation. Many spiders will actively (or passively via their webs) capture more prey than they consume (the reason for this behaviour is not understood); such ‘superfluous killing’ can further augment their effectiveness at controlling pests (Sunderland *et al.* 1999). In laboratory experiments, Mansour and Heimbach (1993) found that three common spider species, *Erigone atra*, *Lepthyphantes tenuis* and *Pardosa agrestis*, together could reduce numbers of the cereal aphid *Rhopalosiphium padi* by as much as 58%. Variation in mobility is important. Some, such as linyphiids (‘money’ spiders), can travel for many miles using a dispersal method known as ‘ballooning’. These spiders let out lines of silk which, if the air currents are favourable, act as parachutes and lift them to great heights (spiders have been captured an astonishing 5 km above sea level) from where they are carried to new locations. By contrast, other species, such as the larger ground-dwelling lycosids (wolf spiders), move by walking, and may travel through two or three fields only during their entire lifetime. A range of feeding strategies is also exhibited: *Tenuiphantes tenuis*, one of the commonest spiders of

farmland, builds a sheet web of between 60 and 95 cm², often anchored to vegetation and placed just above the soil, while wolf spiders will ambush or actively hunt down their prey. Field margin vegetation structure might therefore be predicted to be more important than the mix of species composing a sward in terms of potential impacts on spider communities (Gibson *et al.* 1992).

[Insert Fig 3.2 here]

By contrast, the UK's 400 or so Auchenorrhynca species (leafhoppers, planthoppers and froghoppers) are exclusively herbivorous, sucking sap from their hostplants. The most well-know are probably the immature stages of froghoppers, which produce the spittle-masses, often called cuckoo-spit, which appear in spring on many plants. Hoppers often have very specific feeding requirements and might be more sensitive to the species composition of the habitat than to its architecture.

Lastly, Heteroptera, the true bugs, are a useful indicator group for insect diversity in general for various reasons. The Heteroptera (their name derived from the Greek '*hetero-*' meaning different and '*ptera*' meaning wings, referring to the contrasting texture of the front wings, leathery at the base and membranous at the apex) include a diverse assemblage of insects that have become adapted to a broad range of habitats - terrestrial, aquatic, and semi-aquatic. Like the hoppers, they are characteristic of temperate grasslands. The group includes phytophagous species (which feed on vascular tissues or on the nutrients stored within seeds), as well as predatory species and scavengers. The larval and adult stages are sensitive to changes in their environment, such as vegetation structure and flower abundance (Morris 2000; Zurbrügg *et al.* 2006) and studies have shown that richness of the Heteropteran communities correlates strongly with total insect diversity (Duelli and Obrist 1998).

3.2.1. Margin management and butterflies

We monitored butterflies on the experimental margins, using transects, for three years and the experimental treatments had major, and very different, effects on them (Feber *et al.*

1996). Butterfly abundance was strikingly higher on sown compared to naturally regenerated treatments; as early as the second year of the experiment we recorded a mean of 90.9 butterflies per 50 m plot on sown, uncut treatments, compared to just 39.1 on their naturally regenerated equivalents (Table 3.1).

Although sowing did not increase the total abundance of flowers, crucially, it increased the abundance of types and species of nectar sources that were preferred by butterflies. We discovered this by capturing, harmlessly marking with a permanent pen and releasing, over 650 meadow brown *Maniola jurtina* butterfly individuals and 785 gatekeeper *Pyronia tithonus* individuals. For each of these 1400+ individuals, we recorded which experimental plots they were using, when, and what they were feeding on. These data, combined with over 40 hours of behavioural observations, and monthly counts of flowers on all our margins, revealed that, of the 99 species of plant in flower on the margins in July and August, a mere 15 species were being used as nectar sources and, of these, some were greatly preferred over others. Knapweeds *Centaurea nigra* and *C. scabiosa*, for example, despite together being ranked only as the 45th most numerous flowers in the sward, accounted for a remarkable 12% of all butterfly visits. Oxeye daisy *Leucanthemum vulgare*, the 4th most abundant flower, accounted for a third of all flower visits by butterflies (Feber *et al.* 1994). All three of these species were components of the seed mixture, included with butterflies in mind, and they did not occur on the naturally regenerated swards (Smith *et al.* 1994). We had a rare glimpse of how these plant species had fared over the ensuing thirteen years by repeating our plant surveys in 2001 (Smith *et al.* 2010). Despite this length of time, two of the most favoured nectar sources, common knapweed *C. nigra* and oxeye daisy, were still among the most abundant species on sown plots, while naturally regenerated plots remained relatively poor in nectar sources (Smith *et al.* 2010). So, we had proven that wild flower seed mixtures could be very successful in supplying nectar resources for adult butterflies on farmland, even over the long term, if they are carefully designed. Such mixtures are likely to deliver the greatest biodiversity gain when planted on fertile soils, with a history of intensive management, where other sources of suitable plant colonists are absent and the vegetation is impoverished or dominated by annuals (Smith *et al.* 1994). They will be most beneficial to adult butterflies and other pollinators if they

include a mixture of early (e.g. cowslip *Primula veris*) and later flowering (e.g. field scabious *Knautia arvensis*) species to provide nectar throughout the season.

[Insert Table 3.1 here]

Mowing was one of the more important experimental interventions. In all years, mowing had substantial effects on mean butterfly abundance (Table 3.1). Butterfly numbers were highest on treatments which were uncut, or cut in spring and autumn. Numbers recovered slowly on mown treatments, particularly those that were sown, where oxeye daisy reflowered several weeks after mowing. However, neither butterfly abundance nor species richness regained levels comparable with those on treatments which had not been mown in the summer. Mowing in summer (at the end of June) was generally detrimental to butterfly populations since it removed nectar sources at a time which coincided with highest butterfly abundance. Although two months later there was little difference in flower abundance between cut and uncut treatments, in arable systems, where sources of nectar are patchy or scarce, large-scale mowing may remove all foraging areas except those accessible to the most mobile species, such as the vanessid butterflies (e.g. small tortoiseshell) during the period following the cut.

However, mowing is not always bad for butterflies. Summer mowing can generate late sources of nectar by delaying flowering or initiating reflowering. Currently, this approach is promoted by Entry Level Stewardship in England to extend forage availability for pollinators such as bumblebees (Natural England 2008). Where sward diversity is low, for example where simple seed mixtures have been sown with few forbaceous species, limited-scale mowing may thus be used to manipulate nectar availability throughout the season. Memmott *et al.* (2010) suggest that climate change could reduce the length of season in terms of nectar and pollen provision for bumblebees, but this could be ameliorated by adding extra forage species which flower early in the season (such as red or white deadnettle *Lamium purpureum*, *L. album*) and at the end of the flowering season (such as scabious).

In our experiment, the chief advantage of sown margins lay in their ability to provide abundant nectar resources for adults. Indeed, the criteria used for selecting wildflower species for seed mixture included their nectar source potential, but not their suitability as larval food plants. Nonetheless the sown margins contained some grass species, such as red fescue *Festuca rubra* and small timothy *Phleum pratense bertolonii* which were potentially important hostplants for the satyrid butterflies, including meadow brown, and gatekeeper. While sweep netting confirmed the presence of the larvae (in itself an important finding, as it showed that the butterflies were successfully breeding on the field margins), revealing which grass species they were actually feeding on was a highly challenging task. The larvae are extremely sensitive (falling from their plant at the slightest disturbance), unhelpfully green and hairy (making them difficult to see) and strictly nocturnal in their feeding habits. Undaunted, over spring nights, we crawled along the field margins and managed to locate by torchlight 22 meadow brown and 19 gatekeeper larvae, and tag the grass blades they were consuming, for identification in daylight. To our surprise, we found the larvae to be feeding on a wide range of grasses, including two common and weedy species of farmland, sterile brome *Anisantha sterilis* and blackgrass *Alopecurus myosuroides*, and also ryegrass *Lolium perenne*, a widespread species of intensive grassland, and widely believed to be of little value as a butterfly foodplant.

For these two satyrid species, the results suggested that, where permanent grassy swards existed, other factors such as nectar source abundance were more likely to limit their populations on farmland than was the availability of the larval foodplant. However, many other farmland butterflies have more specific larval foodplant requirements. Common blue *Polyommatus icarus* larvae, for example, feed on bird's foot trefoil *Lotus corniculatus* or black medick *Medicago lupulina*, while small copper larvae rely on common sorrel *Rumex acetosa*, sheep's sorrel *Rumex acetosella* or occasionally dock species *Rumex* spp.; all of these species were found in the naturally regenerated, rather than the sown, swards. While the sown margins had significantly more species in total than the naturally regenerated margins, at least in part because of the complex seed mixture used, the numbers of unsown species that they accommodated were substantially lower. This effect persisted even twelve years after the field margins were established (Smith *et al.* 2010). This implies that very

widespread use of wild flower seed mixtures which do not include host-plants may not be advantageous to butterfly populations. In any large-scale restoration of uncropped field edges by wild flower seeding on intensively managed arable farmland, the inclusion of larval foodplants in the seed mixture, as well as adult nectar sources, is essential.

During the summer, adult females of many species were ovipositing and the larvae of some were feeding or completing their development on their host-plants. As well as affecting nectar source availability, mowing during any part of this period would have disruptive effects on these egg, larval, or pupal stages. For example, mowing during the spring or early summer can result in large-scale losses of larvae of species such as orange tip *Anthocharis cardamines*, whose larvae remain on a single plant of cuckoo-flower *Cardamine pratensis* or hedge garlic *Alliaria petiolata* to complete their development. The orange tip larva is so protective of its plant that the first one to hatch on a given plant will devour any other eggs that have been laid there - the conspicuous bright orange singly laid eggs are designed to deter other females from laying on the same plant. Other butterflies, such as small skipper *Thymelicus sylvestris* and large skipper *Ochloda venata* lay eggs within the grass sheath, which must remain undisturbed if the larvae are to develop successfully.

[INSERT Fig 3.3]

Evidence in support of a patchy rather than widespread approach to mowing management on field margins is neatly provided by the egg-laying habits of two species of farmland butterfly, the small tortoiseshell and the peacock. Both species lay eggs in clumps on common nettle *Urtica dioica* plants, which hatch into clusters of larvae (Fig. 3.3). Data from the experimental margins on the location of these egg clusters revealed that ovipositing small tortoiseshell females almost exclusively preferred short nettle regrowth, in contrast to peacock butterflies which selected tall, mature nettle plants for egg-laying (Fig. 3.4; Feber *et al.* 1999). Studies on small tortoiseshell larvae have shown that larval growth rates and pupal weights are significantly higher on nettle re-growth, the leaves of which are high in soluble nitrogen and water (Pullin 1987). The bigger clumps of peacock larvae may need the greater volume of plant material and physical support of larger plants to complete their

development. Furthermore, the flight periods of both species, as with many butterflies, can vary between years by several weeks according to the weather; higher temperatures leading to earlier emergence. The different requirements of these two species alone, together with variation in their phenology, illustrate the importance of not managing all margins in the same way at the same time on any given farm. Mowing different margins on a farm, or different sections of the same margin, will result in a heterogeneous sward providing breeding opportunities for a wider range of species. It may also have the benefit of extending flowering and thus forage availability for nectar and pollen feeders (above).

[Insert Figure 3.4 here]

3.2.2 Margin management and Araneae, Auchenorrhyncha and Heteroptera

During the first four years of the experiment, a total of 111 species of spider was recorded from a sample of 51 775 individuals. Distinct patterns emerged, the most obvious of which was the significantly higher abundance and species richness of Araneae on uncut compared to cut plots (e.g. Fig. 3.5). The timing of cutting was especially important. Both regimes involving cutting in summer were associated with a sharp reduction in the abundance of Araneae, which persisted throughout the year (Fig. 3.6), while cutting in spring and autumn, despite being the same frequency, had a much less severe effect. Immediately after cutting in spring, the abundance of Araneae was significantly lower compared to uncut plots, but numbers recovered relatively quickly (Fig. 3.6).

Furthermore, the effects of summer mowing on spiders persisted into the following year (Baines *et al.* 1998; Smith *et al.* 1993). Although the effects on spiders of cutting in spring were less persistent than those of summer cutting, they may have particular agricultural significance. Cereal aphids, for example, which overwinter on grassland and hedgerow species, colonise crops in May and June (Hand 1989), and it is at this time that the predatory Araneae can potentially have most impact for crop pest control (Sunderland *et al.* 1986).

[INSERT Figure 3.5 here]

[INSERT Figure 3.6 here]

Management which increased the structural diversity of the field margin swards also increased the abundance and species richness of Araneae. This is likely to result from the requirement of many species of Araneae for specific web-building sites and from higher prey densities in taller vegetation (Southwood *et al.* 1979). Thus, we found that the largest and most species rich communities of spiders were fostered in the absence of regular cutting.

In common with butterflies, two of the other invertebrate groups we studied benefitted from sowing. The abundance and species richness of both spiders and Auchenorrhyncha were higher on sown margins in the first four years of the experiment (Baines *et al.* 1998). It seems likely that this was mediated via habitat heterogeneity (Macdonald *et al.* 2000). Sown margins were likely to provide more heterogeneous habitat architecture, within which web-building niches were consequently more diverse. This hypothesis was supported by measurements of vegetation structure derived from combined measures of vegetation height and density (obtained using a modified sward stick; Butterflies Under Threat Team 1986). Vegetation structure was more complex on sown compared to naturally regenerated margins. The dominance of robust, branching species, such as oxeye daisy (Smith *et al.* 1994), in sown plots is likely to have been important. The greater plant species richness of these swards (Smith *et al.* 1999), again acting through structural changes, may also have increased the abundance of invertebrate prey.

In contrast to the Auchenorrhyncha, sowing had no significant or consistent effects on the Heteroptera. The dietary plasticity of many Heteropteran species (many predatory bugs, for example, are able to feed on plants in the absence of prey) is likely to make them less dependent on plant species composition. Among the herbivorous species, one of the most numerous in our samples was *Lygus rugulipennis*, the tarnished plant bug, which feeds largely on common nettle *Urtica dioica*; this plant was significantly less abundant in sown than naturally regenerated swards.

Auchenorrhyncha, while probably benefiting from enhanced physical heterogeneity of the habitat, are likely to be more dependent on the plant species composition of a habitat. While the group is considered to have rather generalised phytophagous habits (Morris 1971), the majority is known to prefer grasses to other vegetation and some feed exclusively on grasses (Morris 1990). Phytophagous groups may in general show a more direct link with plant species diversity rather than structural complexity. We know that the sown margins in our experiment contained more grass species compared with unsown (Smith *et al.* 1993).

Further evidence that spiders and Auchenorrhyncha were responding to different aspects of the changes in habitat heterogeneity resulting from the different management regimes was provided by their responses to herbicide spraying. Auchenorrhyncha showed a rapid but short-lived decline in the weeks immediately following spraying, while the effect on spiders was delayed by at least a month (Baines *et al.* 1998). This is what we would expect if spiders were more influenced by vegetation structure than were Auchenorrhyncha, as the sprayed, but dead, vegetation stems remained intact for some time after the herbicide application.

Eight years after the field margins were established they were once again sampled for Araneae, Auchenorrhyncha and Heteroptera to investigate whether the pattern of effects of different management regimes on the invertebrate assemblages remained similar (Haughton *et al.* 1999). All of the mowing regimes continued to have a negative impact on the invertebrates, and the most severe impact was that of mowing in summer compared to leaving margins uncut (Table 3.2). This reduced the abundance of all of the invertebrates we identified. As in the first few years of the experiment, the timing, rather than the frequency of cutting, was more important. For example, cutting in summer only, or spring and summer, were more damaging to total invertebrate and spider abundance than cutting in spring and autumn (Haughton *et al.* 1999).

[INSERT Table 3.2 here]

The impacts on invertebrates of sown compared to naturally regenerated margins were less marked eight years after the margins were established (Haughton *et al.* 1999). Of the three groups of invertebrates, only Auchenorrhyncha abundance was, by this stage, significantly increased by sowing. In our experiment, differences in plant composition between the sown and naturally regenerated sward types lessened over this time period (Smith *et al.* 2010; Chapter 2, this volume).

We found no evidence that removal of the cut material was of any benefit to invertebrates over the first four year period (Baines *et al.* 1998); indeed, in the third year of the study, more spider species (mean = 15.8, SE = 0.8), were recorded where the cuttings were left, compared with 12.7 (SE = 1.13) species where they were collected. In a separate exercise, the rarely studied pseudoscorpions (also arachnids), were sampled from the field margins (Bell *et al.* 1999). The ancestral habitat of these invertebrates is leaf litter, with deep woodland leaf litter providing an ideal stable environment. After eight years, leaving hay lying appeared to ameliorate the effects of the cutting regimes on this group of invertebrates (Bell *et al.* 1999). Similarly, eight years after the start of the experiment, Heteroptera abundance was also significantly enhanced by leaving the hay *in situ*, perhaps through altering prey communities. Over the much longer term, one might predict a lowering of invertebrate diversity on these swards, mediated by nutrient addition translating slowly into reduced plant species richness. However, even after 13 years, there was no evidence for reduced plant diversity on the naturally regenerated swards where hay had been left lying (Chapter 2, this volume; Smith *et al.* 2010).

Despite their contrasting ecologies, Araneae, Auchenorrhyncha and Heteroptera all tended to be more abundant and species-rich on uncut compared to cut margins (Smith *et al.* 1993; Baines *et al.* 1998; Bell *et al.* 2002). The removal of habitat structure, cover, and food by mowing make it likely that the majority of invertebrate groups would benefit, at least in the short term, from leaving margins uncut. However, in the short to medium term, some mowing is important if the plant species richness of the margins is to be maintained (Chapter 2, this volume; Smith *et al.* 1994), this also having knock-on effects for species richness of the invertebrate assemblages.

3.3 Does margin width matter for spiders?

We demonstrated that how uncropped field margins are established and managed has different consequences for the invertebrates living on them. Other aspects of field margins might also be influential. For example, one question relates to their optimum width: are wider field margins better for biodiversity than narrow ones? Despite being relevant for the development of agri-environment schemes, we know rather little about this. Field margin widths under agri-environment schemes are determined primarily by economic and practical factors. The studies that have been undertaken suggest there may be effects. For example, wider margins may have higher plant diversity (e.g. Shippers and Joenje 2002). Stoate and Boatman (2002) found that the width of perennial vegetation at the hedge base was associated with the presence of yellowhammer *Emberiza citrinella* and whitethroat *Sylvia communis* breeding territories (Stoate and Boatman 2002). Considering the intricacy of their communities, the effects of margin width on invertebrates are likely to be complex (Macdonald *et al.* 1998). Margin width may affect the movement of invertebrates into the crop during the summer and into overwintering habitats after harvest. A narrow margin might facilitate movement to and from a hedgerow, thus favouring species which overwinter in this habitat; but a wide margin might provide a physically greater area of overwintering habitat for species which require grassy habitats. Habitat area (patch size) has been shown to be important for both specialist and generalist species: Brückmann *et al.* (2010) showed that decreasing habitat connectivity dramatically decreased the abundance of specialists (up to 69%) in both plants and butterflies, while Osborne *et al.* (2008) found that linear features such as hedgerows held a greater proportion of bumblebee nests (20-37 nests per ha) than the equivalent area of non-linear habitats such as woodlands and grassland (11-15 nests per ha). Conversely, species on narrow margins may be more susceptible to spray drift, inadvertent fertiliser application and other management operations. Bundschuh *et al.* (2012) detected increasing grasshopper densities with increasing field margin width next to cereals and vineyards, and densities equivalent to those of grassland sites were observed only in field margins more than 9 m wide, except for field margins next to orchards. Considered together with their results from toxicological studies, they conclude that current insecticide risk

assessments are insufficiently protective for grasshoppers in field margins. The positive relationship between habitat area and species richness derived from theories of island biogeography also suggests that larger areas may hold more wildlife; in their meta-analysis of set-aside and biodiversity, Van Buskirk and Willi (2004) found that larger parcels of set-aside increased species-richness.

Working in collaboration with colleagues at the Royal Agricultural College at Cirencester, we designed an experiment to tackle the question of whether field margin width affected spider abundance and richness in the margin and adjacent crop (Macdonald *et al.* 1998). We established, within a single field in autumn 1995, margins of 2 m, 8 m and 20 m wide (Fig. 3.7). We used a randomised block design, such that each of four blocks contained 80 m lengths of each of the three margin widths, in a random position relative to each other. Margins were sown with a simple grass and clover mixture (comprising sheep's fescue *Festuca ovina* (15%), timothy *Phleum pratense* (15%), crested dogs-tail *Cynosurus cristatus* (10%), cocksfoot *Dactylis glomerata* (15%), creeping red fescue (24%), dwarf perennial ryegrass (15%), white clover *Trifolium repens* (3%) and red clover *Trifolium pratense* (3%) at a rate of 25kg/ha. They were managed with a single cut in late July or early August, and cuttings were not removed.

[INSERT Figure 3.7 here]

Spiders were sampled using pitfall traps and suction sampling in each margin width at 1 m, 5 m and 15 m from the field boundary; all samples in 20 m margins were thus within the margins, while some samples in 2 m and 8 m margins were also in the crop (Fig. 3.7).

The results were not clear-cut or consistent. In May, there was a conspicuous tendency for more spiders to be caught in pitfall traps on the widest margins than on 8 m or 2 m margins (Fig. 3.8), regardless of distance from the boundary. There were more spiders on the 20 m margins at all three distances from the field boundary ($F_{2,9}=16.9$, $P<0.001$). At the 1 m distance, where all pitfalls were within the margins, this implied that, for spiders, the wider field margins constituted a distinct habitat type. In addition to the effect of margin width, there was also a

significant tendency for fewer spiders to be caught further from the boundary ($F_{2,9}=16.9$, $P<0.001$). In spring, then, the evidence was that spiders were more abundant on wider margins, and more abundant closer to the field boundary.

In July when spiders were everywhere more abundant than in May, the spring pattern was not repeated. Similar numbers of spiders were captured in traps on the margins of different widths. Nor was there any evidence that the number of spiders was affected by distance from the field boundary.

By September, any effect of width was obscured by a tendency for more spiders to be caught in the cropped area. The pattern in September (after harvest), was complex. There were more spiders in the crop than the margin at distances of 8 and 15 m from the margin³. Spiders will commonly disperse into crops from field margins; furthermore, in this experiment, the margins were sown with a species-poor grass mixture rather than a complex seed mixture or being naturally regenerated, perhaps reducing their benefit to spiders compared to the crop habitat.

[INSERT Figure 3.8 here]

In summary, spiders were found to be more abundant on wider margins, and closer to the boundary, in spring, suggesting that wider margins constituted a distinct habitat type. Wider margins may have higher plant diversity (Shippers and Joenje 2002), which might affect spider communities, but over the time-scale of this experiment this is an unlikely explanation. Aavik and Liira (2010) found that, for plant communities in agricultural habitats, more specialist species benefited from wider open boundaries, while narrow boundaries hosted more agro-tolerant species. They suggested that this may be due either to the buffering effect of wider boundaries (e.g. protecting species from pesticide or fertiliser drift), or to an increase in available microhabitats within wider boundaries, both of which may be true for spiders in this experiment.

[BOX 3:1 STARTS HERE]

³ $F_{2,9}=7.63$, $P=0.011$ and $F_{2,9}=4.1$, $P=0.054$ respectively

BOX 3:1 Should set-aside be configured as margins or blocks?

The above account demonstrates clearly that the ways in which field margins are managed affects their flora and fauna. What about the spatial configuration of fallowed land? Maybe configuring fallow land as field margins is not the best option. For example, a different physical arrangement of fallowed might affect how easily it can be colonised. There has been little experimental work to answer this, though much speculation. The process of colonisation is fundamental to arable ecology, because of the constantly changing nature of the habitats, particularly through the annual harvest cycle, but little is known of factors which might promote or inhibit movement into arable habitats (Macdonald and Smith 1990).

The introduction of set-aside in 1992 (Chapter 1, this volume) provided an opportunity to investigate the impacts of configuration of fallowed areas of land on invertebrate communities. Set-aside could be arranged either as margins around fields or as whole fields (blocks). In the former case, relatively unproductive land would be lost and there might be benefits for wildlife. For example, field margin set-aside will be close to sources of colonists in the hedgerows, and strips of set-aside may provide a network of colonising pathways through the farm. Margin set-aside may encompass a wider range of environments than whole-field set-aside, because to make up an equivalent area it must be present in more fields. Conversely, whole-field set-aside might also benefit some wildlife. Many predators forage along hedgerows and margins, and therefore their prey species could benefit from large blocks of set-aside, distant from these routes. Blocks of set-aside will also have relatively less edge than similar areas arranged as margins, and therefore a smaller area will be susceptible to spray drift. We therefore asked the following question: Do invertebrate abundances differ on set-aside configured as blocks and margins?

We established four replicate margin networks on two farms, each of approximately 5 ha. A 5 ha block of set-aside was also associated with each margin network. Margins and blocks were sown in autumn 1995 with a grass and clover mixture at a rate of 25 kg/ha and managed with a single cut in late summer. Invertebrates were sampled using pitfall traps and suction sampling in May, July, and September 1997 at 88 locations within the margins and blocks. Adult

Carabidae were identified to species. Staphylinids, other beetles, spiders and aphids were counted, but not identified to species.

Our results showed that, although there were no consistent differences in invertebrate numbers between set-aside arranged as blocks compared to set-aside as margins, there were differences in some months for some groups. Numbers of pitfall-caught beetles in September were higher in blocks compared to margin set-aside and in the suction samples there were more spiders in set-aside blocks compared to margins in both May and July. However, beetles were significantly more abundant on the blocks of set-aside in September pitfall traps⁴. Aphids, which were sampled only in July, were more abundant in margin samples⁵.

We found no evidence for an effect on spiders in pitfall traps. However, in the suction traps there were consistently more spiders in the set-aside blocks (Box Fig. 3:1.1); this was statistically significant in both May and July⁶.

[INSERT Box FIG. 3:1.1 HERE]

Many aspects relating to the establishment and management of set-aside are relevant for efforts to reverse declines in farmland biodiversity. Maintaining an area of appropriately managed low-input grassland or fallowed (naturally regenerated) land on farms is one of the strategies that will continue to be part of Environmental Stewardship, and this has been the focus of voluntary measures in the UK to mitigate the loss of set-aside. Knowledge of how set-aside configuration influences biodiversity can help to focus resources for maximising biodiversity benefit. The results suggested that block and margin set-aside constituted qualitatively different habitats for invertebrates, and that the creation of field margins are a substitute for maintaining or establishing larger low-input sown or fallowed patches, which can offer other resources for wildlife in farmland landscapes.

[END OF BOX 1]

⁴ $F_{1,61}=13.6$, $P=0.0005$.

⁵ $F_{1,61}=4.8$, $P=0.0362$.

⁶ $F_{1,61}=4.2$, $P=0.045$ and $F_{1,61}=11.5$, $P=0.0012$ respectively.

3.4 Effects of boundary type on invertebrates

We have shown that field margin width affected the abundance and diversity of spiders. In this final section of the chapter we describe an experiment that explores the relationship between invertebrates in the boundary habitat and adjacent set-aside.

Set-aside was land removed from arable production for at least one year (rotational set-aside) and sometimes longer (long-term set-aside; Clarke 1992; Firbank *et al.* 1993). From its introduction in 1992, the percentage of set-aside required varied (between 5 and 17.5%) according to market circumstances, reflecting its role as a production control. In 2007, the set-aside rate was reduced to 0% in response to the sharp rise in cereal prices as a consequence of lower world production, increased demand for food, feed and fuel purposes, and low global stocks. Although its principal aim was to reduce agricultural surplus, set-aside was found to have a range of positive impacts on wildlife, if managed appropriately (Andrews 1992; Sotherton 1998; Henderson and Evans 2000; Firbank *et al.* 2003). The ways in which set-aside was established and managed also had implications for the development of agri-environment schemes in the UK.

Set-aside had enormous potential for enhancing the invertebrate and vertebrate populations of farmland, including birds (Henderson *et al.* 2000a,b), invertebrates (Moreby and Aebischer 1992; Moreby and Sotherton 1995) and arable weed species (Firbank *et al.* 1993). The benefits of set-aside for biodiversity were influenced both by how it was established (Critchley and Fowbert 2000) and by its subsequent management (Hansson and Fogelfors 1998; Tattersall *et al.* 1999a; Bracken and Bolger 2006).

We showed that the configuration of set-aside, as margins or whole fields (blocks), also had different impacts on the communities that developed within set-aside, and hypothesized that the type of boundary may also affect the development of biodiversity in adjacent set-aside. For example, Tattersall *et al.* (1999a) showed that margin set-aside that was situated next to

hedgerows had a more abundant and diverse small mammal community (see Chapter 4, this volume), primarily because wood mice *Apodemus sylvaticus* were more numerous in margins, and bank voles *Myodes glareolus*, a hedgerow species, did not venture into the centre of set-aside fields. If some boundary features are rich sources of invertebrate colonists, we might hypothesize that greater abundances of invertebrates would be found in set-aside adjacent to those features. It follows that one would expect more individuals to disperse by chance into the set-aside habitat from such sites, and there may be an element of deliberate emigration from a high density population in which food or oviposition sites might be limited. The result would be higher invertebrate abundance in the set-aside adjacent to high density populations, and a decline in abundance with increasing distance into the set-aside, at least in its first year of existence. The wider policy implication is that the creation of field margins or fallowed areas might be targeted next to certain features to maximise their biodiversity and pest control benefits. We therefore used a large-scale field experiment to ask the following questions: Are field boundaries a potential source of colonists into the set-aside? Are some field boundary types better sources of colonists than others? Does the invertebrate community in set-aside reflect that of potential colonists in adjacent field boundaries? Over what distance does the boundary have an impact on set-aside invertebrate communities?

To answer these questions, invertebrates were collected by D-vac suction sampling at 16 sites in four fields at two of the Royal Agricultural College farms, Coates and Harnhill Manor, in June 1995 (Gates *et al.* 1997). At each site, one sample was taken from the field boundary vegetation, and three samples from the adjacent whole-field set-aside land, at 2 m, 8 m and 16 m from the edge of the field. Animals were identified to order, except for abundant groups such as Diptera which were identified to sub-order. At each site the characteristics of the boundary were recorded (presence or absence of hedge, wall, fence, ditch and bank, and the heights of understorey and hedge vegetation). All set-aside land had been sown the previous autumn with a mixture of winter wheat and mustard, and vegetation on the set-aside was sparse.

3.4.1 Field boundaries as potential sources of colonists

Abundance in the set-aside samples was much lower than in the boundary samples, suggesting that the boundary is indeed likely to be a source of colonists into the set-aside (Gates *et al.* 1997, Fig. 3.9).

The abundance of Auchenorrhyncha and Carabidae, was not affected by distance from the field boundary. Several explanations for this can be suggested. First, the field boundary may not be the source of the animals, but they may be equally likely to colonise the set-aside from the crop or by dispersing from longer distances. Second, the animals may be sufficiently mobile that even if they do originate from the field boundary, their probability of capture may be virtually the same up to 18 m from it. Numbers of Auchenorrhyncha in the set-aside were far lower than in the field boundary, suggesting that the sparse covering of vegetation on the set-aside land made it a particularly poor habitat for this plant-feeding group.

[INSERT Fig. 3.9 here]

3.4.2 Are some field boundary types better sources of colonists than others?

Higher vegetation, the presence of a hedge, and presence of a wall all increased the abundance of invertebrates in the boundary (Gates *et al.* 1997). The presence of a hedgerow influenced the greatest number of invertebrate groups, while the presence of banks and ditches had no effect on abundance of any invertebrate group. Two groups, parasitoids and spiders, were not affected by any of the explanatory variables, and the remaining groups were affected by only one or two variables.

Although abundance of most groups in the field boundary vegetation was related to one or more of the environmental characteristics, no factor was a consistently good predictor. There may have been variation between sites in such factors as soil, microclimate and humidity, and these may have played a part in determining a site's suitability for invertebrates. Asteraki *et al.* (1995) found that these factors played a more important role in

determining the abundance of most species of carabid beetles than the structural attributes of field boundaries, and the same may be true for other groups of invertebrates.

We next looked at how a hedgerow affected the composition of the invertebrate assemblage in the set-aside, using Principal Component Analysis (Fig. 3.10), which enables us to visualise community structures in two dimensions – sample points that are close together on the plot have similar structures. Samples taken from set-aside with and without a boundary hedge tend to separate out into the lower left (an area of more harvestmen and fewer parasitoids and Brachycera) and upper right (an area corresponding to a higher proportion of Auchenorrhyncha and Heteroptera and fewer carabids) of the graph.

[INSERT Fig. 3.10 here]

3.4.3 Are invertebrate assemblages in the boundary structured differently from those in the set-aside, and how do these assemblages change with distance from the boundary?

We carried out a PCA on proportions of different groups in the boundary (0 m) and at 2 m, 8 m and 16 m into the set-aside (Fig. 3.11). Boundary samples were associated with an increasing proportion of Heteroptera, harvestmen and Auchenorrhyncha and a decreasing proportion of carabids. The composition of the samples in the set-aside (distances 2 m, 8 m and 16 m) was similar. In other words, the invertebrate communities in the boundary differed from those in the set-aside, but communities at different distances into the set aside did not differ from each other.

[Fig. 3.11 here]

In summary, we found that boundary type influenced invertebrate abundance and species composition in set-aside. The presence of hedgerow was influential, increasing abundance in the set-aside and affecting community structure. Invertebrate abundance declined with

distance into set-aside.

3.5 Conclusions and recommendations

We have shown that how arable field margins are established and managed can have profound effects on their invertebrate assemblages. Swards established by sowing with a grass and wildflower seed mixture attracted more adult butterflies and were also used as breeding habitat. In the short-term, larger and more species-rich invertebrate assemblages were fostered on unmanaged margins than on those managed by cutting. Leaving field margins uncut for more than one or two years, however, leads to rapid succession to scrub (Smith *et al.* 1993) and is likely to be accompanied by loss of grassland invertebrate species (Usher and Jefferson 1987; Feber and Smith 1995). Some form of rotational cutting, ensuring some areas of tall sward are left uncut each year, is most likely to benefit butterflies and Araneae, as well as other invertebrate groups (Morris 1971; Smith *et al.* 1993; Feber and Smith 1995). On field margins this may be most practically achieved by mowing a swath next to the crop once a year, leaving taller vegetation adjacent to the boundary to be cut once every two or three years, or by mowing different sections of margin in different years.

The timing of cutting was critical, with mid-summer cutting having the most persistent, negative effects (Smith *et al.* 1993; Feber *et al.* 1995, 1996), so cutting at this time should be avoided. Cutting in spring and autumn is substantially less damaging to invertebrates in general, although the benefits to crop husbandry of Araneae as predators may be diminished by cutting in spring, and species of butterfly and other invertebrates that need undisturbed habitats in which to overwinter may be adversely affected by autumn cutting. However, cutting in autumn rather than summer increased the species richness of plants on the field margins over the shorter term (Smith *et al.* 2010) which may benefit invertebrates dependent on a diverse sward.

Field margin width had complex effects on invertebrate abundance and species richness. Field margins of different widths may have constituted different habitats for invertebrates in arable systems, and these might range from narrow margins to whole fields. The presence of a hedgerow influenced the invertebrates found in adjacent set-aside: sites with a boundary hedgerow were associated with increased numbers in most groups. Hedgerows are a valuable habitat in themselves for invertebrates (e.g. Pywell *et al.* 2005), and the presence of a hedgerow next to a field margin has been shown to increase numbers within the field margin of groups such as pseudoscorpions, probably by buffering the field margin from management (Bell *et al.* 1999). For other taxa, such as farmland birds, Vickery *et al.* (2009) conclude that the major influence on the value of a margin (at a field scale) is proximity to a good quality hedgerow (i.e. one that is well established, relatively species-rich, and well managed). Margins near hedgerows may also be favoured by foraging birds (e.g. Henderson *et al.* 2004).

Other studies have shown that the numbers of plants (e.g. Marshall 1989), invertebrates (e.g. Holland *et al.* 1999) and small mammals (Tattersall *et al.* 2002) often decrease with distance from the field boundary and, where good quality field boundaries exist, field margins may be one of the most cost-effective ways of enhancing biodiversity (Vickery *et al.* 2009). Within current agri-environment schemes the greatest emphasis is on management of field margin and hedgerow habitat, although Butler *et al.* (2007) conclude that more effort needs to be made on improving resources within the cropped area, as well as on field margins and hedgerows, if the UK government's target for restoration of farmland birds is to be met. Our results suggested that fallowed land (in this case set-aside) configured in blocks constituted qualitatively different habitats for invertebrates compared to margin set-aside; this was also true for small mammals (Tattersall *et al.* 1999a). Farms with a mixture of configurations are likely to be the most wildlife friendly.

Our recommendation is that blanket management approaches for invertebrates at the farm scale are inappropriate. A diverse farmed landscape with margins of different sizes and different sward structures should be the aim. This will help invertebrate populations, with their differing ecological requirements, to survive and flourish in the characteristically unstable environment of arable systems.

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