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Assessing the value of beetle banks for enhancing farmland biodiversity

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ABSTRACT
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ASSESSING THE VALUE OF BEETLE BANKS FOR ENHANCING FARMLAND BIODIVERSITY

by Susan Rosena Thomas

The perennial herbaceous understorey found in well-maintained hedgerows and grassy field margins provides resources or refuge for a highly diverse fauna. Invertebrates are especially important as they underpin food chains, with many species being valuable polyphagous predators that feed on arable crop pests. However, agricultural intensification has caused many of these non-cropped areas to become degraded or lost, resulting in very high field area to edge ratios. Farmland biodiversity has declined markedly as a consequence. Predator assemblages dependent on margins within their lifecycles are often less abundant and diverse, with slower colonisation of feeding sites. The temperature-buffered conditions found within dense tussocky grasses in margins are particularly crucial for predator overwinter survival. 'Beetle banks' are grass-sown ridges designed to replicate and increase the availability of this kind of habitat, in a simple and inexpensive form. The original design was for single island strips extending across large arable fields, where predators are most impoverished, to effectively shrink the field in terms of spring dispersal into the crop. Early experimental banks still exist, and many more have been sown over the decade since the concept was first put into practice through the recommendation of advisory organisations. However, long-term management strategies for their successful upkeep are not clearly identified. With a known establishment date, beetle banks provide a means of exploring potential successional change or biodiversity development within new habitat.

I assessed age-related differences in the botanical composition of beetle banks, considering potential degradation as overwintering sites, and resource provision for other wildlife. A dense structure was retained, despite age, thus banks continue to be functional for predators for over a decade at least. Increasing summer floral diversity with age may also benefit other insects. Weed presence was no worse than conventional margins, and so control should be relatively straightforward. Associated with this work was an evaluation of whether levels of polyphagous invertebrates, previously reported as high in new sites, were sustained in older beetle banks. I discovered little difference in densities per m^2 between beetle banks and conventional field margins, regardless of age, while boundary-overwintering carabid densities increased though time. Predator diversity was also similar between habitat types through the year. A large-scale trapping experiment was undertaken to evaluate the spatial-temporal patterns of predatory Carabidae in fields adjacent to beetle banks through the crop season. A novel spatial analysis was used to explore the distributions of different species groups. I found evidence to support the description of a 'wave' of boundary-species emerging from refuges and dispersing across the field. In contrast, field-inhabiting species were slow to develop from field centres and may be of less value for pest control. Beetle banks appear as valuable as conventional boundaries for aiding carabid dispersal into crops. Subtle microclimate, prey distribution or edaphic factors probably accounted for the spatially and temporally fluctuating activity-densities of beetles observed through the season. In addition, the abundance of predatory Empididae was similar within a beetle bank and a hedgerow, with a low, homogeneous presence at increasing distances from them, coinciding in time with serious cereal pests. Thus beetle banks may also contribute useful habitat resource for these little studied insects.

I hypothesised that simple sown grass strips would contain a lower diversity of other invertebrates when compared to older, botanically complex habitats, although this difference might lessen with age. There was evidence to support this view. Beetle banks were found to contain useful, albeit lower, densities of game bird chick-food, when compared with conventional field margins; additionally furnishing nesting cover for adults birds. Severe declines in wild game are attributed to losses of these invertebrates vital for chick survival, as well as inadequate provision of nesting and brood-rearing habitat. Orthopteran species richness was similar between beetle banks and conventional margins, although there were compositional differences in capture; and older banks were increasingly speciose. Grasshoppers favoured mid-field banks, whereas bushcrickets tended to prefer hedgebottoms. Additionally, Lepidopteran species composition was investigated. As expected fewer butterflies were observed in beetle banks than hedge banks on conventionally managed farmland, but the grass swards clearly were of value, with butterfly presence related to floristic species richness and diversity. Better management, such as incorporating conservation headlands alongside beetle banks, and protection from agronomic activities in the field, may be a means of further enhancing the resources that beetle banks provide for these invertebrates of increasing conservation concern.

A supplementary chapter of this thesis describes the findings of a questionnaire survey sent to a cohort of farmers in southern England, to elucidate their current perceptions, opinions and use of the beetle bank design.

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"...Because half a dozen grasshoppers under a fern make the field ring with their importunate chink...do not imagine that those who make the noise are the only inhabitants of the field."

Edmund Burke, 1729-1794

1. General introduction

1.1 Biological diversity on arable farmland

1.1.1 Importance of the arable ecosystem in the UK landscape

The arable ecosystem is composed of cropped fields and non-cropped areas such as field boundary strips, hedgerows and woodlands. It may support many hundreds of species. Around 7-8% of the known arthropod fauna in the UK, very approximately 1800 species, are found closely associated with the plants communities found on farmland (Potts, 1991). There may be 400 predatory species in cereals alone (Potts & Vickerman, 1974). On lowland farmland, around 300 flowering plant species have been recorded, with the total for western and central Europe being over 700 (Hill *et al.*, 1995). Additionally, many bird, mammal and amphibian species are found on farmland. Its principal importance for biological diversity is because it makes up a very large proportion of the UK land area. Nearly 20% of the total surface area of the British Isles is covered by arable and horticultural crops (Hill *et al.*, 1995), with cereal production alone recorded as taking up more than three million hectares (http://www.maff.gov.uk, 2001). This area is around sixteen times that given over to all statutorily protected Nature Reserves (Potts, 1991), yet until recently has received little general public interest or awareness. An ecological system almost exclusively dependent on human management, the arable landscape has undergone the changing impact of newly developed agricultural practices almost continuously since the first crops were cultivated in Britain at around 3000 BC (Wilson, 1994a). In recent times, because of technological innovation, the rate of such change has been dramatic, increasing the vulnerability of those species resident within arable farmland.

1.1.2 *Difficulties of living within the arable ecosystem*

This ecosystem presents a challenging environment to any organism, because it is a highly dynamic system, where there is continuous, severe disturbance occurring at intervals within both seasons and years. This includes soil tillage, the application of agrochemicals, harvesting, and usually a sequence of crop rotation. Actions such as the removal of almost all plant cover at harvest time, and sudden burning events (now rarely practised), for instance, have disruptive effects on shelter, food and microclimate for animals and plants incidental to the crop. Therefore, the population dynamics of many species found in the arable ecosystem tend to be characterised by declines and recoveries, which are often dependent on strong dispersal abilities. Many plant species exhibit r-selected traits, such as having a short generation time, high reproductive effort and many small, highly dispersible offspring (Froud-Williams & Chancellor, 1982; Marshall, 1989). Other organisms exhibit extensive mobility, for example, birds and mammals such as hares move around within different fields and other habitat types within the landscape (Macdonald & Smith, 1990). Small mammals in particular have been found to have very mobile populations in the farmed landscape (Szacki *et al.*, 1993). Some invertebrates may have annual life histories, but many are less able to disperse because of their size, and have developed other strategies to cope with the environment. For example, some Carabidae species overwinter as larvae underground to avoid desiccation and carry out activities such as feeding and breeding in the spring when there is ground cover.

Despite the adaptation challenges of such high disturbance levels, many species thrive within agricultural fields and their margins, and their presence and abundance is determined by factors that operate at a range of scales within the arable landscape (Booij & Noorlander, 1992):

At the field scale, different crops have distinct microclimates and physical structures to which different species may be specialised. Each of these crops requires different soil tillage, pesticide inputs, fertilisation regimes and weed management, all factors which also have impact on the species found within them. There have been numerous observational or manipulative studies to examine the effect of these factors. For example, Booij & Noorlander (1992), when investigating invertebrate diversity, found that the kind of crop grown had the greatest impact, with those providing most early cover containing the most diverse range. Humidity and temperature differences in stands of differing density of just wheat alone gave rise to distinct arrays of polyphagous predatory invertebrates (Honêk, 1988). Species of Carabidae, such as *Amara*, have been found to prefer areas of more weedy cover in fields

(Powell *et al.*, 1985; Honêk, 1997). Ellsbury *et al.* (1998) concluded that carabid densities and diversities were higher in fields with lower chemical inputs.

The farm itself can be viewed as another scale. The kinds of crops that are grown within the farm rotation, and how the farm is managed as a whole, i.e. whether under a conventional, integrated or organic regime, may affect the species composition of plants and animals present. Carabidae abundance and species richness was higher in organically and bio-dynamically farmed systems compared to the conventional farming practices of the region studied (Carcamo *et al.*, 1995; Pfiffner & Niggli, 1996). Staphylinidae, Neuroptera and parasitoids were found to be more abundant in organic carrot fields when compared to those farmed conventionally (Berry *et al.*, 1996). Other studies have investigated species differences both at the crop and farming system level combined; for example, Holland *et al.* (1994b) found crop type had greater influence on the diversity and abundance of predatory invertebrates, but little difference between integrated and conventional farming systems was seen. Booij (1994), in contrast, found both factors determined species composition, with integrated or organic management generally having a positive effect on species richness, enhanced in crops with early and persistent ground cover.

Finally, there may be an impact on species diversity and dispersal at the landscape scale. This includes factors such as the spatial arrangement of crops, fields and their margins, hedgerows, ditches, copses and woods, and the farm buildings and roads present. The arable ecosystem is often described, therefore, as a 'habitat mosaic', where all these different land uses, financially productive or otherwise, are interspersed together. The existence of a habitat mosaic has been recognised as important for maintaining invertebrate diversity in the arable landscape (Duelli *et al.*, 1990). Organisms may require different habitats at different stages of their lifecycle. For instance, the carabid beetle *Agonum dorsale* requires dense field margin vegetation to shelter over winter, but finds its aphid prey out within crop fields in summer (Jensen *et al.*, 1989). Birds such as carrion crows and rooks require tall trees for nesting but also open fields in which to forage (Macdonald & Smith, 1990). Partridges require sheltered hedge-banks in which to breed but open fields in which to raise their young (Aebischer *et al.*, 1994). There are many other examples of this need for heterogeneity.

1.1.3 Why biodiversity on arable land has suffered in recent times

The biological diversity on farmland has declined in recent years because of the drive for greater yields, which has been achieved through an intensification of production. There are many descriptions about the damage - habitat losses and species declines - that has occurred (for example, McLaughlin & Mineau, 1995; Burel & Baudry, 1995). Since the most significant changes in agricultural production have only really taken place in the last few decades since the Second World War, full realisation of the resulting environmental damage has occurred only relatively recently. There are a number of inter-linked factors that are now recognised as responsible:

There has been a change to large-scale monoculturing of crops in arable production, particularly of cereals. A decline in the variety of plant species under cultivation has also occurred. An example is that of oats, a major cereal crop in the 1950s, occupying 25 % of arable land (Hall, 1995), but much less frequently grown today. In contrast, oilseed crops such as rape, have become dominant because of the availability of subsidies and markets, or because they may be grown as an industrial crop on set-aside land. Many farmers now specialise on either livestock or arable crops because of land suitability and economics. This has led to an abandonment of rotations, including grass leys, the loss of areas of permanent pasture, and a switch from spring sown to autumn sown crops, with also the replacement of once a year hay-making with grass silage cut more frequently and earlier in the summer (Hill *et al.*, 1995).

Economic changes have also resulted in many farms being swallowed up into increasingly large estates, as they have lost the ability to remain competitive. Currently, around 33 % of farms in the UK occupy an area of 50 hectares or greater, with 16 % covering 100 ha or more (Potter, 1997). The average farm size of many other European countries is much smaller than this, especially in those countries on the northern agricultural margins or towards the south.

1.1.3.1 Habitat losses

The substitution of increasingly technological, mechanised labour for person- and horse- power, has resulted in the well-documented removal of non-crop habitats to allow an expansion in field sizes, which in turn allows larger farm machinery to manoeuvre in fields (Edwards, 1970; Wilson, 1990). Farmers have found it easier to expand production by working in a more simplified landscape, where hedgerows, trees and pieces of woodland have been taken away, ditches and ponds filled in, and areas of wetland, saltmarsh, natural grassland or heath have been 'improved'. Frequently, this has been to facilitate agricultural production where it would have previously been impossible, and has resulted in the direct losses of resident species. The complexity of habitat structure in the farm landscape has therefore become diminished.

The habitat losses described have also meant that the remaining pockets of non-cultivated land have become fragmented and increasingly isolated from one another. Populations within these areas may be more vulnerable to potentially damaging activities taking place in the surrounding land; for example they may receive drift from pesticide or fertiliser treatments of adjacent fields. They also may suffer more long-term problems, such as isolation from major populations, and this is exacerbated if the species concerned has a low ability to disperse. Patches of favourable habitat, such as woods, hedges etc. can be viewed using 'island biogeography theory' (MacArthur & Wilson, 1967), as they may suffer the same kinds of isolation and survival problems. Habitat patch size and shape, permeability and isolation are all factors known to influence species movement patterns (Fry, 1995). There are many studies relating to the problems of habitat fragmentation on farmland; for example, regarding carabid beetle movement (Halme & Niemala, 1993; Davies & Margules, 1998; Petit & Burel, 1998a; Kinnunen *et al.*, 1996), or other arthropods (Duelli *et al.*, 1990).

Many pieces of habitat may act as corridors, connecting populations over a scattered area, and their removal may prevent or reduce movement between isolated patches. This is recognised, although there continues to be considerable dispute about the extent of corridor use, for a broad range of different organisms (Dendy, 1987). The value of hedgerows as movement corridors for small mammals has been re-assessed, and suggested as highly likely for certain species (Tew, 1994), following work that described them as important for dispersal (Bennett, 1990; Zhang & Usher, 1991). Mark-recapture experiments have demonstrated that invertebrates use hedgerows for dispersal, as well as for permanent residence (Burel, 1996). The persistence of butterfly metapopulations in fragmented landscapes has been partially attributed to the presence of habitat corridors (Fahrig & Merriam, 1994), and some bat species have been shown to utilise linear landscape elements in the arable ecosystem (Verboom & Huitema, 1997).

One of the most often discussed environmental changes in the arable landscape has been the removal of hedgerows (Greaves & Marshall, 1987). Until the early 1980s, approaching 28, 000 km of hedge was removed in the UK each year (Barr *et al.*, 1993), Approximately 22% of all hedgerows was lost between 1947 and 1985 (Hill *et al.*, 1995). Despite widespread concern after the publication of these reports, the loss continued to the present time. The removal of not only hedgerows, but also other linear landscape features along field margins such as ditch banks, has now been documented as progressing at a disturbingly high rate in many other European countries (Marshall & Moonen, 1998). Hedgerows, in particular, are one of the oldest human-made features in the landscape, in some places dating back to prehistoric times (Bannister & Watt, 1994). They have many species closely associated with them, which are lost when they are removed (Bunce *et al.*, 1994). Degradation of those remaining, by poor maintenance practices and direct neglect, is also damaging for communities within them (Muir & Muir, 1987). The structure and growth form of hedgerows has an influence on fauna; for example, different shapes of hedge may support specific bird species (Sparks *et al.*, 1996). Even the length of a hedgerow has been shown to relate to the biodiversity within it (Mader & Muller, 1984). Additionally, hedges are known to provide sheltered areas for butterflies (Dover *et al.*, 1997), and places of residence for small mammals, which become very rapidly established in even newly planted blackthorn hedges (Woods, Dunleavy & Key, 1996).

Hedgerows and other types of field boundary have not just suffered reductions in their overall length; often their width has been reduced because of the desire for field size expansion. Hedgerow bases, often an area rich in herbaceous plants, may be reduced in width through close ploughing. Additionally, spraying out the base in an attempt to reduce the risk of pernicious weeds spreading into the crop actually creates a more suitable area for such species, requiring further control (Boatman *et al.*, 1994). Compounded with a lack of protection from stock feeding within fields, this has meant that sometimes all that is left of a hedge is the shrubby component, standing virtually within the field itself, rather than being part of a dense hedgerow bank. This width erosion also results in the boundary becoming more vulnerable to pesticide and fertiliser drift from applications taking place within the field (Longley & Sotherton, 1997). Sadly, despite observations on the mis-management and dereliction of hedgerows, seemingly for a number of centuries (Bannister & Watt, 1994), there has been little awareness of what impact this may have had on the species that they support.

Intensification of agricultural production may not always lead to species losses, but may result in less noticeable changes in species composition. Burel *et al.* (1998) investigated invertebrate, bird and mammal biodiversity along a gradient of agricultural landscapes farmed with an increasing level of intensification, and found that in many cases, species composition changes were observable.

1.1.3.2 Agrochemical inputs

Pesticide usage has increased enormously since the escalating production of synthetic compounds in the developing chemical industry following the Second World War. An estimated 2.5 million tonnes of pesticides are applied yearly in agriculture worldwide, of which around 80 % is used in developed countries (Pimentel, 1995). Other agrochemical products, especially non-organic fertilisers, have also been used in increasing quantities. An approximate 400-fold increase in applications of nitrogen fertiliser has occurred in European countries since 1950 (Potter, 1997). Again, this has allowed marginal, less fertile land to be used for arable production, destroying the original vegetation and associated fauna. Areas of low fertility have been long recognised as sustaining high plant diversity, and irreparable damage is done when they are fertilised.

A variety of crops grown under low and high pesticide and fertiliser input regimes revealed greater abundance and diversity of beneficial Carabidae in the low input fields, without significant yield losses (Ellsbury *et al.*, 1998; Berry *et al.*, 1996; Carcamo *et al.*, 1995; Pfiffner & Niggli, 1996). This indicates that farmers may often be using more artificial inputs than are actually economic.

Declines in the food supplies of many invertebrates have been strongly linked to increasing pesticide usage over the last few decades (Potts, 1984). Weed-feeding invertebrates have declined as a result of herbicide use, fungi-feeding species from the application of fungicides, and polyphagous predators from insecticide application (Potts, 1984; 1997). Many compounds are toxic to a broad spectrum of organisms, and even the current trend towards the development of new products that target specific pests, have not been as beneficial as desired. Even 'selective' compounds still affect all species within a particular taxon, rather than an individual pest species.

Insecticides, in particular, have received extensive study. It is now realised that although their most obvious damaging effect is to cause direct mortality on species other than the targeted pest, they may also be responsible for causing indirect mortalities, although effects are little known for most species (Jepson, 1989; Thacker, 1991). For example, *Agonum dorsale* that had survived selective insecticide treatment were shown to suffer reduced fecundity (Basedow, 1990). The effects of treatments may also be surprisingly long lasting (Basedow, 1990; Jepson, 1989). Frampton & Çilgi (1994) found that the adverse effects of a variety of insecticides on Carabidae populations persisted for several months.

Species may differ in their vulnerability because of their phenology. The adult carabid *Bembidion obtusum* is active in cereals during the autumn when insecticides may be applied to control potential BYDV-transmitting aphids. In contrast, at that time *Trechus quadristriatus* is protected by being mostly underground as a larva, despite being of greater vulnerability because of its more permeable immature cuticle (Macdonald & Smith, 1990). Diurnal activity patterns are also important (Holland, 1998). Day active Carabidae, Staphylinidae and Linyphiidae are more exposed to daytime applications than those species active at night. Thus individual species respond in different ways to an insecticide application, making generalisations impossible.

The Lepidoptera are another group at risk from both direct spraying and residual deposits of pesticides, and they may be exposed to a number of applications in their lifetime. Indirect effects of agrochemical use, such as those affecting their host plants, are also considered significant (Dover, 1994; Feber & Smith, 1995). Using laboratory bioassay methods an extensive number of insecticides have been shown to have detrimental toxicological effects on the larvae of many butterflies (Davis *et al.*, 1991; Çilgi & Jepson, 1994).

Extensive herbicide use has pushed many plant species out of the system, particularly those that rely on dispersal mechanisms resembling those of the crop plants themselves (Macdonald & Smith, 1990). This then only leaves those plants with short life cycles and long dormancy to remain successful. Survival is also enhanced by early flowering, prolific seed production, herbicide resistance, and close physiological resemblance to the crop plant, as well as by features such as the ability to re-grow from rhizome fragments. Opportunistic annual weeds such as *Poa annua* (annual meadow-grass), *Senecio vulgaris* (groundsel) and *Veronica persica* (common speedwell), can germinate and reproduce throughout the year; whereas species such as *Centurea cyanus* (cornflower), *Adonis annua* (pheasant's eye) and *Fumaria purpurea* (purple ramping-fumitory) are now almost completely lost from arable fields. A restricted number of species truly thrive in arable fields, examples being the pernicious weeds *Bromus sterilis* (barren brome) and *Galium aparine* (cleavers) (Sotherton & Page, 1998).

The development of highly nitrogen-responsive crop varieties has led to other chemical inputs being required, such as plant growth regulators to counteract excessive, weak-stemmed growth. Cereals that grow at higher densities with intensive application of inorganic fertilisers have the impact of shading out the growth of other weed species, because of their rapid canopy formation (Hill *et al.*, 1995; Wilson, 1999). Misplaced fertiliser deposition into field margins and hedgerows can enhance competitive, nitrophilous weed species, to the detriment of other plants (Tsiouris & Marshall, 1998).

1.1.4 Species relevant because of their value to farmers

Many of the organisms threatened by the problems of agriculture outlined above may actually have quantifiable value to the farmer. It has only been realised relatively recently that the arable ecosystem is like any other: there is a complex interaction between all the many organisms present. Rather than trying to eradicate all species incidental to the crop, regarding them all as pests and weeds, it may be better to allow the coexistence of many. Significant numbers may be providing control over the excessive population growth of other species through competition and predation. Recently, it has been realised that although crop pest outbreaks such as by cereal aphids and wheat blossom midges, may have always occurred, encouraged by external factors such as the weather, such outbreaks may have worsened since the removal of key species responsible for 'natural' biological control. This elimination of pests and weeds has also produced problems further up the food chain, where other important groups have suffered from deficiencies in food and hosts (Potts, 1991 & 1997; Chamberlain & Fuller, 2000).

Species that are of value to the farmer are outlined as follows:

(Pathogenic fungi are also important, but are not considered here).

1.1.4.1 Beneficial invertebrates

Beneficial invertebrates are often very numerous and pervade the entire arable landscape. The group that is often most obvious to the farmer is that of the pollinators, because they fly conspicuously about the flowering crop; these include various species of bee, especially bumblebees (*Bombus* species; Hymenoptera), honeybees (*Apis mellifera*; Hymenoptera) and hoverflies (Syrphidae; Diptera). The success of many crops is totally reliant on the behaviour of these insects, and yields suffer if their populations are not thriving (Williams, 1991; Osbourne & Williams, 1996). Hymenopteran pollinators, bumblebees in particular, have been shown to be in serious decline in the UK (Williams, 1982; Osbourne & Williams, 1991).

Less apparent are parasitoids, mostly tiny wasp species particularly of the Braconidae (Hymenoptera). These attack a range of host insects, most importantly aphids, but also including various other species including rape-damaging flea beetles.

The most species-rich group is that of predatory invertebrates. These may be either prey (pest)-specific or polyphagous (generalist) feeders (Holland, 1999). Ladybirds (Coccinellidae) and the larvae of hoverflies and lacewings (Chrysopidae) are members of the first group. Aphids are a major dietary component, present on wheat and barley as well as on peas, beans, and maize crops. The second group contains species predominantly from the ground beetle (Carabidae), rove beetle (Staphylinidae), money spider (Linyphiidae) and wolf spider (Lycosidae) families, and have been found to be highly important biological control agents in arable crops (for example, Potts & Vickerman, 1974; Chambers *et al.*, 1983; Chiverton, 1986; Sunderland *et al.*, 1987; Holland & Thomas, 1997b). Manipulative studies involving their exclusion by these authors have often shown both quantity and quality reductions in crop yield resulting from pest damage. Other species from the true bug (Hemiptera), true fly (Diptera; e.g. Empididae), earwig (Dermaptera), harvestmen (Opiliones) and mite (Acari) taxa are also known to be important generalist predators. Species within this group have a very wide range of mobility and dispersal capabilities, and are usually opportunistic in feeding habits (Holland, 1999).

A high diversity of beneficial invertebrates within the arable ecosystem is the only way of effectively ensuring efficient biological pest control, as when there is a range of means of attack over the entire season, pest species are vulnerable throughout their lifecycles and are more controllable (Sunderland *et al.*, 1997).

1.1.4.2 Game birds

Running a game shoot may be a profitable, if contentious to some, means of diversifying the farm income. *Perdix perdix* (grey partridge) abundance has declined drastically over the last few decades (Potts, 1986) and this species is now listed in the UK Red Data Book (Batten *et al.*, 1990). *Alectoris rufa* (red-legged partridge) populations only appear stable because of large-scale reared bird releases but their wild populations are in severe decline (Hill & Robertson, 1988). This has been clearly associated with the overall decline of invertebrates in the agroecosystem (Potts, 1997). The survival of chicks of partridges and *Phasianus colchicus* (pheasant) in their first few weeks of life is highly dependent on a high protein intake provided by an invertebrate diet (Green, 1984; Hill, 1985; Potts, 1986; Rands, 1988). As described earlier, the increase in herbicide usage, the summer use of foliar insecticides, and the loss of undersowing, have all been clearly implicated in causing increased chick mortality because of the lack of available invertebrate food (Rands, 1986). Adults feed almost exclusively on plant material; with diet items consisting of grain, leaves and roots of grasses and dicotyledonous plants (Middleton & Chitty, 1937). Clearly if the crop is too 'tidy', there will be little material like this available to the birds. Additionally, adult bird breeding success has been shown to occur in response to the availability of nesting cover during the settling period in spring, as well as being determined by nest predation (Potts, 1997), and so losses of suitable non-crop habitat is another factor that has contributed to population crashes. It is not just wild populations that are threatened - the release of reared birds to establish breeding populations will be wasteful of money and labour if the habitat offers them little support.

1.1.5 Other species of current interest or concern

Farming practice impinges on a great number of other taxa, records of many indicating that they were very commonly seen in the past but are now threatened in terms of their abundance and or diversity.

1.1.5.1 Arable plants

The other flora within fields, apart from the crop plant, given the broad and unhelpful label of 'weeds', has become increasingly threatened since intensification. Many species have become extinct, and others that used to be commonly seen across arable fields are now restricted to the extreme edges, where there may be less efficient application or efficacy of agrochemical treatments, and poorer or more compacted soil, with reduced crop yields (Wilson, 1994b).

It has been suggested that the levels of nitrogen that are currently applied to cereal crops are almost as effective at suppressing weed species as the application of herbicide, through out-competition by the crop itself (Wilson, 1999). Many other habitat types across the UK have received a great deal of concern and conservation effort because of the presence of endangered plants, but until recently, there has been little interest in the arable landscape, and as a result, there has been extensive damage. More than twenty-five arable weed species are now classified as 'Nationally Scarce' and approximately thirty are 'Red Data Book' species. A considerable number of these are currently considered to be extinct or no longer found on arable land (Wilson, 1994b), indicating the need for action. Stevenson & Kay (1999) have recently identified disturbing declines in many threatened species through the extensive surveying of arable farmland. As well as the impact of agrochemicals outlined earlier, other practices, including a switch to autumn cropping, intensive cultivation, and the development of broad-spectrum residual herbicides have also contributed towards a loss of botanical diversity within the agroecosystem.

1.1.5.2 Threatened invertebrates

Grasshoppers (Acrididae) and bush crickets (Tettigoniidae) have suffered huge population declines. Grasshoppers are almost never found in British cereal fields (Green, 1984; Potts, 1986). The same changes in farming practice that have affected other farmland organisms have undoubtedly been responsible for these declines. One species, *Chorthippus apricarius*, was once common along country lanes across central Europe but is now designated as endangered, with the decline again blamed on overuse of pesticides (Fischer *et* *al.*, 1996). Modern grassland management involves high annual inputs of nitrogen. Van Wingerden *et al.* (1992) found that where nitrogen inputs were increased on grasslands in The Netherlands, grasshoppers first declined in species number and then in density.

Broad-spectrum herbicide use in fields encourages annual grass species production in adjacent boundaries, leading to a species poor community (Smith & Macdonald 1992). Accidental fertiliser application causes field margins to become more nutrient rich, further reducing diversity. As the Lepidoptera require both suitable larval food plants and nectar sources for the adults, a decline in floral diversity will inevitably reduce habitat suitability for this insect group (Hill *et al.*, 1995). Lepidoptera may also be affected directly by pesticide use. Longley *et al.* (1997) and Longley & Sotherton (1997) recorded butterfly larvae mortality on drift-contaminated vegetation from hedge bottoms, even when these where protected by a buffer zone between the sprayed area and the margin.

1.1.5.3 Birds other than game species

Few bird species, with the exception of grey partridge described previously, are restricted purely to farmland. Usually they have broader habitat requirements including, for example, woods or marshes, or migration to habitats in other countries altogether. A few species, such as *Crex crex* (corncrake), *Burhinus oedicnemus* (stone curlew) and *Coturnix coturnix* (quail), in contrast, have a large proportion of their population restricted to farmland. Open field species such as *Vanellus vanellus* (lapwing), *Alauda arvensis* (skylark), *Miliaria calandra* (corn bunting) and *Motacilla flava* (yellow wagtail) contribute only about 7-14% of bird numbers on lowland UK farms (Hill *et al.*, 1995); however, the British Trust for Ornithology and others report that there are extremely severe declines in the abundance of these species (such as Chamberlain & Fuller, 2000; Batten *et al.*, 1990).

Species such as *Sylvia communis* (whitethroat), *Sylvia curruca* (lesser whitethroat), *Carduelis cannabina* (linnet), *Emberiza citrinella* (yellowhammer), *Turdus iliacus* (redwing) and *Turdus pilaris* (fieldfare) use hedgerows for food, shelter and nesting sites at various times throughout the year (Hill *et al.*, 1995), and are threatened by the loss of this habitat.

Bird species including redwing, lapwing, fieldfare, *Turdus merula* (blackbird), *Turdus philomelos* (song thrush), *Sturnus vulgaris* (starling) and *Corvus* species (corvids) prefer to feed on permanent grassland during the winter, finding little value in the ever increasing cover of winter cereals and oilseed rape, where densities of soil invertebrates may be low (Tucker, 1992). Cereal stubbles and ley fields offered little better feeding opportunities. Conventional farming eventually leads to a reduction in the amount of organic matter in the soil, and its structural deterioration, (El Titi, 1995) with declines in invertebrates such as earthworms and leatherjackets being an indirect result. Reduced weed seed availability from intensive herbicide use is also implicated.

The importance of differently managed field margins for farmland birds has been reviewed by Vickery *et al.* (1998). Wilson *et al.* (1999) suggest that uncultivated field margins, hedgerows and verges are likely to become increasingly important sources of seed and invertebrate food for birds on intensively managed farmland. Marginal areas of tall tussocky grass have been recorded as especially important for corn buntings (Brickle, 1999).

1.1.5.4 Small mammals

Small mammal species, *Micromys minutus* (harvest mice) in particular, are reported to have suffered large population declines over the last few decades (Perrow & Jowitt, 1995). Again the culprit appears to be intensive pesticide use and loss of good quality habitat. Schauber, Edge & Wolff (1997) found that small mammals were more susceptible to the detrimental effects of an organophosphate application in mown plots, rather than those in denser vegetation. They suffer reduced body growth and survival, and with the effects persistent for several weeks, it suggests that their vulnerability may be high when present in cereal fields. Pesticide persistence can be very long-lived; indirect exposure effects on small mammals to herbicide residues have been reported months after treatment (Clark *et al.*, 1996). Other treatments such as the application of molluscicides to fields are now known to be highly damaging to small mammals (Johnson *et al.*, 1991 & 1992)

Often, farmers have viewed small mammals as vermin, of no perceivable interest and sometimes responsible for the depletion and spoiling of food and grain stores (Green, 1979). Wood mice have been implicated in disease transmission to both livestock and human, as it has been found that they may carry a number of different pathogenic organisms, such as *Leptospirosis*, and other parasites (Cox, 1970; Twigg, Cueden & Hughes, 1968). Despite this, there has been little recognition of the benefits small mammals may bring; for example, many partially feed on major crop weed seeds, especially within dense, uncut field margins, and thus may influence the population dynamics of such weeds (Povey, Smith & Watt, 1993). The grass species selected as diet components, *Alopecurus myosuroides* (blackgrass), *Avena fatua* (wild oats) and *Bromus sterilis* (barren brome) are extremely problematic, pernicious weeds and any natural control is to the farmers' benefit.

Small mammals are important components in the diets of many other farm-inhabiting animals. It has been suggested that viable weasel populations could not be supported on farmland if not for the concentrations of small mammals in hedgerows (Tew, 1994). Foxes and stoats are other predators of small mammals (Boone & Tinklin, 1988). Both voles and shrews are important in the diet of tawny owls, a species known to have been in decline, (Southern & Lowe, 1968); and barn owls and kestrels have been found to feed on many different species of small mammal on farmland (Pettifor, 1984; Taberlet, 1986; Tew & Macdonald, 1993; Redpath, 1995).

1.1.5.5 Other animals

Lepus europaeus (brown hares) have suffered significant population declines across Europe, which has led to concern, although there is no quantified data available on population levels in the UK, save for bag records (Langbein *et al.*, 1999). The loss has been noted for several decades (Tapper & Parsons, 1984). They are now consequently listed within the UK Biodiversity Action Plan (BAP: Anon., 1995a). Hares are known to inhabit more variegated fields, preferring areas close to field margins, and are not favoured by large fields and continuous cropping regimes (Lewandowski & Nowakowski, 1993). Tapper & Barnes (1986) suggest that their numbers have declined most in areas where the farm landscape has been simplified by field enlargement and block farming.

Pipistrellus pipstrellus (the pipistrelle bat) has been recorded as using linear landscape features such as hedgerows, field margins and tree lines, possibly for orientation, shelter from the wind and because these provide sufficiently high quality habitat in which to forage. They rarely crossed open fields and meadows (Verboom & Huitemsa, 1997). This is another species listed as under threat within BAP.

Other animals such as badgers, hedgehogs and deer, resident on arable farmland, are also dependent on the presence of a heterogeneous habitat mosaic.

1.1.6 Resource provision to enhance or manipulate species

There has been much recent research concerned with the introduction or greater provision of food or shelter resources onto arable farmland, to enhance populations of species that may be beneficial for biological pest control, or provide game rewards. Research has also involved the manipulation of predatory invertebrate populations, so that they can be in the right place at the right time for maximum control of crop pests. The benefits to other non-beneficial species have frequently been only of secondary interest, because of no perceivable economic advantage. Now, conservationists are giving much more attention to these other organisms that happen to live within the arable ecosystem because many, previously regarded as common, are now infrequently recorded or rare. McLaughlin & Mineau (1995) suggested that in order for there to be an increase in both invertebrate and vertebrate diversity, the farm landscape heterogeneity should be increased. They advocated the protection and enhancement of non-cultivated areas, the re-introduction of smaller fields; a diversification of the crops grown, inter-cropping and greater crop rotation. A minimum of 5% non-cropped areas is recommended should a farm follow integrated farming guidelines (El Titi *et al.*, 1993). Some of these approaches are outlined below.

Other approaches to lessen species declines in arable fields now include the use of pesticides with a more precise mode of action and reduced persistence. There has been increases in the use of new, more active agrochemicals that can be applied at much lower rates (Anon., 1996), and can be used with recently developed precision application methods, such as patch-spraying, in order to reduce the impact on non-target organisms. Unfortunately, registration costs mean that broad-spectrum products remain favoured, as they have a wider potential use over those with specific targets.

1.1.6.1 Within the crop environment

Tactics for increasing the resources available within the cultivated area itself are varied. One method is 'inter-cropping', where usually two crops, occasionally more, are grown together within the same field. Usually, parallel strips of the plants are grown, though adjacent patches may also be placed in the field. The objective is to disable the locating abilities of pest species. Many herbivorous pests, such as aphids, use chemical cues to find appropriate host plants, and these may be obscured if not in a single large stand. Additionally, many generalist predators are suggested to be more effective in poly-cultures (Russell, 1989). There are greater labour and management costs of inter-cropping, less efficient harvests and often yield reductions, and so it is unlikely to become popular in UK cereal growing (MacLeod, 1994), although it may be used with field vegetables such as sweetcorn, cabbages, beans and courgettes. The inter-cropping of leeks with celery has been investigated for weed suppression, though the impact on arthropods in the system was not considered (Baumann *et al.*, 2000).

'Undersowing', another form of inter-cropping, is a technique where one crop is sown and another is placed within it, either sown at the same time or later, usually so that the second continues to grow after the first has been harvested. Examples are the establishment of grass leys under spring barley, and clover within Brussels sprouts. Densities and diversities of arthropods within such fields may be greatly increased, with corresponding declines in aphid populations being noticeable (Vickerman, 1978). Where crops are undersown with leguminous plants, soil fertility may also increase, lessening the need for artificial fertiliser application. Unfortunately, farmers dislike seeing high dicotyledonous weed levels that can develop in undersown fields. Some success has been shown with more recently developed clover: cereal bi-cropping regimes (Clements *et al.*, 1999).

Overall, increasing plant diversity within the crop will provide more food directly to phytophagous species, provides host plants where alternative invertebrate food supplies can be found by predatory species, and gives greater physical habitat heterogeneity to accommodate more invertebrate species overall. Increased invertebrate abundance will also allow game species to increase in number.

The use of 'conservation headlands', in which the outer six metres of the field receive only selective spraying with narrow-spectrum pesticides, again allows the development of greater plant and invertebrate diversity. It also lessens drift into the field boundary and deposition into the hedge (Sotherton *et al.*, 1989; Sotherton, 1991; Sotherton & Page, 1998). As the edge area of the field often suffers from problems such as soil compaction from excessive vehicle wheeling, allowing other plants to grow along with the crop rarely makes a great deal of difference to already slightly lowered yields. There are many reports of the value of conservation headlands. Rare plant species have an area of the field in which to thrive (Wilson, 1994a). Butterfly populations are enhanced when they are present (Rands & Sotherton, 1986; Dover *et al.*, 1990; Dover, 1991). Increased species number and diversity of invertebrates have been recorded within them (Hassall *et al.*, 1992). Weed seeds, which are a very nutrient-rich component of most rodents' diets, may be more available (Chiverton & Sotherton, 1991; Macdonald & Barrett, 1993).

'Set-aside' was designed as a method of bringing a percentage of arable land out of production for periods of time, to help reduce overproduction. This is a short-term (sometimes only one year) and frequently rotational system of leaving the field fallow. It was introduced in 1992 when UK farmers were first required to take 15% of arable land out of production. Some kind of green cover has to be present over winter to prevent leaching, and can either be actively sown or naturally regenerating (Tattersall *et al.*, 1999). Very productive, mostly annual plant communities, dominated by the most successful modern crop weed species, tend to spring up in set-aside fields, especially if naturally re-generating. Those species that are rare or endangered do not benefit at all, as the soil is usually far too fertile, and competition too intense. Invertebrate populations do not benefit unless the set-aside is well managed (Sotherton, 1998) although birds may benefit from increased seed feeding possibilities in some cases. Game bird population growth was supported in set-aside fields (Moreby & Aebischer, 1992). Tattersall *et al.* (1997) looked at the use of one-year set-aside by small mammals and concluded that it was not a particularly suitable habitat for them.

Slightly greater abundance was found in set-aside after two years (Tattersall *et al.*, 1999). Sown set-aside may provide greater benefits than that naturally re-generated, with a long-term approach allowing undisturbed perennial flora to establish, benefiting invertebrates (Corbet, 1995). However, there is currently a trend for industrial crops to be grown on set-aside because of the financial pressures on farmers to maintain incomes, with a doubling of the amount grown from 1999 to 2000 (http://www.maff.gov.uk, 2001). 120, 000 hectares of industrial oilseed rape alone was grown in 2000 as opposed to only 25, 000 the previous year, a trend unlikely to be advantageous to wildlife.

Another approach to improve the biological diversity of the crop environment is to grow a more extensive range of crop plants. Spring canola, crambe, and sunflower have received interest as alternative oilseed crops within wheat cropping in USA (Nielsen, 1998), with amaranthus, triticale, chickpea, safflower, clovers, lupin, vetch and meadowfoam being investigated there and in Australia (Beech & Leach, 1989; Becker *et al.*, 1992; Young & Youngberg, 1996; Asseng *et al.*, 1998). Summer savoury cropping has been evaluated in Scotland (Svoboda *et al.*, 1990). The use of alternative oilseed and game cover crops such as borage, coriander, buckwheat, safflower and pot marigold, particularly favourable foraging resources for beneficial hoverflies, has been investigated in the UK (MacLeod, 1992). A recent MAFF funded initiative has been created to investigate novel crop growing on a number of East Anglian farms, though on a tiny scale and with the emphasis on providing economically viable alternative to traditional crops, rather than any wildlife benefits (Cook *et al.*, 2000).

There has been a great deal of research recently into different types of farming systems as a means of improving profitability but also to reduce the environmental impact of farming and achieve greater sustainability. Low-input and organic farming regimes may be more beneficial overall for species that reside in arable fields in the long term. Through survey work, Feber *et al.* (1997) recorded significantly more non-pest butterfly species on organic than on conventional farmland. A greater species richness and overall abundance of epigeal arthropods was found in organic wheat compared to that conventionally farmed in another study (Pfiffner, 1990). Holland *et al.* (1994a) provides a thorough review of many long-term lower input farming system research projects that have been carried out recently across western Europe including the UK. The frequently used description 'integrated farming' refers to incorporating ecological knowledge into sustainable agronomic and economic farm practice. Unfortunately, any potential environmental benefits of these schemes must defer to whether they can be economically successful. However, many schemes are attempting to quantify both financial and environmental benefits and results are slowly being incorporated into current farming practice (Jordan, 1998; Jordan *et al.*, 2000).

1.1.6.2 Outside the crop area

Resource enhancement or manipulation on land outside the actual cropped area has received extensive research in recent years. A number of authors, for example Morris & Webb (1987), Basedow (1987), Kaule & Krebs (1989), Boatman *et al.* (1989) and Wilson (1994b) have described the importance of field margins. The replacement of hedgerows that have been removed previously is now advocated, and better maintenance of those remaining, including the re-seeding of the hedgebottom, and the avoidance of trimming or cutting procedures at certain times, such as when birds are nesting, (Marshall & Moonen, 1998).

The original roles and requirements of field margin strips were to delineate the edge of the field, limit movement of stock between fields, provide shelter for stock and crops, reduce soil erosion, and to harbour beneficial invertebrates and plants, especially those which were a source of wood or fruit. This list has now extended to consider functions such as the promotion of biodiversity and farm wildlife conservation, the maintenance of landscape diversity and historical features (Marshall & Moonen, 1998), roles that are less clearly identifiable and reflect recent environmental conservation and cultural concerns. A diverse, 'patchwork' landscape of fields surrounded by complex margins certainly has greater aesthetic value than bland cereal prairies.

The addition of various kinds of annual or perennial herbaceous vegetation strips either along current field boundaries, or replacing those absent, can both improve feeding resources and provide habitat where species can shelter and reproduce. There are many options available for farmers to establish these on their land, according to the objectives needing to be met. What boundary habitat already is in existence; the weed problem history of the farm; agronomic management practices being carried out; the funds available for establishing and maintaining the habitat; local climate; soil type and fertility, and many other factors, all need consideration. Marshall and Moonen (1998) provide an extensive review of all the options available in the UK and Europe, describing how they may be set up and managed, their agronomic and economic implications, potential benefits and conflicts of interest to farmland wildlife.

Set-aside, outlined earlier, can be used as a margin strip. Management is dependent on whether the strip is part of a rotation or left as a longer-term option, and if the objective is agricultural or conservation-related (Tattersall *et al.*, 1999). Funding is available, and benefits include provision of foraging and nesting resources for farmland birds and small mammals, though site longevity and resultant composition has an impact on the habitat's value (Tattersall *et al.*, 1999).

Floral strips, either of a single species or a mixture, can be placed alongside the field edge, benefiting pollinator, parasitoid and predatory invertebrates by enhancing feeding resources. Wildflower strips have been sown to enhance beneficial invertebrate numbers in cereal fields (Heitzmann *et al.*, 1992; Lys & Nentwig, 1992; Wyss, 1995; MacLeod, 1999). Florally diverse field margins were found to be especially important for hoverflies (Cowgill, 1989), with the non-native *Phacelia tanacetifolia* (Hydrophyllaceae) strongly attractive to this insect group (Carreck & Williams, 1997). When this species was sown alongside cereal crops, it led to the increased presence of these and other beneficial invertebrates in the crop (Holland & Thomas, 1996; Hickman & Wratten, 1996; Holland, Thomas & Courts, 1994), with increased oviposition leading to greater aphidophagous larvae densities in the crop in some cases. The presence of floral margins is also very important with regard to maintaining high numbers of bumblebee pollinators in farmland (Dramstad & Fry, 1995). In addition, they may be good places in which to site beehives (Marshall & Moonen, 1998)

Beneficial invertebrate-attracting plants may be useful for reasons other than their potential biocontrol value. They may provide a crop of economical value in themselves, for example, coriander; or in the case of species such as *Phacelia*, act as a green manure (MacLeod, 1994). Therefore growing fields or small patches among other crops may be as useful as field-bordering strips. Unfortunately, flower strips are rarely grown on commercial farms, although they may be an option within set-aside. Some disadvantages include the costs of repeated sowing of annual species, seed encroachment into the crop, and encouragement of pest butterfly species (Marshall & Moonen, 1998). Increased mollusc grazing has been reported alongside flower strips (Frank, 1998).

A final method developed to increase the resources available for beneficial invertebrates is that of sowing grass strips. Principal roles for these have been to protect existing boundaries or watercourses from agrochemical pollution, provide erosion control, limit annual weed ingress into crops, and improve access to hedges and ditches for maintenance. Benefits to wildlife have been increasingly appraised (e.g. Sotherton, 1985; Boatman *et al.*, 1989; Andersen, 1997; Huusela-Veistola, 1998; Barker & Reynolds, 1999; and many others). Grass strips may limit the colonisation of local flora, and will not allow rare annual species to survive (Marshall & Moonen, 1998). They may also impede the between-field movement of invertebrates (Frampton *et al.*, 1995).

Within this last option is beetle bank creation within fields, and this is outlined below. Farmers may regard these practices of resource creation or manipulation outside the cropped area as easier to deal with, as they do not involve altering the whole field agronomy. However, they do remove potentially productive areas of land, which within the current farming climate has financial implications.

1.2 What are beetle banks?

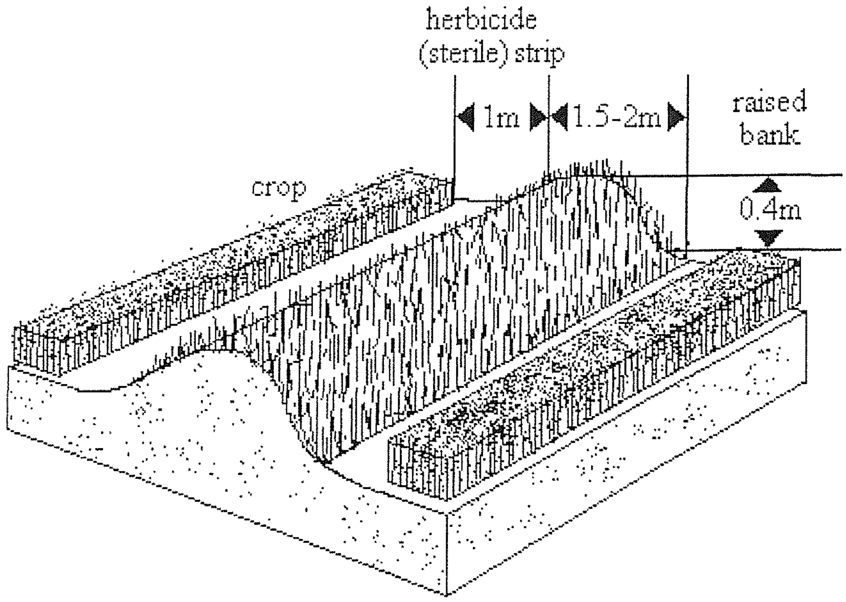
1.2.1 Physical characteristics

The polyphagous predatory invertebrates described earlier have lifecycles that involve the overwintering survival of either the adult or larval stage, following spring or autumn reproduction respectively. A few species are able to remain active throughout much of the winter on the soil surface, sometimes within the field itself, despite the lack of cover, while others remain below ground to avoid exposure. However, many other species migrate from the field back into boundary areas, seeking dense vegetation in which to shelter. Grasses that have a tussock-making growth form have been found to be especially important in providing optimal conditions for the shelter and survival of predators in cold and wet conditions (Luff, 1966; Bossenbrook *et al.*, 1977; Desender, 1982; Thomas *et al.*, 1992b; Asteraki *et al.*, 1992 & 1995). Species such as *Dactylis glomerata* (cock's-foot), *Holcus lanatus* (Yorkshire fog) and *Arrhenatherum elatius* (false oat-grass) are the best examples of tussock-forming grasses. As the tussock stool forms, old dying or dead leaves remain attached to a clump from which new growth emerges, and the entire structure allows a buffered microclimate to develop within (Luff, 1965). Temperature fluctuations within are significantly less than those external to the tussock, and resulted in greater survival of invertebrates sheltering within them compared with other plant structures or just bare soil (D'Hulster & Desender, 1982; Thomas, 1991).

As described, many field boundary habitats such as hedgerows have been lost or are poorly maintained (Watt & Buckley, 1994) so that little dense grassy cover remains at their bases (Pollard, 1968; Dunkley, 1997). Thomas (1989, 1990 & 1991) and Thomas *et al.* (1991) provide reports on the development of tussock grass sown raised banks that were devised to provide perennial, herbaceous hedgerow bottom-type vegetation in a simple and inexpensive form. These were set up to extend in a single strip across the centres of large arable fields. Cock's-foot and Yorkshire fog were found to be the most suitable species for sowing, along with the addition of some mat-forming grasses such as *Festuca rubra* (creeping red fescue), to provide ground cover in between the developing tussocks (Thomas *et al.*, 1991; Sotherton, 1995). Persistence, lack of drift from the original sowing site, and seed cost were all factors relevant to choice of grass species. The grass banks were raised above the height of the field to ensure that the grass bases did not suffer any waterlogging, to further ensure ideal overwintering survival conditions for the invertebrates. Water saturation and ice formation can lead to the mortality of not only the predators themselves, but also of prey species, fungi etc. on which they will feed when warmer conditions allow for increased activity.

These grass banks were originally designed to be placed in the middle of large arable fields, where predator populations are most impoverished, to effectively 'shrink' the field size in terms of invertebrate densities and dispersal, compensating for the increasing field size. Farming management was not supposed to be affected by the placing of these ridges across the field, because a gap was recommended at each end, so as not to hinder the manoeuvring of large machinery, allowing the field to be cultivated as a single unit. A gap of around 25m was suggested, this being the width of a typical standard spray boom, allowing normal single treatment of the field headland.

Figure 1.1 *Cross-section through a beetle bank*



Because of the high densities of predatory beetles reported in the first experimental sown grass ridges, they promptly received the name 'beetle banks', which is now how they are usually referred to. Sotherton (1995) describes the original guidelines for the commercial creation of beetle banks. In autumn, two plough passes were found sufficient to create a well-drained earth ridge, around 40cm high and 1.5-2m wide (Figure 1.1). This should be drilled with grass seed at a rate of approximately 3g m^{-2}. A greater rate may be required if the bank can only be sown in spring, to compensate for losses by bird feeding. It was suggested that initially, opportunist weeds could be sprayed out with a non-residual herbicide, though further treatment should not be carried out. Topping of flowering heads was suggested as a possible summer management activity to limit seed spread into the cultivated area, though the developing grass tussocks should not be damaged, and the practice was described as probably being rarely needed. It was indicated that beetle banks were features that could be viewed as non-permanent, as they could be ploughed up should the farmer require an alteration to the way the field was used.

Arable farmers throughout the UK have taken up the beetle bank design, and although there still appears to be only a small number in existence, the number is rising. Advisory organisations have come to the conclusion that may make a useful contribution to an integrated pest control approach on the farm, and additionally provide habitat to improve the diversity and abundance of other fauna. Both The Game Conservancy Trust, who collaborated with the University of Southampton in devising the original design, and various regional Farming and Wildlife Advisory Groups are currently encouraging farmers to put beetle banks onto their land. MAFF (Anon., 1999a & b) also currently suggests the establishment of beetle banks as part of a range of improvements that farmers may make on their land.

1.2.2 Economics

Farmers within the Countryside Stewardship Scheme (Anon., 1999b) are now eligible for a grant payment for beetle banks and grass field margins, providing £750 per hectare, which translates to £15 per 100m of habitat per year. Additionally, those farmers within the bounds of the pilot Arable Stewardship Scheme, which was established to investigate other means of encouraging wildlife on arable farms within Cambridgeshire/Suffolk and Shropshire may also receive this funding (Anon., 1999a). Beetle banks are principally 'sold' to farmers on the financial grounds that they contribute high densities of predators into crops as part of an IPM programme, although their economic benefits have only ever been calculated indirectly. When considering the cost-benefits of establishing beetle banks there are two major factors: the loss of land that could be profitably cropped; and potential savings in the cost of pesticide applications and resultant yield loss prevention. Collins (1999) presented an economic profile for beetle banks, suggesting that several pounds per hectare could be saved if their presence could keep an aphid population below spray threshold levels by enhancing natural predatory control. Actual figures relate to the choice of agrochemical, application procedure, and crop being grown.

The grants provided within the CSS and ASS compensate mainly for the small yield losses resulting from land removed from production, and so the small savings in pesticide costs is merely a useful addition. However, they may not give sufficient incentive to farmers who have not been able to enter such schemes to set up beetle banks. More environmentally conscious farmers may be more easily persuaded that along with other measures, beetle banks may be a valuable means of increasing biodiversity on their land, which could bring indirect financial rewards in time. However, there are a number of disincentives for such thinking; for example, farmers with beetle banks who are not part of the CSS or ASS have to deduct the area of land that they occupy from claims made within the government-funded Arable Area Payments Scheme (http://www.maff.gov.uk, 2001). Farms trying to enter the CSS (for which there is only around a 60% acceptance rate) are judged by the whole farm environment, including the pre-existence of features such as beetle banks amongst a range of conservation measures. Yet only new ones will receive funding, so that if selected, it is almost worthwhile ploughing up the old banks to re-establish them in order to be eligible for the funds. Finally, the payments obtainable are fixed values calculated from old wheat prices, and do not necessarily relate to current figures (P. Thompson, personal communication).

1.2.3 What research on beetle banks has taken place to date?

The original research carried out by M. B. Thomas to investigate the most appropriate design for beetle banks, and their potential value on arable farmland, consisted primarily of measuring the overwintering densities of predatory invertebrates within them, which changed from 'open-field' to 'boundary' species as they became established (Thomas, 1989; 1991). Thomas examined the physical conditions, including temperature, within beetle banks that gave best survival over the winter, and looked at the availability of prey to these invertebrates. He also attempted to examine the penetration of predators into the crop from beetle banks in spring, principally by assessing predation rates at distance from the source (Thomas, 1991). From his results he suggested that the apparent 'wave' of invertebrates dispersing from the beetle bank caused a more even spread of these across the field than would have been the case without the bank present.

A. MacLeod, who attempted to further extend the data set on predator densities in beetle banks, followed up this initial work. He was interested in whether the densities in those newly created banks were sustained in following years. He presented evidence that densities, though highly variable across locations and years, developed in these first experimental beetle banks to levels greater than in adjacent field boundaries (MacLeod, 1994). He evaluated the two sites, which had reached six years old at the time of his study.

The Allerton Research and Educational Trust, at Loddington, in Leicestershire, run by the Game Conservancy Trust, is an experimental farm that has set up beetle banks. These have been monitored for beneficial invertebrates since establishment, and recently, K. Collins reported on predator densities within these sites. Although initially significantly lower, after three years, densities in the new banks were found to compare favourably with those of conventional hedgebanks (Collins *et al.*, 1996). Three species of grass, *D. glomerata*, *Arrhenatherum elatius* and *Phleum pratense*, were all considered favourable for sowing, although *H. lanatus* seed was deemed too expensive and difficult to obtain. She also attempted to evaluate the influence of beetle banks on aphid populations developing in wheat, by assessing pests within and without predator exclosures at increasing distance from a beetle bank. There was evidence for aphid densities increasing at distance from the bank, with higher levels of infestation in the predator-excluded areas; however, a direct causal influence of the beetle bank was somewhat difficult to establish (Collins *et al.*, 1997).

Also at Loddington, harvest mice were recorded in one beetle bank (Boatman, 1998). Tall, dense vegetation, especially that of dense grass, is known to be favoured by this species (Harris, 1979), and so this led to work by S. Bence to investigate small mammal presence in these *D. glomerata* sown banks. She found that they can provide an ideal habitat for harvest mice, sustaining much higher populations than were found in other marginal habitat (Bence, 1999). Field voles were found to be significantly more numerous in new hedges that had been sown with *D. glomerata*, indicating the suitability of this plant for nest building (Woods, Dunleavy & Key, 1996), so beetle banks may be useful for a range of species. These findings currently lack support from other sites.

A. Barker recently evaluated the value of sown grass field margins, within which category she also grouped beetle banks, as suitable habitat for sawflies and other gamebird chickfood insects. Although these strips were considered important, it was only those with a low percentage cover of *D. glomerata* that contained the highest sawfly abundance. It was considered that rather than these dense grass stands, conservation headlands, with their greater accessibility, would be better habitat for gamebird chicks (Barker & Reynolds, 1999).

1.3 What remains unanswered? Aims and hypotheses of thesis

Despite the considerable interest shown when the concept and design of beetle banks was being developed, follow-up research has been more limited. They are currently promoted as of value to farmers within a range of conservation-related options that can be taken up on the farm (Anon., 1999a & b), but there is limited information relating to their ecology and appropriate management, and many questions remain outstanding.

More specifically, because they have a known establishment date, beetle banks provide a valuable means of exploring successional growth and change, and the potential development of biodiversity within simple linear field margin-type habitats. The results of such studies can be used to compare beetle banks with other more complex non-cropped field margins to evaluate whether beetle banks can fulfil equivalent functions despite being significantly more easy and inexpensive to create, and flexible within the farm layout. The aims of this thesis were as follows:

1. To assess the botanical diversity and evidence for successional change within beetle banks. It was hypothesised that there would be age-related differences in the composition of different sites. Degradation of quality, such as weed or scrub encroachment and cover loss would indicate that they become less suitable as overwintering sites for polyphagous predators, and thus require a more active management strategy.

2. To evaluate the densities of predatory invertebrates in beetle banks. The hypothesis under test was whether densities reported in newly created banks, in previous research, are sustained in longer established sites, despite any possible changes outlined above.

3. To acquire more evidence that banks contribute to better spatial and temporal distributions of predators in crop fields, by evaluating field populations through time and distance from the source population. Hypotheses under test related to whether there truly is a 'wave' of dispersing predators emerging from beetle banks, whether patterns are the same as those from conventional field margins, and whether there was evidence that

beetle banks act as a 'reservoir' of predators that could contribute to biocontrol later in the season, following depletion of already dispersed predators in the field.

4. To quantify the diversity of other fauna that might become established within them, and compare this to conventional field margins. It was hypothesised that simple grass strips would contain lower levels of diversity compared to older, botanically complex habitat, although this difference might lessen with age. The question that needs to be addressed is whether there is a need to balance beetle bank management for optimal overwintering habitat for predators, with their use as protected refuge habitat for species of conservation concern, thus receiving minimal interference.

A final aspect of this work aimed to conduct a survey of current farmer use and perceptions of beetle banks. What are farmers now actually establishing in their fields? From where are they getting their guidelines about beetle banks, and are they following them? Such information will relate to long-term advice on beetle banks, such as whether they might require re-establishment after a finite period.

Plate 1.1 *A newly established beetle bank within a 47.5 ha arable field, with new grass and ephemeral weeds emerging*

The farmer has sited the bank to incorporate an existing stand of trees.

Plate 1.2 *A beetle bank in winter, consisting of grass tussocks of both live and dead grass*

At this site, the bank replaces a lost hedgerow.

Plate 1.3 *The dense grass sward of a well-established five-year old beetle bank*

Here, the farmer has divided the 46 ha field into two smaller fields, each at different stages of the crop rotation.

Plate 1.4 *One of the first experimental beetle banks, at fourteen years old, dividing a field into areas of 22 and 29 ha*

The strip has become wider; its height has sunk to field levels, and is now botanically diverse; yet predator populations remain abundant within it.

2. Botanical diversity & succession in beetle banks

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2.1 Abstract

Beetle banks are simple, grass-sown raised strips providing habitat for invertebrate predators of arable crop pests and other farmland wildlife. To date, research has mainly been concerned with examining such predators. Here, I examined the botanical species composition and diversity of a range of beetle banks in southern UK over two summers and a winter, and compared with that of typical, adjacent field margins including grassy hedge-banks and strips. Beetle banks had lower species richness and H' diversity than these field margins, but these characteristics were found to increase with age until those over a decade old had approximately equal diversity. Few individual plant species were found exclusively in either habitat. Beetle banks provided more grass cover, especially that of tussock grass, but less herbaceous cover and fewer melliferous plants compared with field margins. Weed cover was not significantly different between habitat types, and varied considerably. This may concern some farmers, particularly when economically threatening species are present, though crop encroachment may be minimal and control is relatively straightforward. Overall, beetle banks appear to retain a dense vegetational structure, despite increasing botanical diversity, and so are of value as refuge habitat for predatory invertebrates for over a decade at least. Increasing floral diversity may benefit other beneficial invertebrates. As simple, inexpensive features, beetle banks provide a means of dividing fields and enhancing farmland biodiversity, while requiring minimal management.

2.2 Introduction

During the last 50 years in the UK, a very large number of hedgerows have been removed and of those that remain, many are poorly maintained (Greaves & Marshall, 1987; Barr & Parr, 1994). This has led to a loss of diversity, not just of floral species richness and corresponding faunal diversity, but also in the shape, structure and type of hedgerows (Muir & Muir, 1987). This loss still occurs on some farms; however, in contrast, farmers elsewhere are replanting hedgerows, repairing existing ones, and adopting schemes such as adding perennial herbaceous vegetation strips along current field boundaries (Kaule & Krebs, 1989; Marshall *et al.*, 1994; Kleijn *et al.*, 1998). Many important functions of hedgerows and other field boundary habitats have only been investigated in recent years. They may provide overwintering sites for crop pest predators, corridors for vertebrate and invertebrate population dispersal, game shelter and reproduction sites, temporary and permanent habitats for a number of organisms (Boatman, 1992a; Aebischer, Blake & Boatman, 1994; Boatman & Wilson, 1988).

Predatory invertebrates, such as carabid and staphylinid beetles and spiders, can be valuable biological control agents in arable crops (Potts & Vickerman, 1974; Chambers *et al.*, 1983; Chiverton, 1986; Sunderland *et al.*, 1987). Many such species overwinter outside the field in marginal habitats, and dense, tussocky grass has been found to be important in providing optimal microclimate conditions for shelter and survival (Luff, 1965; Asteraki, *et al.*, 1992 & 1995). Inadequate management of many of the surviving hedgerows means that they have little dense cover at their bases (Pollard, 1968; Dunkley, 1997). Often, fields may be ploughed right up to tracks or boundaries, and so grassy edges have been lost. Large field sizes associated with large vehicles and machinery have led to change in the ratio between crop area and amounts of non-crop refuge habitat on farmland. Large fields may have an impoverished predator fauna in their centres because of the distance edge-overwintering spring colonisers must travel (Wratten *et al.*, 1984; Duffield & Aebischer, 1994).

Beetle banks were designed for placement in the middle of fields to provide more overwintering habitat for beneficial invertebrates (Thomas & Wratten, 1988; Thomas *et al.*, 1991; Thomas *et al.*, 1992c), and enable greater spring re-colonisation of the field from shorter distances. However, since their introduction more than a decade ago, little follow-up research has been carried out on beetle banks. Overwintering predator densities were measured in newly established banks (MacLeod, 1994; Collins *et al.*, 1996) and monitored for a period; and more recently, work has been carried out to attempt to establish the impact of beetle banks on aphid densities in the crop (Collins *et al.*, 1997). However, there has been little study of vegetational composition and structural changes within banks, and their suitability for different invertebrate taxa or other wildlife. Successional changes in plant community structure may occur, with consequences for their faunal composition. More diverse vegetation has been found to be associated with increased insect diversity when either species or structural diversity was examined (Murdoch *et al.*, 1972; Lawton, 1983; Basset & Burckhardt, 1992; Gardner *et al.*, 1995; Thomas & Marshall, 1999).

D. glomerata tussocks were found to disintegrate after a period of 7-10 years (Luff, 1965), and so beetle banks may not continue as ideal overwintering habitat. Farmers who have set up banks have little information regarding appropriate management of banks once established, such as how or whether to keep the grass stand dense and what to do if weed species that may be crop invasive become dominant within the banks. Additionally, it is likely that spray drift from the crop area will occur, causing damage to grasses in the bank. Drift of pesticides has been demonstrated to damage both flora and fauna of hedgerows and other field margins (Singh *et al.*, 1990; Marrs *et al.*, 1991b; Longley *et al.*, 1997; Longley & Sotherton, 1997). Less competitive growth of a damaged grass stand could leave opportunities for species compositional changes in the beetle bank e.g. weed invasion. The associated invertebrate populations present, including not just predators but also other groups such as nectar- and pollen-feeding insects and pest species, may be altered.

2.2.1 Aims of study

I aimed to examine beetle banks established for varying periods of time to determine their floral composition and its change with age. I aimed to compare the floristic diversity of beetle banks with other conventional field margins, such as grass edges and hedgerows, in particular considering factors such as the incidence of weed species.

2.3 Materials and methods

2.3.1 Study sites

In July 1998 the flora of nine beetle banks on an estate in Hampshire, UK was assessed. Ranging in age from 1 to 13 years old, each had been established by ploughing an earth ridge in autumn, and hand sowing *D. glomerata*. There has been no further management of the banks. A "sterile strip", i.e. a 0.5m gap between the crop and the margin was created yearly along each side of the banks by a single glyphosate treatment after crop establishment. Banks were 300 - 900m long, 2 - 5m wide, on slightly flinty calcareous silty clay loams. Each site was visited in January-February 1999, to assess the vegetation present over the winter period.

In July - August 1999 22 banks from five estates were assessed in Hampshire and Wiltshire. Sites sampled were <1 to 14 years old and all except two had been sown with *D. glomerata*, *F. rubra* (red fescue) being included in the seed mix in some sites. Beetle banks were 200 – 900m long, 2-6m wide, on slightly flinty calcareous silty clay loam soils.

In both years, one of the margins of the field, consisting of either a grassy hedgerow bottom or grassy non-shrubby edge, was randomly selected with each beetle bank, to provide a comparison of an established linear margin habitat. The choice was often limited as several margins consisted merely of an earth track. Of necessity the beetle banks and field margins were of variable aspects.

2.3.2 Botanical recording

In each beetle bank or field margin, at intervals of 10m, a 0.71m x 0.71m quadrat was placed on the ground and all herb layer vegetation within recorded by species as percentage cover, using only one observer to avoid subjective discrepancies. Observations were made directly above the vegetation, attempting to include the element of vegetation stratification, where the sum of all species cover could exceed 100%. Overall plant cover to a maximum of 100% was assessed separately. Inaccuracies when recording plant cover by eye are possibly over-emphasised (Kent & Coker, 1993), and the method was found to be rapid and consistent following intermittent double-checking.

Twenty quadrats were positioned at random across the width of each strip. Plants were classified as 'tussock' (i.e. both live and dead grass that had formed dense, clumped stools), 'other grasses', 'herbaceous plants' or 'woody plants'. Additionally, 'nectar providers' (i.e. species known to provide an abundant supply of nectar for invertebrates such as butterflies, hoverflies and bees; Fussell and Corbet, 1993; Comba *et al.*, 1999), 'grass weeds' and 'broad-leaved weeds' (i.e. pernicious, economically-threatening and crop-invasive species including *Alopecurus myosuroides* (blackgrass), *Bromus sterilis* (barren brome), *Elymus repens* (couch); *Sonchus* species (sowthistles), *Cirsium* species (thistles), *Galium aparine* (cleavers) and *Stellaria media* (chickweed)) were recorded in the summer; with 'litter' and 'moss' categories recorded in the winter. The annual, biennial or perennial life cycle of each plant was also recorded.

2.3.3 Quadrat size and sample size evaluation

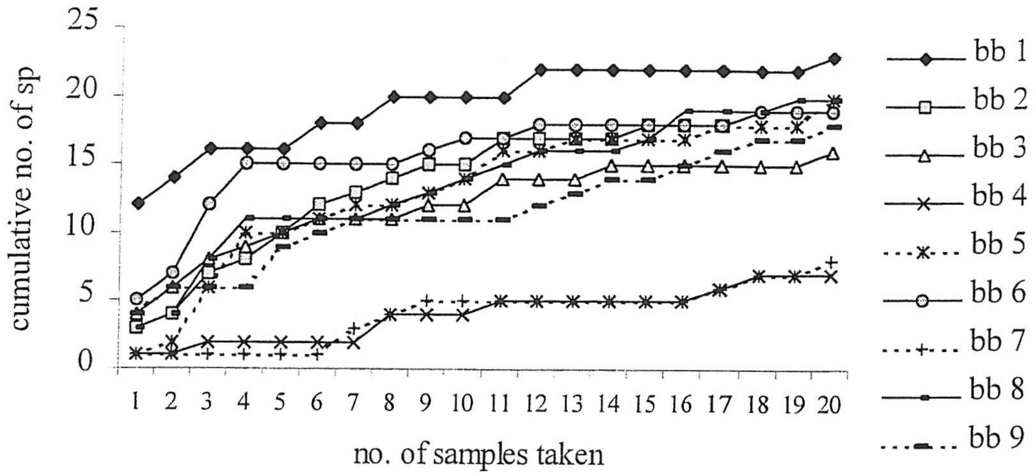
A quadrat was used to establish a standard area within which the vegetation could be recorded. The size of quadrat used is important in its relationship to the kind of vegetation being recorded; in particular, to the size of the plants, their spread, and the way in which they are distributed. If there are the same number of individual plants within several areas, different sizes of quadrats thrown into those areas will produce different results if the plants have regular, clustered or random distribution patterns (Kent & Coker, 1993). Species-area curves can be calculated, where species number are plotted against quadrat size, with the asymptote indicating the minimum area for sampling that particular plant community.

However, as this method is only supposed to work in areas where the vegetation is fairly homogeneous, clearly defined and not on the edge of other vegetation types, it was not likely to be generally applicable. A quadrat that was large enough to incorporate the clumping of grass tussocks visible in the plant strips assessed, yet small enough for an adequate sample number to be taken, was therefore used. If it took too long to sample the replicated sites; for instance, more than weeks, there might have been seasonal change in the species composition. A 0.71 cm x 0.71 cm = 0.5 m^2 quadrat was considered most suitable for this study.

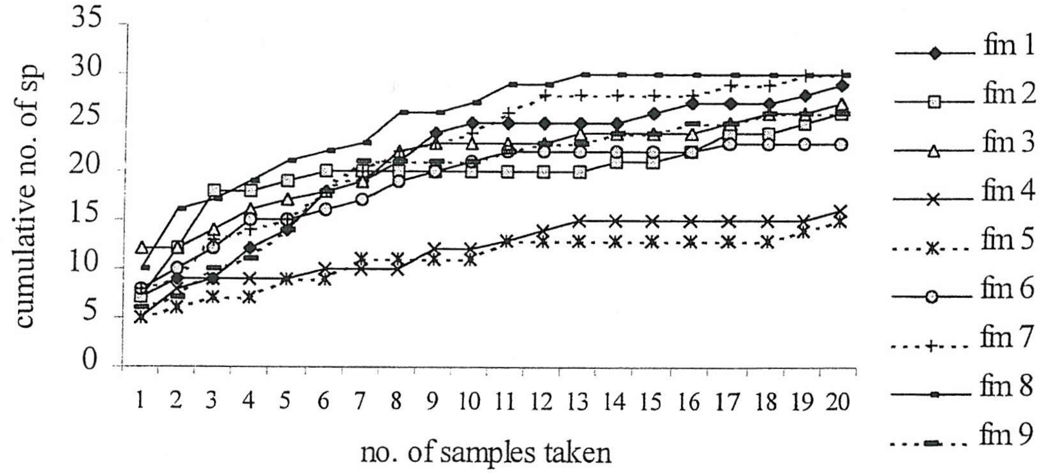
It was necessary to determine the optimal number of quadrats to record in beetle banks and field margins in order to obtain a representative sample of the diversity present. Twenty samples per site were assessed initially, and for each site the cumulative mean number of species recorded was plotted against number of samples taken. Plots for all sites assessed in the first experimental sampling year indicated that the graph asymptote had not been reached, but the slope of the curve was very shallow at this point (Figure 2.1). Therefore, a sample size of 20 was deemed adequate, as it indicated that only a very small number of extremely rare species within the habitats might have been missed.

Figure 2.1 *Cumulative number of plant species present in quadrats recorded during summer assessment, 1998*

a) beetle banks



b) field margins



2.3.4 *Diversity measurement*

Species richness (S) is the most extensively used measure of diversity. However, to compare diversity between beetle banks and with that of field margins, in terms of both species richness and proportional abundance, a diversity index was also calculated. There are many different indices available, and there has been considerable discussion of the relative value of each (Magurran, 1988). Mostly, problems relate to the difficulty of using an index to compare different kinds of habitat. The Shannon-Wiener Index was selected because of its frequency of use in similar studies, which could allow comparison of results. The index reflects species dominance as most affected by changes in the abundance of the rarest species, and is sensitive to sample size. It is simple to calculate and may be used for parametric statistical analysis, as repeated measures of diversity are usually normally distributed (Magurran, 1988). One assumption of Shannon-Wiener is that all species are represented in the samples taken, and if this is not met, the index calculated can become flawed (Peet, 1974). The calculated value mostly falls between 1.0 and 3.5, and rarely exceeds 4.5 (Margelef, 1972; Magurran, 1988).

2.3.5 Analysis

Plant cover, species richness and the Shannon-Wiener Diversity Index (H′; using percentages values for each species) were examined for each of the sampling sites. For each beetle bank or field margin the mean value of species richness and diversity was calculated and used in subsequent analyses, to avoid pseudoreplication. Regression analysis was used to relate species richness and H′, as well as tussock and weed cover, with beetle bank age. Paired t-tests were used to compare logit-transformed means of beetle banks and field margins, after assessing homogeneity of variance.

2.4 Results

2.4.1 Summer vegetation

Total vegetation cover was significantly lower in beetle banks than in field margins in both sampling years (Table 2.1). A total of 82 plant species was recorded in beetle banks over the sampling period, compared with 89 in field margins, though many species were represented by only a single plant in a single quadrat. Field margins had a significantly higher mean species richness and vegetational diversity when compared to beetle banks, in both of the sampling years (Table 2.1). However, the oldest banks had diversity indices above 1, almost equal to the average of 1.35 for field margins.

Cover of grasses tended to be higher in beetle banks compared with margins, the difference being significant for the larger 1999 sample (Table 2.1). The same pattern was found for tussock species. Although all except two of the beetle banks had been sown with *D. glomerata*, the amount of this grass was highly variable, with a mean of only 34% cover overall. This was much greater than that of the field margins (Table 2.2). A decline in the amount of tussock grass with age of beetle bank was found in summer 1998 ($r^2 = 0.65$, $F_{1,8} = 13.1$, $P < 0.01$), but not in summer 1999 ($r^2 = 0.03$, $F_{1,21} = 0.60$, $P = 0.45$), where the more extensive range of banks was examined.

Higher herb cover was found in field margins than in beetle banks in both sampling years, the difference significant in 1999. The same pattern occurred for nectar-providers (Table 2.1). Weed levels did not differ significantly between the two habitats, for either grass or dicotyledonous species, but may give farmers concern as cover ranged from 3 up to 22%. There was no relationship between age of beetle bank and amount of weed cover present, in either year.

The number of species present was high in newly established beetle banks; it declined sharply in two-year old sites, increasing after three years (Figure 2.2). A polynomial regression showed a highly significant relationship between species richness and age ($r^2 = 0.62$, $P < 0.001$; $y = -0.0162x^3 + 0.3925x^2 - 2.5103x + 7.277$). Similar patterns were exhibited in the diversity index. Beetle bank diversity was high for newly established sites, dropped rapidly in the second year to steadily increase in older sites (Figure 2.3). A polynomial regression indicated a significant positive relationship between diversity and age ($r^2 = 0.64$, $P < 0.001$; $y = -0.0039x^3 + 0.0917x^2 - 0.5612x + 1.367$).

Five species were found exclusively in one or other habitat, of which three were shrubby species, found in the grass bottoms of hedgerows (Table 2.2). *Stachys sylvatica* (hedge woundwort), usually found in shady hedge bottoms, was not recorded in any beetle banks, and *Sonchus arvensis* (perennial sowthistle) did not occur in any field margin. *Urtica dioica* (common nettle) and *Torilis japonica* (hedge parsley) both occurred to a greater extent in field margins than in beetle banks, in terms of both percentage cover and the number of sites at which they were present (Table 2.2).

In 1998, there was no clear trend in the number and proportion of annual, perennial or biennial herbaceous species in relation to age (Figure 2.4). In 1999, there was a trend for greater cover by annual species in young beetle banks, with more cover by perennials in following years, because of the predominance of developing grasses; however, there was no obvious change in composition later (Figure 2.5).

Table 2.1 *Mean percentage cover (+ SE) of different categories of vegetation in beetle banks and field margins sampled in summer, with results of paired t-tests for differences between beetle banks and margins*

	1998 sampling			1999 sampling		
mean (+ SE)	beetle banks	field margins		beetle banks	field margins	
number of species present	3.88 (0.51)	6.13 (0.42)	t = 2.12, d.f.=16, *P* = 0.002	3.81 (0.44)	6.78 (0.23)	t = 2.03, d.f.=33, *P* < 0.001
H' diversity	0.50 (0.06)	1.09 (0.07)	t = 2.12, d.f.= 9, *P* = 0.004	0.75 (0.08)	1.35 (0.05)	t = 2.04, d.f.=33, *P* < 0.001
total vegetational cover	78.8 (2.92)	90.5 (1.80)	t = 2.12, d.f.=16, *P* = 0.002	80.7 (2.18)	87.7 (1.28)	t = 2.04, d.f.= 33, *P* = 0.04
% grass cover	72.5 (3.24)	70.5 (6.96)	t = 2.20, d.f.=11, *P* = 0.55	68.0 (4.62)	55.7 (5.06)	t = 2.02, d.f.= 42, *P* = 0.007
% tussock cover	55.7 (6.82)	38.0 (9.62)	t = 2.12, d.f.=16, *P* = 0.15	38.0 (5.65)	25.6 (4.15)	t = 2.02, d.f.= 42, *P* = 0.04
% woody plant cover	0.46 (0.22)	6.44 (3.72)	t = 2.31, d.f.= 8, *P* = 0.09	0.32 (0.16)	11.3 (3.17)	t = 2.08, d.f.= 21, *P* = 0.002
% herbaceous plant cover	9.42 (2.80)	19.2 (6.63)	t = 2.23, d.f.=10, *P* = 0.11	15.1 (3.30)	29.4 (4.85)	t = 2.03, d.f.= 35, *P* = 0.002
% nectar-providers	7.78 (2.09)	18.1 (6.56)	t = 2.26, d.f.= 9, *P* = 0.09	13.6 (3.03)	30.6 (5.12)	t = 2.03, d.f.= 35, *P* = 0.001
% cover of grass weeds	14.6 (7.68)	15.6 (6.36)	t = 2.12, d.f.=16, *P* = 0.95	22.6 (6.90)	12.5 (3.74)	t = 0.31, d.f.= 32, *P* = 0.04
% cover of dicot weeds	6.57 (2.03)	3.05 (0.63)	t = 2.23, d.f.=10, *P* = 0.11	12.2 (3.02)	6.34 (0.99)	t = 2.04, d.f.= 31, *P* = 0.24
n =	9	9		22	22	

Table 2.2 *Mean percentage cover (+ SE) of plants in beetle banks and field margins, from 1999 summer sampling data, and the % of those sites that contain each species*

Species	Mean % cover of this sp. in beetle banks (+SE)	% of beetle banks with this sp.	Mean % cover of this sp. in field margins (+SE)	% of field margins with this sp.
Grasses:				
Agrostis gigantea	**1.32** (0.97)	27.37	0.15 (0.14)	4.55
Agrostis stolonifera	0.48 (0.47)	9.09	**7.45** (2.55)	72.73
Alopecurus myosuroides	0.24 (0.23)	13.64	0.04 (0.04)	9.09
Arrhenatherum elatius [1]	**3.82** (2.01)	59.09	**17.98** (3.73)	95.45
Bromus mollis	0.05 (0.03)	27.27	0.05 (0.04)	22.73
Bromus sterilis	**7.93** (5.21)	50.00	**2.25** (1.13)	63.64
Dactylis glomerata [1]	**34.19** (5.66)	90.91	**2.57** (0.67)	86.36
Elymus repens	**6.81** (2.70)	59.09	**5.91** (1.94)	100.00
Festuca rubra	**12.31** (4.06)	45.55	0.94 (0.56)	45.45
Holcus lanatus [1]	**1.04** (0.46)	36.36	**3.12** (1.77)	27.27
Lolium perenne	0.91 (0.57)	40.91	**3.14** (1.55)	63.64
Phleum bertelonii	0.26 (0.16)	13.64	0.91 (0.81)	27.27
Poa trivialis	**1.50** (0.60)	68.18	**5.05** (1.36)	95.45
Woody plants:				
Clematis vitalba	0.21 (0.14)	13.64	0.91 (0.36)	40.91
Hedera helix	0	0	**3.43** (1.29)	54.55 #
Prunus spinosa	0	0	0.81 (0.30)	54.55 #
Rosa canina	0.002 (0.002)	4.55	0.10 (0.06)	27.27
Rubus fruticosus	0	0	**2.95** (1.23)	68.18 #
Herbaceous plants:				
Anthriscus sylvestris	0	4.55	0.66 (0.44)	59.09
Arctium lappa	0.07 (0.04)	13.64	1.07 (0.47)	27.27
Artemisia vulgaris	0.20 (0.14)	13.64	0.29 (0.15)	22.73
Cirsium arvense [2]	**3.25** (0.97)	63.64	**1.00** (0.31)	72.73
Cirsium vulgare [2]	0.25 (0.12)	27.27	0.74 (0.55)	27.27
Convolvulus arvensis [2]	0.37 (0.21)	27.27	**2.12** (0.65)	68.18
Galium aparine [2]	0.41 (0.15)	59.09	**1.92** (0.75)	59.09
Geranium dissectum	0.11 (0.06)	36.36	0.02 (0.01)	13.64
Glechoma hederacea	0.03 (0.03)	4.55	**2.41** (0.99)	54.55
Heracleum sphondylium	0.13 (0.11)	13.64	**4.67** (1.15)	72.73
Lamium album	0.01 (0.01)	4.55	0.10 (0.05)	31.82
Lapsana communis [2]	0.02 (0.01)	9.09	0.04 (0.02)	22.73
Myosotis arvensis	0.03 (0.02)	22.73	0.06 (0.04)	18.18
Papaver rhoeas [2]	0.82 (0.75)	22.73	0.12 (0.12)	4.55
Ranunculus repens	0.17 (0.17)	4.55	0.41 (0.29)	22.73
Rumex obtusifolius	0.16 (0.08)	18.18	0.30 (0.11)	31.82
Senecio jacobaea	0.54 (0.25)	40.91	0.01 (0.01)	9.09
Sonchus arvensis [2]	0.18 (0.10)	22.73 #	0	0
Stachys sylvatica	0	0	0.16 (0.07)	27.27 #
Taraxacum officinale [2]	0.13 (0.07)	18.18	0.15 (0.10)	18.18
Torilis japonica	0.25 (0.25)	4.55	**6.30** (3.63)	54.55
Urtica dioica	0.19 (0.11)	13.64	**7.87** (1.94)	77.27

nos. in **bold** = more than 1% mean cover # spp. only found in that habitat alone

[1] tussock-forming species; [2] important nectar-providing species

Only those species that were found in > 20% of beetle banks and/or field margins are included. (n = 22 for each habitat).

Figure 2.2 *The mean number of plant species(S) found growing in beetle banks, using quadrat cover assessment, against age of bank in years, from 1998 and 1999 summer sampling. (y = 1.64x + 0.63)*

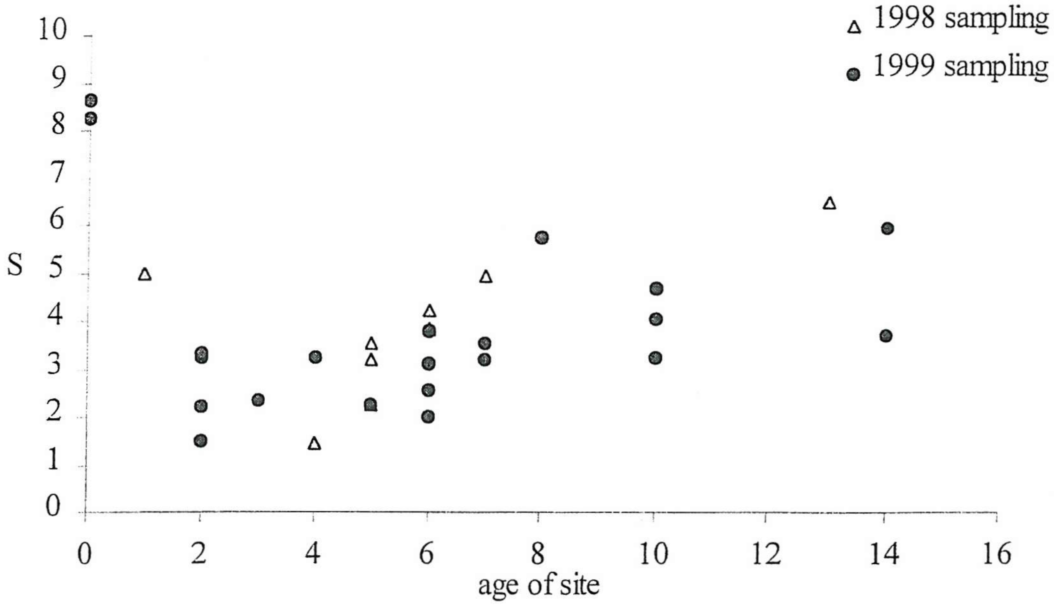


Figure 2.3 *Mean Shannon-Wiener vegetational diversity (H') of beetle banks, against age of bank in years, from 1998 and 1999 summer sampling. (y = 7.41x + 1.89)*

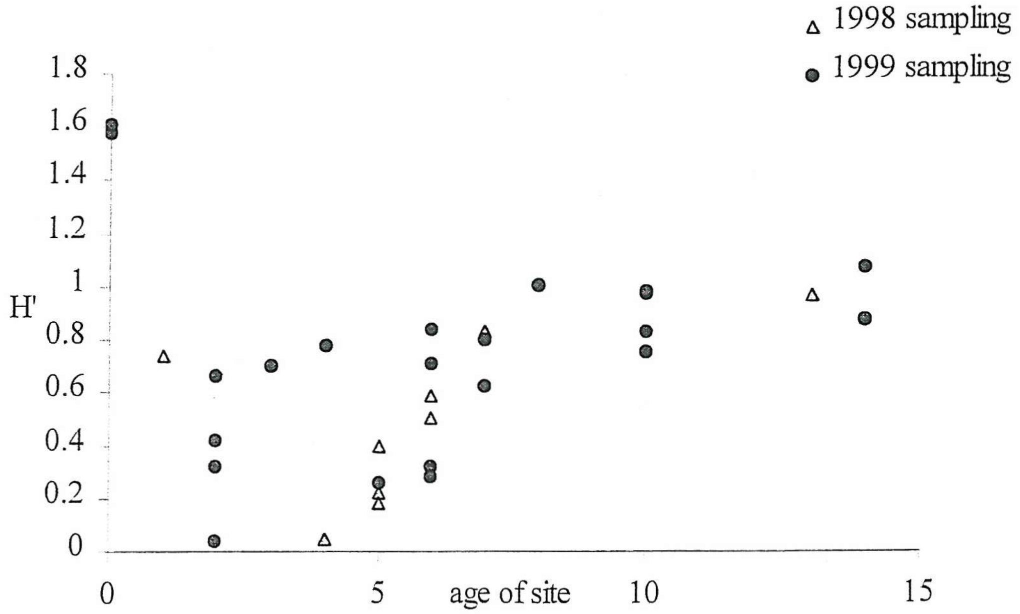


Figure 2.4 *Proportion of herbaceous species with different life history strategies in beetle banks of different ages, 1998 summer sampling*

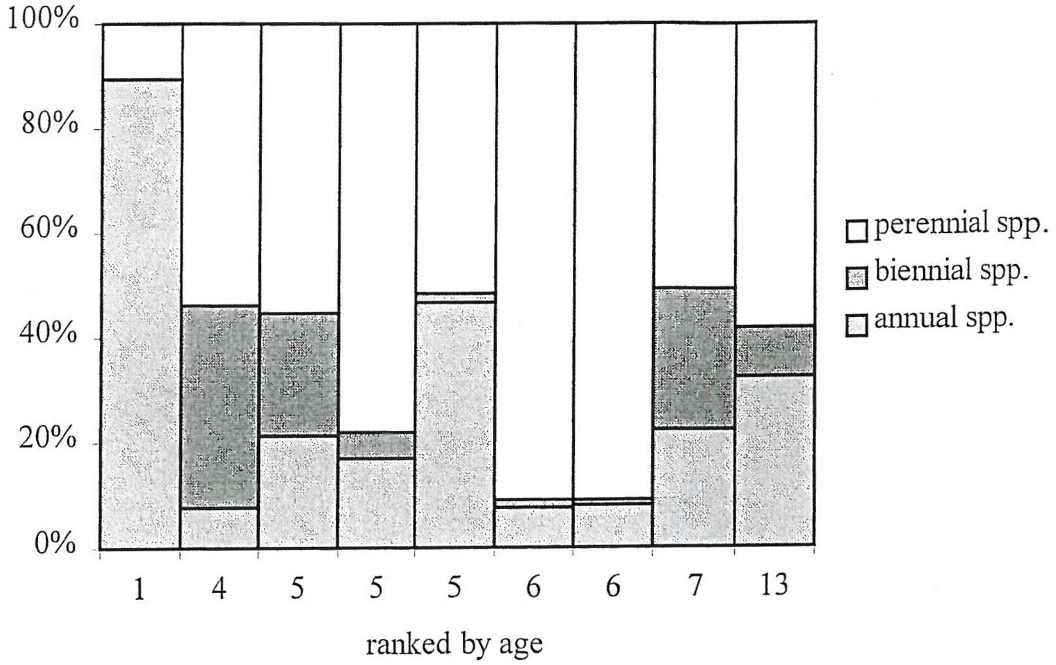
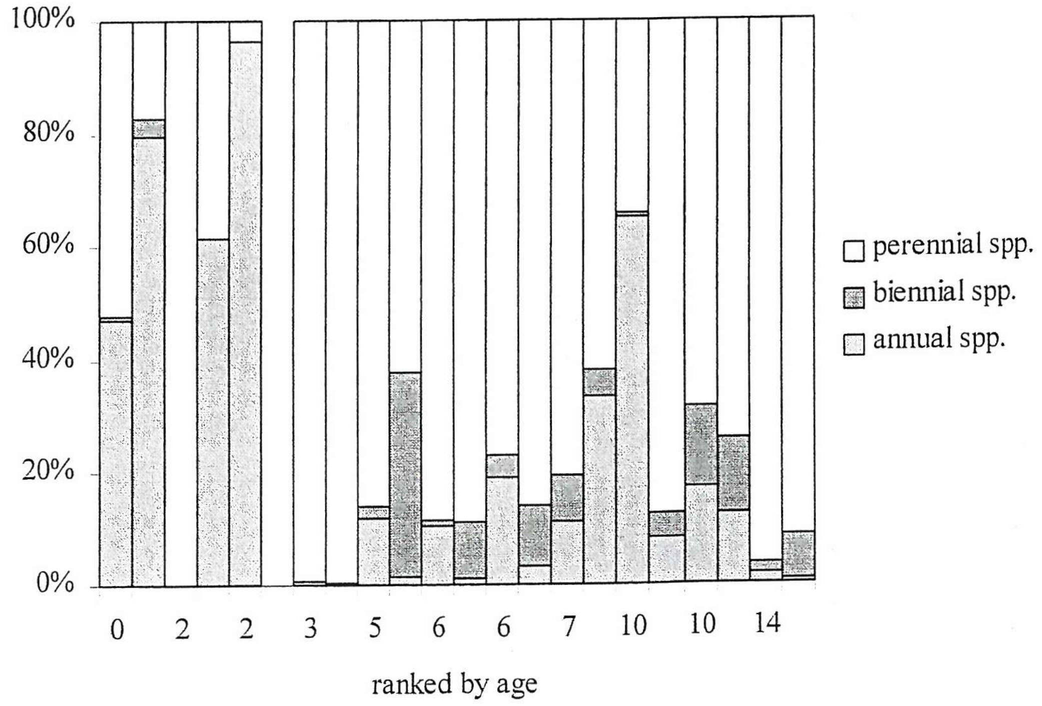


Figure 2.5 *Proportion of herbaceous species with different life history strategies in beetle banks of different ages, 1999 summer sampling*



2.4.2 Winter vegetation

Overall plant cover was high on all sites during winter, and there was no significant difference between beetle banks and margins (Table 2.3). Significantly more grass tussock was present in beetle banks than in margins (Table 2.3), although the overall amount was not particularly high, and was variable between fields (Figure 2.6). Linear regression analysis found no relationship between bank age and tussock cover ($r^2 = 0.26$, $F_{1,8} = 2.49$, $P = 0.16$). Neither plant litter nor moss cover differed between habitat types.

A total of 20 plant species was recorded in beetle banks, 33 in the field margins; the mean species richness of banks being significantly lower than that of field margins during the winter (Table 2.3). Many more species were found exclusively in field margins than had been the case over the summer (Table 2.4). Only *Senecio jacobaea* (common ragwort) was found exclusively in beetle banks, although there was little of it present at this time. No woody plants were recorded in the beetle bank sites examined.

As for summer vegetation, there was a significant positive relationship between plant species richness and age of beetle banks in winter (Figure 2.7) ($r^2 = 0.82$, $F_{1,8} = 31.3$, $P <$ 0.001).

Table 2.3 *Mean percentage cover (+ SE) of different categories of vegetation in beetle banks and field margins sampled in winter, with results of t-tests between habitat type*

mean (+ SE)	beetle banks	field margins	
number of species present	2.51 (0.46)	5.29 (0.49)	t = 2.12, d.f. = 16, $P < 0.001$
total vegetational cover	79.75 (4.01)	86.42 (2.59)	t = 2.12, d.f. = 16, $P = 0.18$
% grass cover	20.24 (3.07)	30.76 (5.56)	t = 2.26, d.f. = 9, P =0.02
% tussock cover (live & dead grass)	25.14 (6.36)	5.29 (1.81)	t = 2.31, d.f. = 8, P =0.03
% dead plant litter	35.47 (2.91)	29.91 (5.76)	t = 2.18, d.f. = 12, P =0.41
% woody cover	0	10.21 (3.95)	t = 2.31, d.f. = 8, P =0.03
% herbaceous cover	1.37 (0.52)	10.46 (3.82)	t = 2.31, d.f. = 8, P =0.04
% moss	12.41 (6.34)	7.51 (3.67)	t = 2.12, d.f. = 16, P =0.51
n =	9	9	

Table 2.4 *Mean percentage cover (+ SE) of plants in beetle banks and field margins, from 1999 winter sampling data, and the % of those sites that contain each species*

Species	Mean % cover of this sp. in beetle banks (+SE)	% of beetle banks with this sp.	Mean % cover of this sp. in field margins (+SE)	% of field margins with this sp.
Grasses:				
Agrostis gigantea	0.18 (0.18)	11.1	**1.43** (0.85)	77.8
Agrostis stolonifera	0.18 (0.16)	22.2	**4.18** (2.34)	77.8
Arrhenatherum elatius	0.06 (0.06)	11.1	**7.25** (3.00)	88.9
Dactylis glomerata	**13.1** (2.75)	100	**1.06** (0.28)	77.8
Elymus repens	**4.26** (2.85)	22.2	**2.78** (0.91)	66.7
Festuca rubra	0	0	0.89 (0.74)	44.4 #
Holcus lanatus	0.48 (0.43)	22.2	**2.78** (2.65)	33.3
Poa trivialis	**1.70** (0.87)	88.9	**12.87** (4.13)	100
Woody plants:				
Hedera helix	0	0	**9.37** (3.63)	66.7
Rubus fruticosus	0	0	0.84 (0.54)	44.4
Herbaceous plants:				
Anthriscus sylvestris	0	0	**5.21** (3.47)	66.7 #
Cirsium arvense	0.36 (0.18)	66.7	0.16 (0.12)	33.3
Cirsium vulgare	0.05 (0.02)	44.4	0.01 (0.01)	11.1
Galium aparine	0.19 (0.11)	55.6	0.44 (0.25)	66.7
Glechoma hederacea	0.13 (0.13)	11.1	0.29 (0.14)	66.7
Heracleum sphondylium	0	0	0.53 (0.34)	66.7 #
Lamium album	0	0	0.14 (0.07)	33.3 #
Ranunculus repens	0.02 (0.02)	11.1	0.99 (0.62)	33.3
Rumex obtusifolius	0.08 (0.07)	22.2	0.12 (0.07)	44.4
Senecio jacobaea	0.17 (0.09)	33.3 #	0	0
Stachys sylvatica	0	0	0.38 (0.34)	33.3 #
Taraxacum officinale	0.01 (0.01)	11.1	0.14 (0.13)	22.2
Urtica dioica	0	0	1.05 (0.45)	55.6 #

nos. in **bold** = more than 1% mean cover # spp. only found in that habitat alone

Only those species that were found in more than 20% of beetle banks and/or field margins are included. (n = 9 for each habitat).

Figure 2.6 *Mean percentage cover of tussock grass present in beetle banks and field margins, from 1998-9 winter sampling*

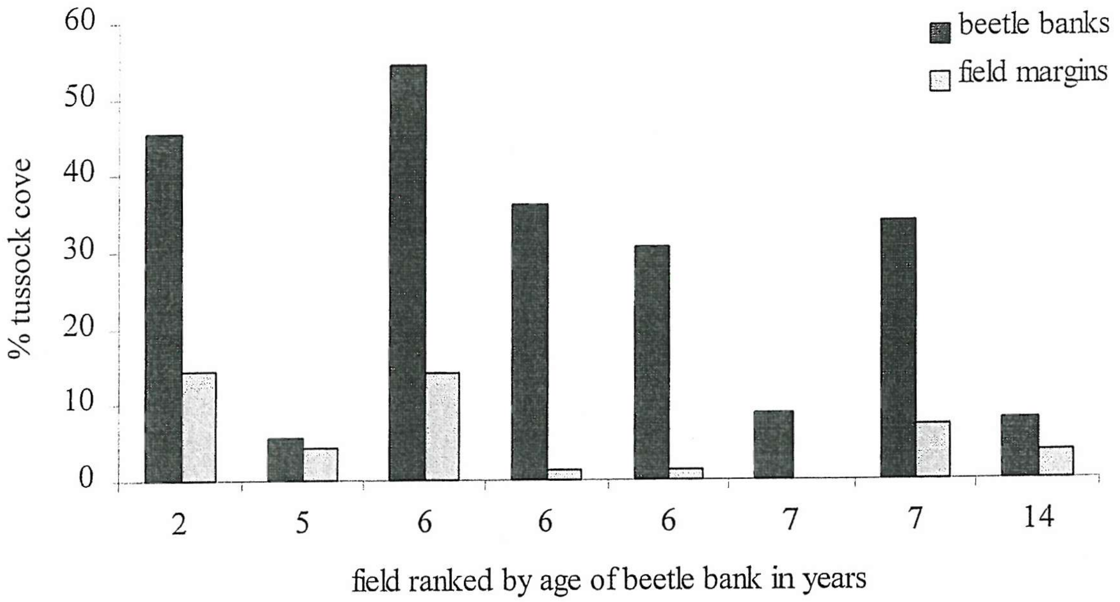
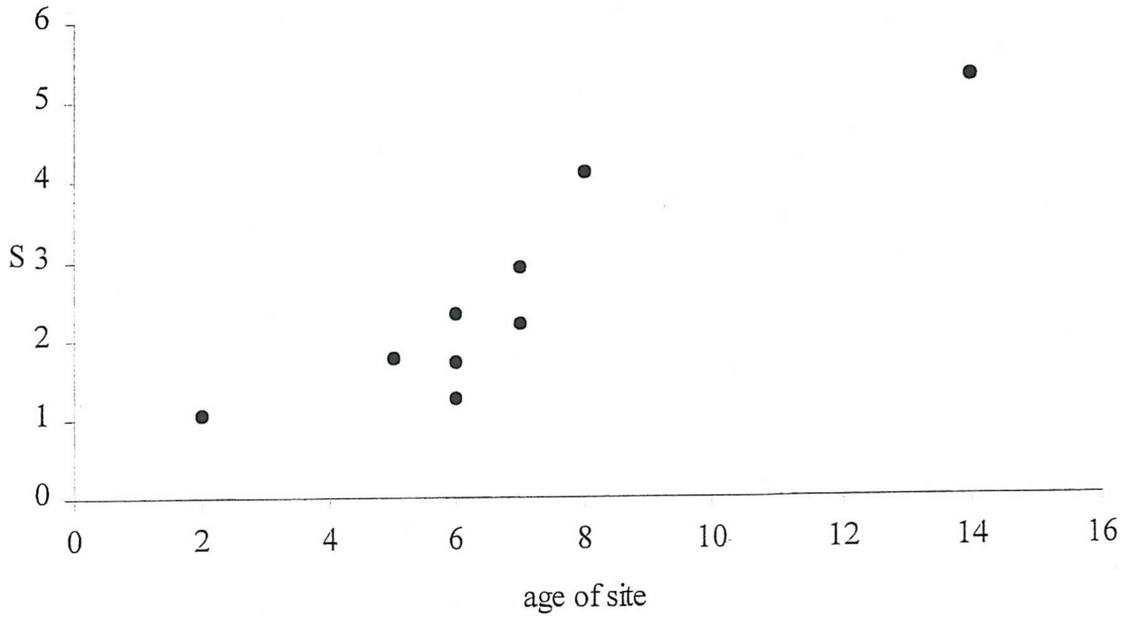


Figure 2.7 *The mean number of plant species (S) found growing in beetle banks, banks, using quadrat cover assessment, against age of bank in years, from 1998-9 winter sampling. (y = 0.395x - 0.166)*



2.5 Discussion

2.5.1 *Comparison with established margins*

Floral richness and diversity in beetle banks were lower than adjacent conventional field margins, and were highest in young and old beetle banks. Grass cover was higher in beetle banks than in margins, while herbaceous plants, including nectar-providers, and woody plants were more abundant in field margins. These patterns were consistent across sample years and across seasons. The disturbance when a bank is created is expected to cause many dormant weed seeds in the fertile, mid-field soil to germinate. After establishment, competitive exclusion of these ephemeral weeds by sown perennial grass takes place, with gradual colonisation by more competitive species as in any sown grassy sward (e.g. Crothers, 1991; Gathmann *et al.*, 1994). The comparatively low abundance of herbaceous plants and nectar sources suggests that beetle banks probably support fewer invertebrate species; oldest banks, however, were approaching levels of diversity found in field margins. Invasion by woody plant species indicates that through succession, beetle banks may develop a composition similar to hedgerows. Grass stands containing cock's-foot are suggested to decline and require reseeding after a decade (Crothers, 1991). Tussocks are reported to decay through reduced panicle production and competitive ability after this length of time (Luff, 1965), so that overall cover declines and other plants are able to invade.

2.5.2 *Weed development and control*

Weed cover was not significantly different between beetle banks and margins, but often was at a level that could cause the farmer to perceive a risk to the crop. Smith *et al.* (1999) found that uncropped arable field edges managed to enhance biodiversity were very unlikely to affect weed densities within the crop, particularly when sown with non-invasive perennial species. Sown beetle banks should likewise not affect the crop. Placing herbaceous strips besides hedges may limit weed ingress into arable fields, and is recommended (Boatman, 1992). Sterile strip between the field boundary or beetle bank and crop can be an extra barrier to potential invasion (Boatman & Wilson, 1988) but fewer than half of the sites examined had such strips in place. However, farmers still remain concerned about weed invasion from margins managed for biodiversity (Marshall & Moonen, 1997). The use of contact grass weed herbicides for localised wild oats, blackgrass and barren brome removal may be acceptable within local guidelines (Anon., 1999 a, b). Regular monitoring may mean that little intervention is required.

The threat to the plants on the beetle bank from within-field agrochemical applications is a concern. After normal commercial applications and in typical conditions, significant levels of pesticide spray can drift into hedgerows (Longley *et al.*, 1997; Longley & Sotherton, 1997). Beetle banks, particularly where located in the centre of fields, are even more vulnerable. Herbicide drift is known to have serious effects on plants (Marrs *et al.*, 1991; Marrs & Frost, 1997), and granular fertilisers permeating field edges also affect species composition (Tsiouris & Marshall, 1998), giving competitive advantages to invasive nitrophilous plants such as *Bromus sterilis* (sterile brome). Plant diversity was higher along unsprayed winter wheat edges compared to those treated with herbicide, and it was suggested that reduced fertiliser inputs would further increase their floristic value (de Snoo & van der Poll, 1999). Three-quarters of the field margins assessed in the present study contained *Urtica dioica* (stinging nettle), a species indicative of high soil phosphate and nitrogen levels, indicating drift may have occurred for a number of years. Although little *Urtica* was recorded on the beetle banks in the present study, the sites may be vulnerable to drift because of their mid-field location.

There is conflict between which plants constitute problematic weeds, and those that actually have some conservation value. Species such as *Cirsium arvense* (creeping thistle), *C. vulgare* (spear thistle) and *Senecio jacobaea* (ragwort) were present on many of the sites studied, but these plants require control by law. However, such species may support many invertebrate species such as moths and picture-winged flies, especially where they have been growing for an extended period of time (Ausden & Treweek, 1995). Even the presence of nettles is useful, e.g. as hosts for Nymphalid butterflies; thus it could be suggested that some weed species should be tolerated at low levels if they do not encroach the crop, for conservation benefit.

2.5.3 Deterioration as invertebrate refuges and potential limitation by management

It is unclear how the vegetational changes found may affect the suitability of beetle banks for the support of polyphagous predatory invertebrates. Tussocky grass is said to be the optimal vegetation for predators, as the buffered microclimate within it allows maximum survival in cold and wet conditions (Luff, 1965; Bossenbrek *et al.*, 1977; Desender, 1982; Thomas *et al.*, 1992). Carabid densities were positively correlated with *D. glomerata* cover by Thomas *et al.* (1992); however, this work only investigated one recently colonised site, where the extrapolated densities were highly variable and numbers of tussock clumps per unit area were recorded, rather than the overall amount present. In another study, Dennis *et al.* (1994) found greater survival of polyphagous predators in *D. glomerata* tussock plots compared with *Lolium perenne* or bare earth plots. The higher levels of tussock on the banks compared to margins examined in the present study, indicate that despite ageing and steady colonisation by other plants, these sites may remain more valuable for sheltering predatory invertebrates. However, concurrent research (Chapter 3) found variable densities of predatory invertebrates in beetle banks, not clearly correlated with the amount of tussock grass present, in either summer or winter. Indeed, Thomas *et al.* (1994) found that sown field margin strips dominated by non-tussock species provided good overwintering habitat for invertebrate survival within a year of establishment, although it is not known if such sites permanently sustain populations. Overall it seems that tussock-forming grasses are beneficial to polyphagous predators, and these grasses were more abundant in beetle banks than in field margins. There was no consistent relationship between the amount of tussock-forming grass and age of the beetle bank, despite the steady colonisation by other plants, so it would appear that beetle banks do not necessarily deteriorate over time in terms of offering a refuge for beetles.

Longer term active supervision of beetle banks may be required to provide enduring overwintering habitat quality, actions including the re-seeding of bare patches to maintain a dense sward cover, spot-treatment with an approved selective contact herbicide, or localised cutting, of specific pernicious weeds such as thistles or ragwort. Such guidance has recently become available to farmers who have established beetle banks under the Countryside Stewardship Scheme in the UK (Anon., 1999b). A regular overall cut every 2-3 years to prevent the encroachment of suckering and woody species is also suggested in grassy margins, though specifically in beetle banks this should only consist of topping the flowering sward, so as not to damage its dense bottom structure. The Game Conservancy Trust's advisory service agrees with this approach. Additionally, it is recommended that dead grass is allowed to build up to provide camouflaged cover for nesting bird species (Vickery *et al.*, 1998), and this was abundant in all sites examined in this study.

It has been reported that *H. lanatus*, suggested as an alternative to *D. glomerata*, may 'drift' from its original sowing site, and could become invasive to the crop area (Collins, 1999). Its seed costs are often considerably higher than that of *D. glomerata*, and thus its use is best avoided.

2.5.4 Value for other invertebrates

Interestingly, the active incorporation of wildflower seed into tussock grass mixes for sowing on beetle banks has been suggested, to specifically provide resources for bumblebees, parasitoids, hoverflies and butterflies. Whether this diminishes the habitat suitability for overwintering invertebrates, or beetle bank longevity is unknown. Further long term study of this are needed to evaluate the viability and management implications of such practice

2.5.5 Conclusions

In summary, beetle banks retain a vegetational structure that is a suitable refuge for predatory invertebrates for over a decade at least. They also support a steadily increasing floral diversity, which it seems reasonable to tolerate so long as dense vegetational ground cover needed to provide good overwintering conditions is sustained. They do support some weed species but no more than conventional field margins, and these may be controlled by simple measures. Given that beetle banks are very cheap to establish, they do appear to offer a practical and simple means of dividing fields and enhancing farmland biodiversity.

3. Beetle banks as refuges providers for polyphagous predators

Presented as oral paper 'The refuge role of beetle banks and field margins for Carabidae on UK arable farmland: densities, composition and relationships with vegetation', at the X European Carabidologists Meeting, Tuczno, Poland, 24-27/9/01; and under submission as a proceedings paper.

Presented as oral paper *'Beetle banks are valuable for maintaining beneficial invertebrate densities and diversity on farmland'*, at the British Ecological Society Winter Meeting, Leeds, 20-22/12/1999.

Findings outlined in '*Beetle bank ecology*' S. Thomas (2000). *The Game Conservancy Review of 1999,* **31**, 86-87.

3.1 Abstract

In early work on beetle banks, tussocky grasses such as *Dactylis glomerata* were shown to be important habitats for aphid-specific predatory invertebrates. Subsequent maturation of such tussocks could have an effect on the ability of beetle banks to shelter overwintering invertebrates in the long-term, and so either increase or reduce their value in integrated biological control. However, initial studies did not consider such possible changes. This study aimed to discover whether densities reported in newly-created banks are sustained in sites that have been established for several years; and additionally how these compare to typical, conventionally-managed field margins. It also aimed to examine community composition within the sites. Soil and surface sampling was carried out on a range of beetle banks of different ages. Polyphagous predator densities ranged widely, but tended not to be different from those of conventional field margins. Older beetle banks contained more predators per m^2 and in particular, densities of 'boundary overwintering' Carabidae increased though time. Unexpectedly, 'open field' species did not decline as had been noted in earlier studies. Overall, densities of predators were comparable with results from these other studies, suggesting that beetle banks remain valuable habitats for polyphagous predators for a number of years. Comparison of the results from earlier work suggests that exceptionally high populations occasionally recorded following beetle bank establishment are not usually supported when longer-term patterns of predator density in overwintering sites are examined.

Predator diversity was low in all overwintering sites, although beetle species richness was found to increase with age. Patterns found over the winter were generally sustained into the spring and summer, with usually few major differences in predator densities and diversity between habitat type. The study site possibly represented an atypical farm, with the creation of beetle banks concurrent with good field margin management, no doubt contributing to the similarities between habitats measured here.

Low diversity suggests that only a limited number of species are available for potential spring biocontrol in the crop, thus it is important that overwintering conditions encourage maximum predator survival. Simple prescriptions such as beetle bank creation can contribute greatly to enhancing the levels of predators available in arable fields.

The dense vegetation in beetle banks buffered temperatures not only through extremes of cold in winter, but also through the remainder of the season.

3.2 Introduction

Overwintering predator densities were assessed in the first beetle banks soon after their creation, in order to evaluate whether the design could provide an alternative to conventional hedge bases in augmenting polyphagous predators within large arable fields. The first banks were established on the Leckford Estate, Hampshire during spring 1987 by sowing experimental mixtures of grasses onto prepared soil banks, but unfortunately have now been removed. The main conclusion from the first three years work on these habitats, reported by Thomas *et al.* (1991 & 1992c) was that tussocky grasses such as *Dactylis glomerata* were shown to be very important habitats for aphid-specific predators such as *Demetrias atricapillus, Forficula auricularia* and *Tachyporus chrysomelinus*. The subsequent growth and maturation of *D. glomerata* tussocks (Luff, 1965) could have an effect on the ability of such beetle banks to shelter overwintering invertebrate populations in the long-term, and so either increase or reduce their value in integrated biological control. However, these initial studies did not consider such possible changes. The provision of beetle banks on farmland received considerable attention following the development of the design and is currently promoted by The Game Conservancy Trust, Farming and Wildlife Groups (FWAG) and MAFF, the latter giving financial support (Anon., 1999a & b). Therefore it is important to study such newly created habitats over longer time periods to determine whether conclusions drawn from data collected during the early stages are maintained in later years (MacLeod, 1994).

3.2.1 Aims of study

This study aimed to discover whether densities reported in newly created banks are sustained in sites that have been established for longer lengths of time; and additionally how they compare to typical field margins. I also aimed to evaluate species diversity within the sites to establish if this changed with age, an aspect that had not been considered in previous studies.

3.3 Materials and methods

3.3.1 Study sites

The assessment of polyphagous predator density and diversity was carried out on beetle banks and field margins on the slightly flinty calcareous silty clay loam soils of a north Hampshire estate, UK (map reference: SU 593534).

Five beetle banks, ranging in age from 1-2, 5-6, 6-7, 7-8 and 13-14 years since establishment were chosen, of variable aspect and condition. Each was paired with a typical, permanently established field margin also bordering the field adjacent to the beetle bank. Field margins selected were raised grassy or herbaceous banks, which in some cases also contained shrubs at the apex of the bank, i.e. could be full hedgerows.

3.3.2 Invertebrate sampling methods

Following methods by Thomas (1991) and MacLeod (1994), destructive sampling was carried out at seasonal intervals, including winter 1997-8 (January & February), spring (within May emergence period), summer (August) and winter 1998-9 (February). Sample points were randomly selected along the ten sites by blind-throwing a quadrat from the previous sampling location. Surface-active fauna was removed with a Ryobi vacuum suction-sampler (Stewart & Wright, 1995) over an area of 20cm^2, and collected into a labelled polythene bag (Plate 3.1). A turf sample of this area, to a depth of approximately 20cm, was then immediately removed by spade and placed into a separate labelled bag (Plate 3.2). A review of sampling methodologies used in similar research suggested that sod depth is an important factor with respect to overwintering Coleoptera. Some species of Carabidae can be found as low as 35cm (Dennis *et al.* 1994), although other research has found few lower than 5cm (Kennedy 1994), hence the generous depth allocation used here.

Ryobi samples were frozen, and turf samples were kept in cold storage at 4°C to inhibit predation, prior to sorting. All invertebrates present were removed and stored in 70% alcohol, before identification to species for Carabidae and Staphylinidae families, and to family for Araneae. In some cases, 'species groups' were used because of difficulties of identification and time-constraints, for example, '*Aleochara*' and '*Xantholinus* spp'. Carabid and Staphylinid larvae were separated, but not identified to species. Data from both sampling methods were pooled together, to compare absolute density per unit area.

Plate 3.1 *Using the Ryobi vacuum suction-sampler to remove invertebrates active on the soil surface of a beetle bank*

Plate 3.2 *Examination of a turf sample cut from a beetle bank*

Shannon-Wiener diversity (H') was calculated using numbers of individuals per species for each of the three major taxonomic groups Carabidae, Staphylinidae and Araneae. The index was chosen as it provides a useful method of comparing between sites and habitats, especially where a number of replicates have been taken (Magurran, 1988). If calculated for a number of samples, the indices are normally distributed, allowing parametric statistics (Magurran, 1988). Also, being widely used, it facilitates comparison with other studies, although results need to be considered with respect to the identification approach, where not every individual species had always been recorded. Additionally, beetle bank Carabidae were categorised into 'boundary' species (those mainly dependent on field boundary habitats as overwintering refuges, e.g. *Agonum dorsale*, *Asaphidion flavipes*, *Bembidion lampros*, *Demetrias atricapillus*) and 'open-field' species (those that are often found in field centres throughout winter, e.g. *Bembidion obtusum*, *Notiophilus biguttatus*, *Pterostichus madidus*, *Trechus quadristriatus*) (Sotherton, 1984, 1985; Thomas, 1991; refer to Table 4.1). This could indicate if there were any age-related changes in the community structure within the beetle banks, in terms of the proportion of these carabids.

3.3.3 Sample size evaluation

Between 12 to 15 samples were taken at each location. Preliminary work to quantify the optimal sample size to use followed methods described in Chapter 2. Results indicated that the cumulative running mean and standard error as proportion of the mean showed little variation beyond this range, in keeping with results from similar methodology assessments carried out by Dunkley (1997; personal communication).

3.3.4 Analysis

For overwintering data, two-way ANOVAs (GMAV5 for Windows; Underwood & Chapman, 1998) were performed to compare differences in predator densities and diversities, for each taxonomic group. Sample year and type of habitat were set as the two fixed factors. All data was log (x + 1) transformed to increase homogeneity of variance, which was tested by Cochran's test. For spring and summer densities and diversities, a one-way ANOVA was performed for each predator group to examine differences between habitat, following transformation as before. Linear regression was performed on the combined data from both winters to examine any relationships between both overwintering predator densities per m^2 (transformed data) and predator diversity, and age of beetle bank.

3.4 Results

3.4.1 Overwintering Carabidae densities

Carabidae densities in the overwintering sites ranged from around 200 to 300 per m^2 (Figure 3.1). There was no significant difference between the overall density of Carabidae in either sampling year ($F_{1, 296} = 3.76$, $P = 0.053$) or habitat types ($F_{1, 296} = 0.02$, $P = 0.891$), and the interaction was not significant ($F_{1, 296} = 0.01$, $P = 0.94$).

Species composition remained highly similar between the two habitats within the same year (Figure 3.1), although differed slightly between years. *Bembidion lampros* strongly dominated catch, and was especially abundant in the second year, in both beetle banks and field margins. *Amara* species were frequently caught in the first sampling year, but were less abundant in the second. *Demetrias atricapillus* was another highly abundant species, with a very consistent capture. With the exception of *Harpalus* species, few large body-sized species were captured.

A weak positive relationship between Carabidae density and age of bank was shown ($r^2 = 0.38$, $F_{1, 8} = 4.97$, $P = 0.06$).

A trend for increasing densities of 'boundary-type' (Thomas, 1991) carabids per m^2 was indicated, with increasing age of beetle bank sampled ($r^2 = 0.40$, $F_{1, 8} = 5.31$, $P = 0.05$), as might have been predicted. However, in contrast with the limited evidence presented by other workers, there was no decline in the mean density of 'field-type' species per m^2; in fact, there was a weak trend for their densities to also increase with age ($r^2 = 0.25$, $F_{1, 8} = 2.63$, $P = 0.14$) (Figure 3.2).

Figure 3.1 *Carabidae densities in refuge habitats, sampled winter 1997-99, indicating composition of numerically important species*

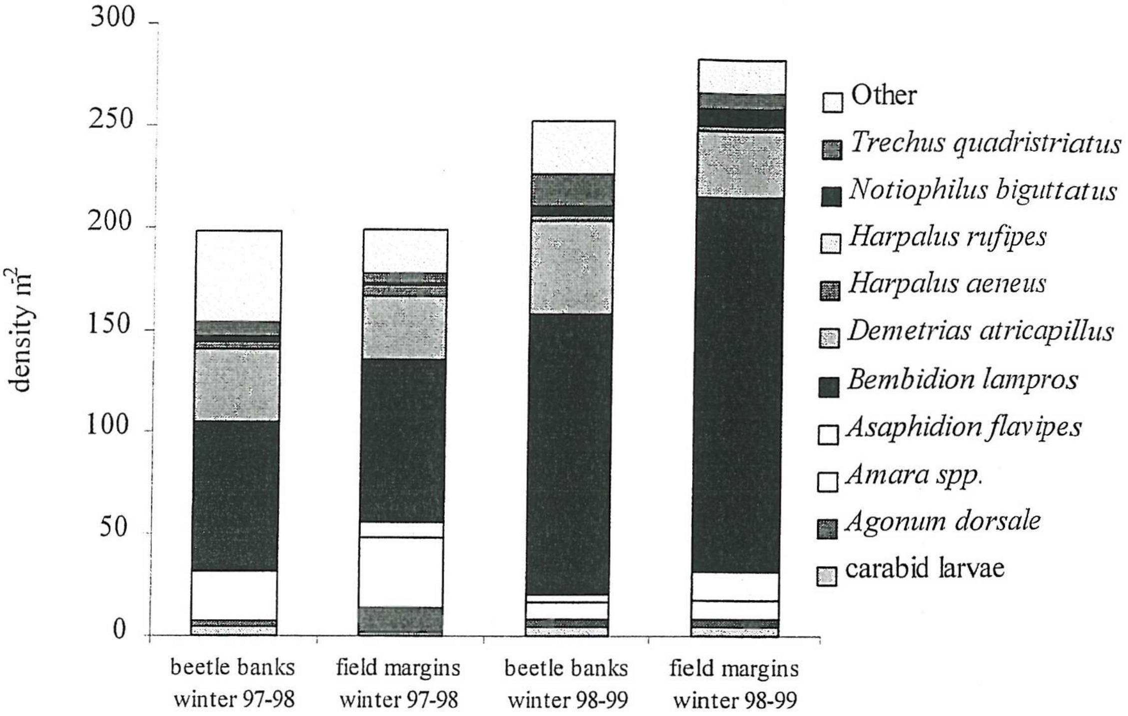
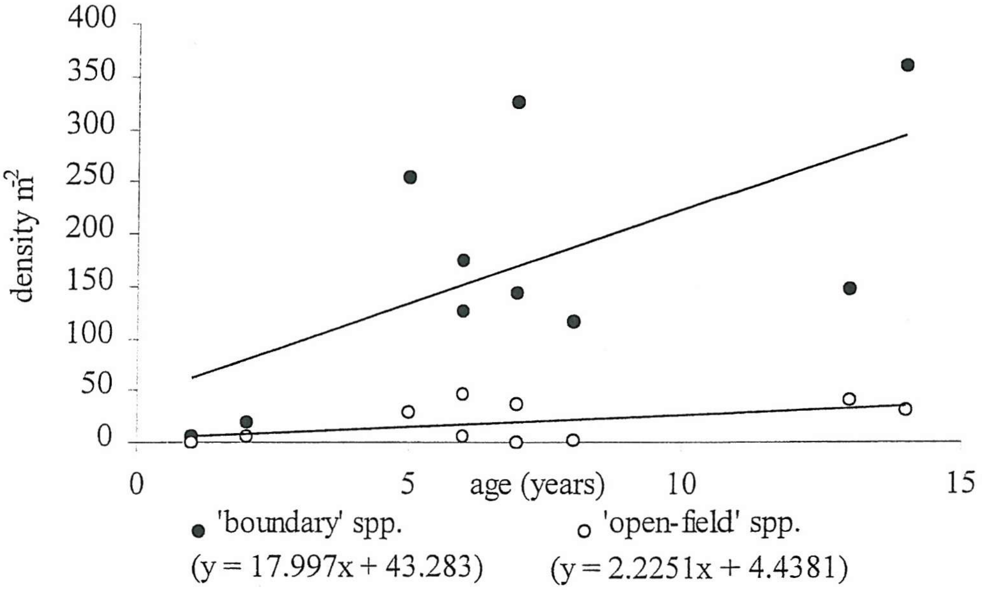


Figure 3.2 *Mean overwintering densities of 'boundary' or 'open-field' Carabidae species in beetle banks of increasing age, with linear regression lines*



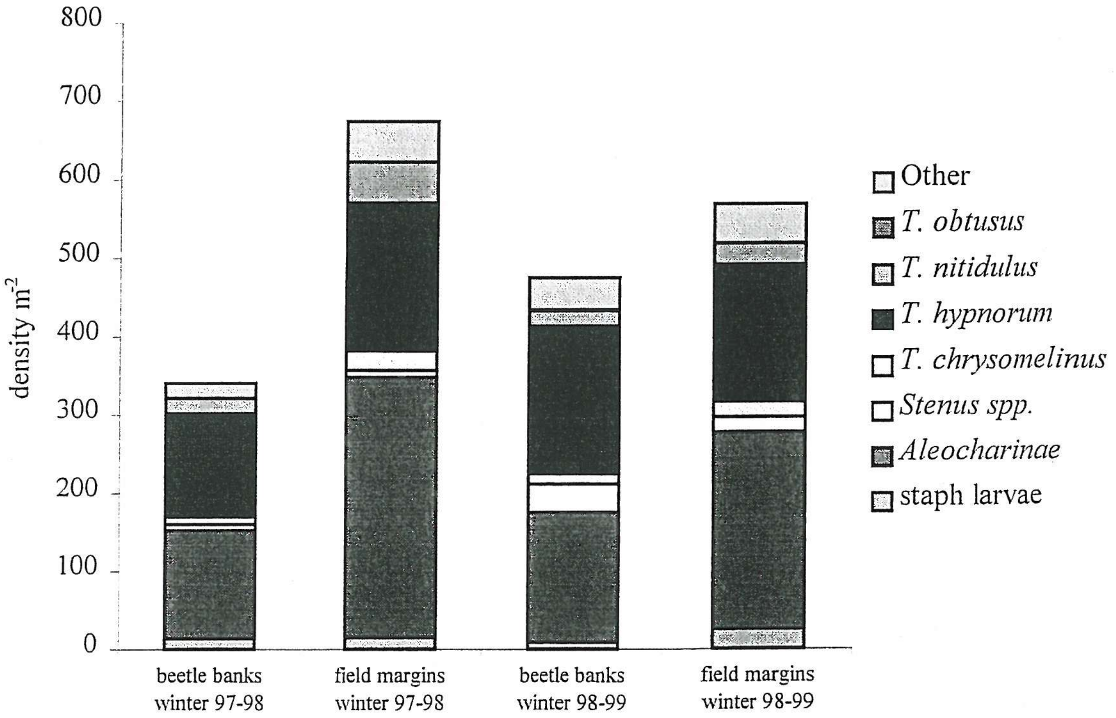
3.4.2 Overwintering Staphylinidae densities

Staphylinidae density was significantly lower in beetle banks compared to field margins ($F_{1,296} = 32.9$, $P < 0.001$), and although not different between years ($F_{1,296} = 0.92$, $P = 0.339$), resulted in a significant interaction between year and habitat ($F_{1,296} = 6.27$, $P = 0.013$). *A posteriori* tests indicated the interaction was attributable to the first year of sampling.

Composition was very consistent between habitats and across sampling years. *Tachyporus* species accounted for nearly half of all capture, with the Aleocharinae family of small staphs of similar high abundance (Figure 3.3). *T. hypnorum* was the most numerically dominant species overall.

Staphylinidae density did not indicate a linear relationship with beetle bank age ($r^2 = 0.006$, $F_{1,8} = 0.05$, $P = 0.83$), although there was a trend for density to be greatest in banks of medium age, though lower in very young or old sites. A better fit was indicated by the polynomial equation $y = -9.8983x^2 + 157.16x - 53.569$, which produced $r^2 = 0.7123$.

Figure 3.3 *Staphylinidae densities in refuge habitats, sampled winter 1997-99, indicating composition of numerically important species*



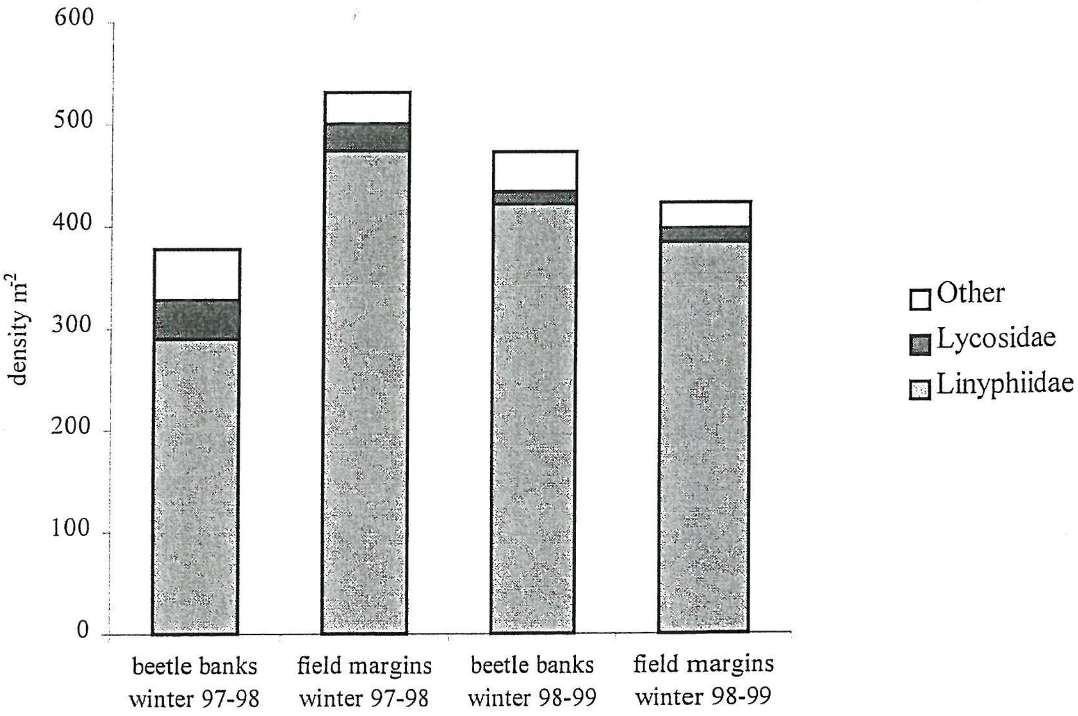
3.4.3 Overwintering Araneae densities

The year × habitat interaction was significant for Araneae ($F_{1, 296} = 4.5$, $P = 0.035$), and again attributable to slightly lower densities in beetle banks in the first sampling year following *a posteriori* tests. Overall, however, there was no difference between year ($F_{1, 296} = 3.09$, $P = 0.08$) or habitat type ($F_{1, 296} = 4.5$, $P = 0.933$) for Araneae.

The Linyphiidae strongly dominated capture composition, and were at the highest densities in field margins in the first sampling year. Low densities per m^2 of Lycosidae were recorded. Other spiders, many of which may be indiscriminate predators on both crop pest species and other beneficials, and included families such as the Tethragnathidae, were captured in very low numbers and thus grouped together as 'others' (Figure 3.4).

Araneae densities did not show any increase with beetle bank age ($r^2 = 0.12$, $F_{1, 8} = 1.07$, $P = 0.33$).

Figure 3.4 *Araneae densities in refuge habitats, sampled winter 1997-99*

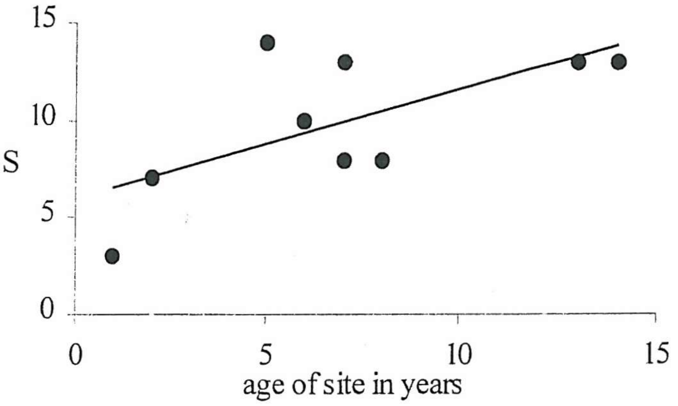


3.4.4 *Overwintering polyphagous Coleopteran diversity*

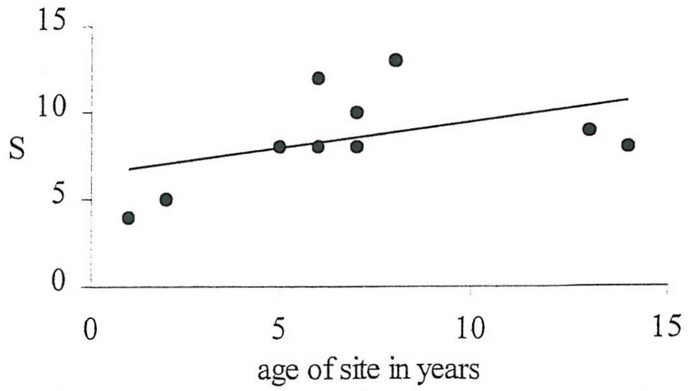
Both Carabidae and Staphylinidae species richness increased with beetle bank age (Figure 3.5), although this trend was only significant for the Carabidae. For each family, there was no significant difference between mean S of beetle banks and conventional field margins (Carabidae: $t_{18} = 2.10$, $P = 0.76$; Staphylinidae: $t_{18} = 2.10$, $P = 0.11$). Beetle banks contained a total of 22 carabid species in 1997-98 and 19 in 1998-99, with field margins containing 19 and 15 respectively. Totals of 11 and 15 species of staphylinid were found per sampling year in beetle banks, with 17 and 16 respectively in field margins.

Figure 3.5 *Overwintering predatory Coleopteran species richness (S) in beetle banks*

a) Carabidae: $R^2 = 0.44$; $F_{1,9} = 6.37$, $P = 0.04$; $y = 0.5618x + 6.0235$



b) Staphylinidae: $R^2 = 0.21$; $F_{1,9} = 2.08$, $P = 0.19$; $y = 0.3041x + 6.4016$



The Shannon-Wiener Index produced diversity values between 0.64 to 1.15 for the predatory groups in both habitats and years (Figures 3.6 and 3.7). There was no significant difference in Carabidae diversity between sampling years and habitats ($F_{1,296} = 0.14$, $P = 0.708$; $F_{1,296} = 2.96$, $P = 0.087$ respectively) and the interaction was not significant ($F_{1,296} = 0.58$, $P = 0.445$).

Diversity of Staphylinidae was significantly lower in beetle banks ($F_{1,296} = 21.7$, $P < 0.001$), although this did not vary between years ($F_{1,296} = 1.09$, $P = 0.297$) and the interaction was not significant ($F_{1,296} = 0.25$, $P = 0.615$).

Conversely, Araneae diversity was significantly lower in field margins ($F_{1,296} = 8.02$, $P < 0.01$), but did not vary between years ($F_{1,296} = 0.55$, $P = 0.458$) nor was the interaction significant ($F_{1,296} = 5.1$, $P = 0.476$).

Predator diversities did not indicate any relationships with age of beetle bank.

Figure 3.6 *Mean (+ SE) Shannon-Wiener diversity of predators in refuge habitats, sampled winter 1997-98*

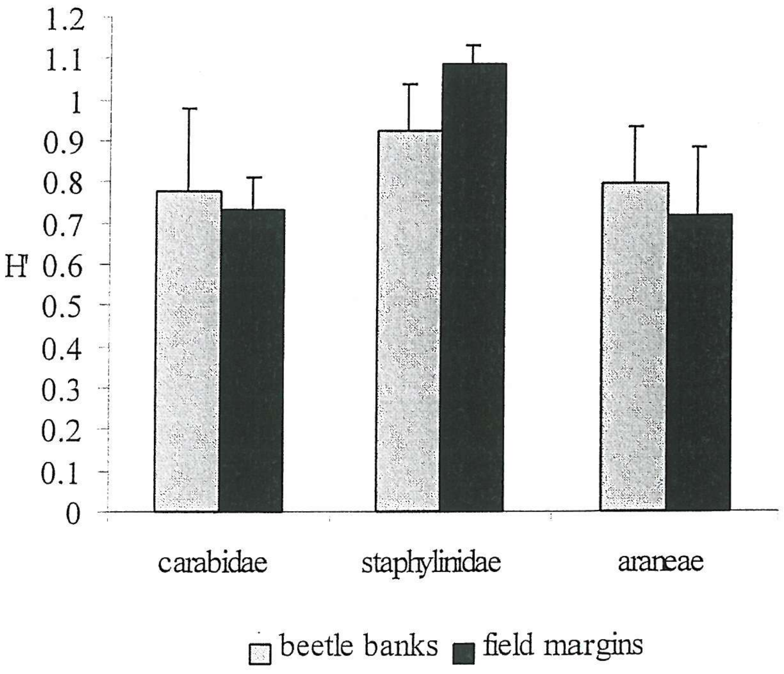
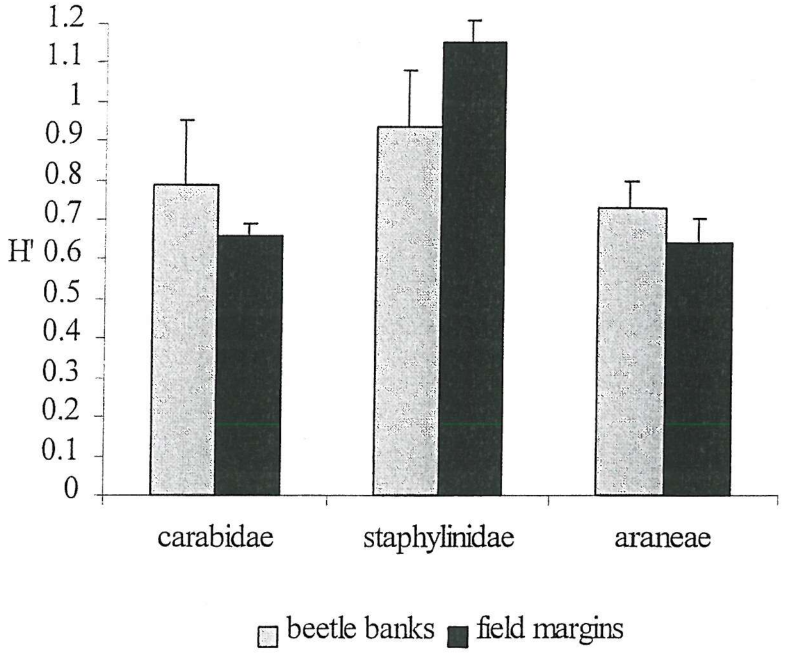


Figure 3.7 *Mean (+ SE) Shannon-Wiener diversity of predators in refuge habitats, sampled winter 1998-99*



3.4.5 Spring predator density and diversity

Polyphagous predator densities that were found in the beetle banks and field margins ranged from around 20 to 270 individuals per m^2. There were significantly greater numbers of Carabidae in beetle banks compared to field margins ($F_{1, 118} = 5.59$, $P = 0.002$). Staphylinidae and Araneae density did not significantly differ between habitat type ($F_{1, 118} = 1.39$, $P = 0.241$and $F_{1, 118} = 0.58$, $P = 0.446$, respectively).

Carabidae composition in spring had changed from that of winter, with far fewer *B. lampros*, and many more larvae, especially so in the beetle banks. There were a large cumulative number of carabids not recognised as particularly important crop pest predators, which resulted in a predominance of the 'other' species category (Figure 3.8). The capture of different Staphylinidae species was very similar between beetle banks and field margins, and again the majority of these were from the Aleocharinae family. *T. hypnorum* was numerically dominant in beetle banks, but there was a more even capture of all *Tachyporus* species in field margins (Figure 3.9). Araneae composition was very similar between habitats in spring, but there was a greater relative proportion of Lycosidae to the highly abundant Linyphiidae when compared to the winter samples (Figure 3.10).

Carabid diversity differed significantly between beetle banks and field margins ($F_{1, 118} = 8.40$, $P = 0.005$) over the spring sampling period. However, even in the more diverse beetle banks, H′ was low. Staphylinidae and Araneae diversity did not differ between habitat type ($F_{1, 118} = 1.83$, $P = 0.179$ and $F_{1, 118} = 3.67$, $P = 0.060$ respectively), and was also very low (Figure 3.11).

Sample size was considered too small (with only four beetle banks sampled) to assess for a meaningful relationship between densities or diversity and site age.

Figure 3.8 *Carabidae densities in refuge habitats, sampled spring 1998, indicating composition of numerically important species*

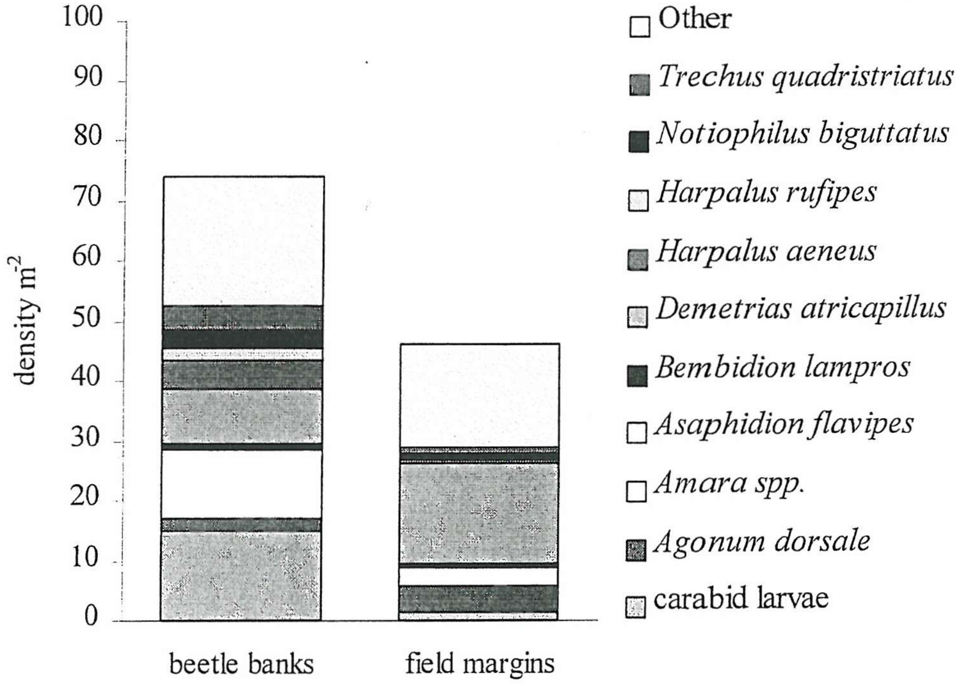


Figure 3.9 *Staphylinidae densities in refuge habitats, sampled spring 1998, indicating composition of numerically important species*

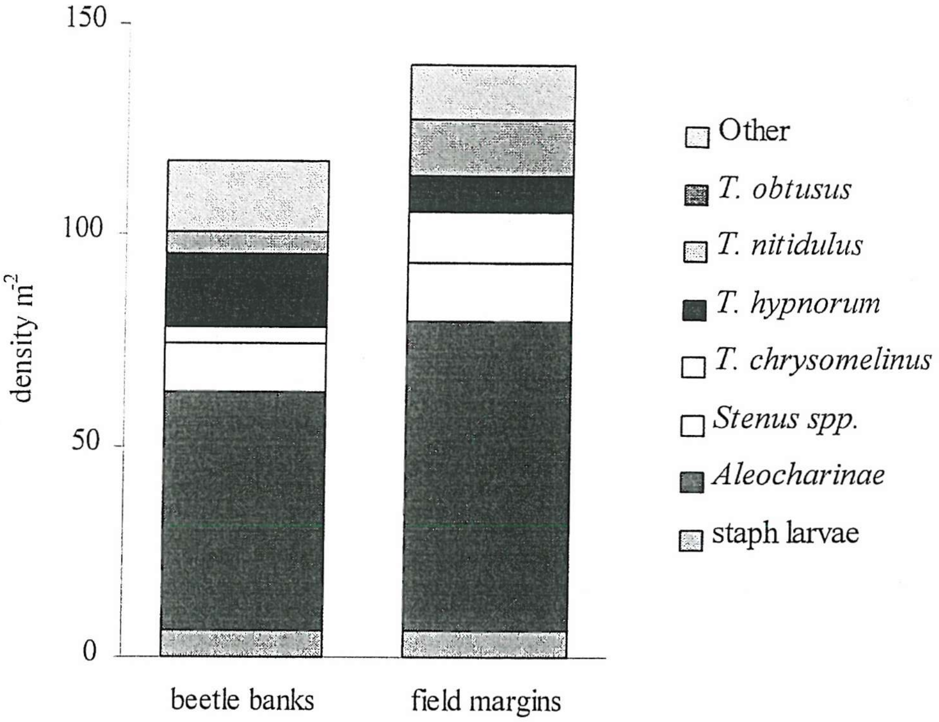


Figure 3.10 *Araneae densities in refuge habitats, sampled spring 1998*

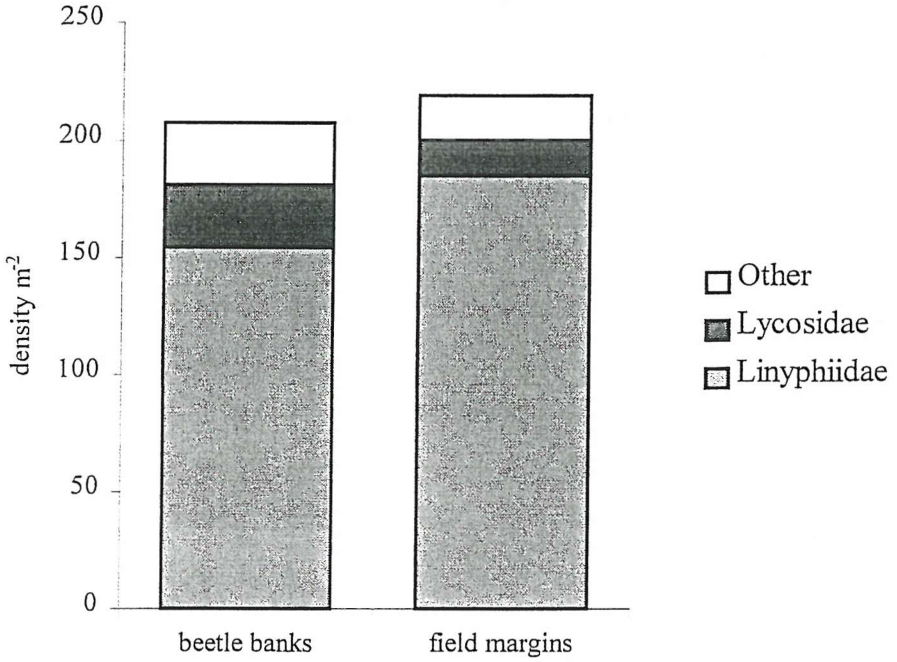
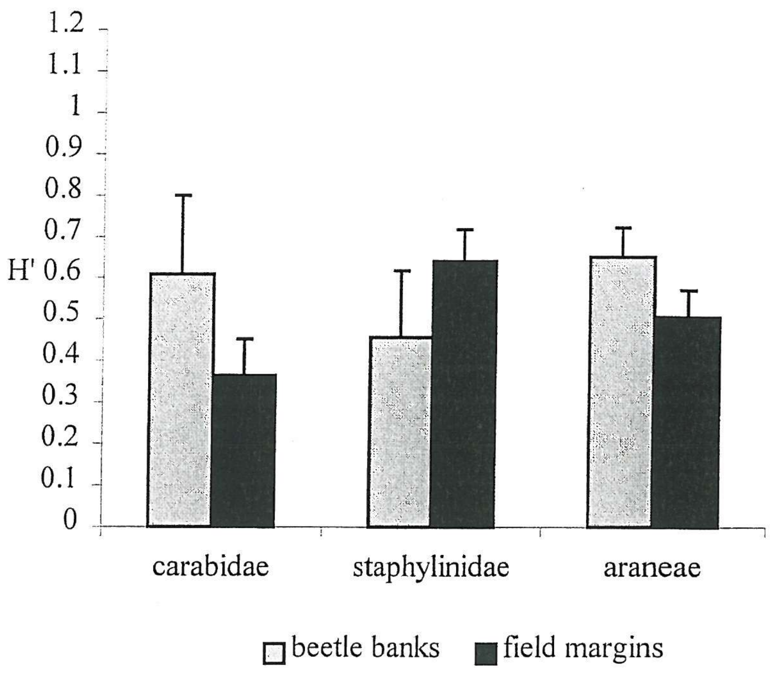


Figure 3.11 *Mean (+ SE) Shannon-Wiener diversity of predators in refuge habitats, sampled spring 1998*



3.4.6 *Summer predator density and diversity*

The densities of predators sampled in beetle banks and adjacent field margins in summer ranged from around 75 to 680 individuals per m^2. Densities per m^2 were significantly higher in beetle banks than in margins for Carabidae ($F_{1, 128} = 8.11$, $P = 0.005$), for Staphylinidae ($F_{1, 128} = 6.83$, $P = 0.01$) and for Araneae ($F_{1, 128} = 10.55$, $P = 0.002$).

Species composition in the three taxa was very similar between the two habitats. There was much greater similarity in densities between the key species of Carabidae captured than had been the case earlier in the season (Figure 3.12), although *B. lampros* still accounted for a large proportion of the catch. *Trechus quadristriatus* densities were similar to *D. atricapillus*, but the proportion of other species such as *Agonum dorsale* was also nearly as great. Staphylinidae composition was dominated by *T. hypnorum* and *Aleochara* species in both habitats, in similar proportions to winter samples (Figure 3.13). Linyphiidae remained the dominant component of the Araneae catch (Figure 3.14).

H′ diversity of Carabidae was significantly higher in beetle banks than field margins ($F_{1, 118} = 9.87$, $P = 0.002$) over the summer sampling period. In contrast, both Staphylinidae and Araneae diversity did not differ ($F_{1, 118} = 0.04$, $P = 0.852$ and $F_{1, 118} = 0.99$, $P = 0.32$ respectively). Again, although higher than in the spring, diversity values were low (Figure 3.15).

Again, the sample size used for summer density and diversity assessment in beetle banks was considered too small for meaningful relationships with age to be shown. No trends were evident when values were plotted.

Figure 3.12 *Carabidae densities in refuge habitats, sampled summer 1998, indicating composition of numerically important species*

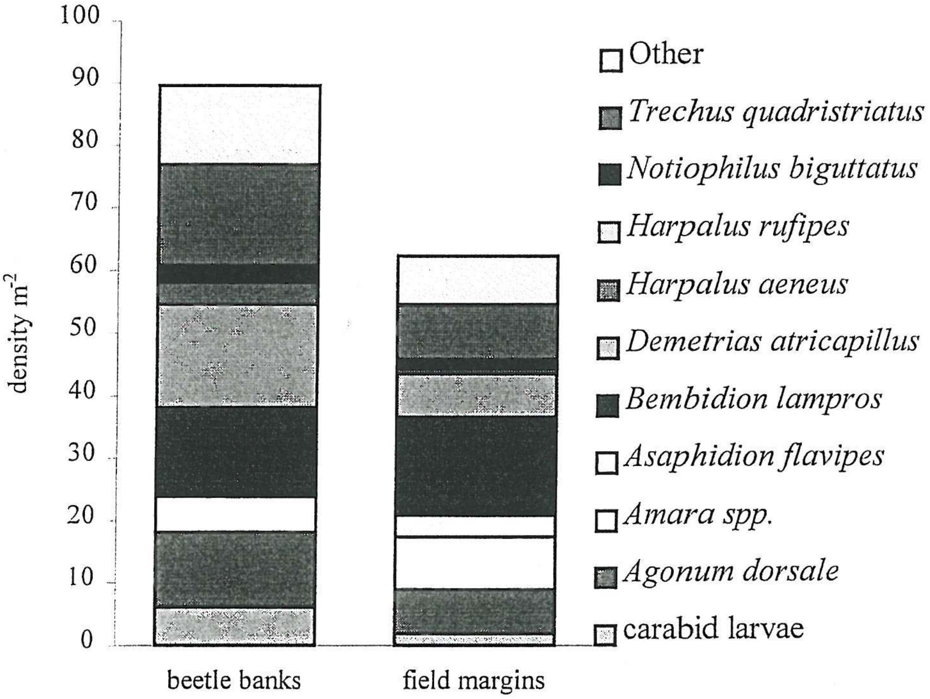


Figure 3.13 *Staphylinidae densities in refuge habitats, sampled summer 1998, indicating composition of numerically important species*

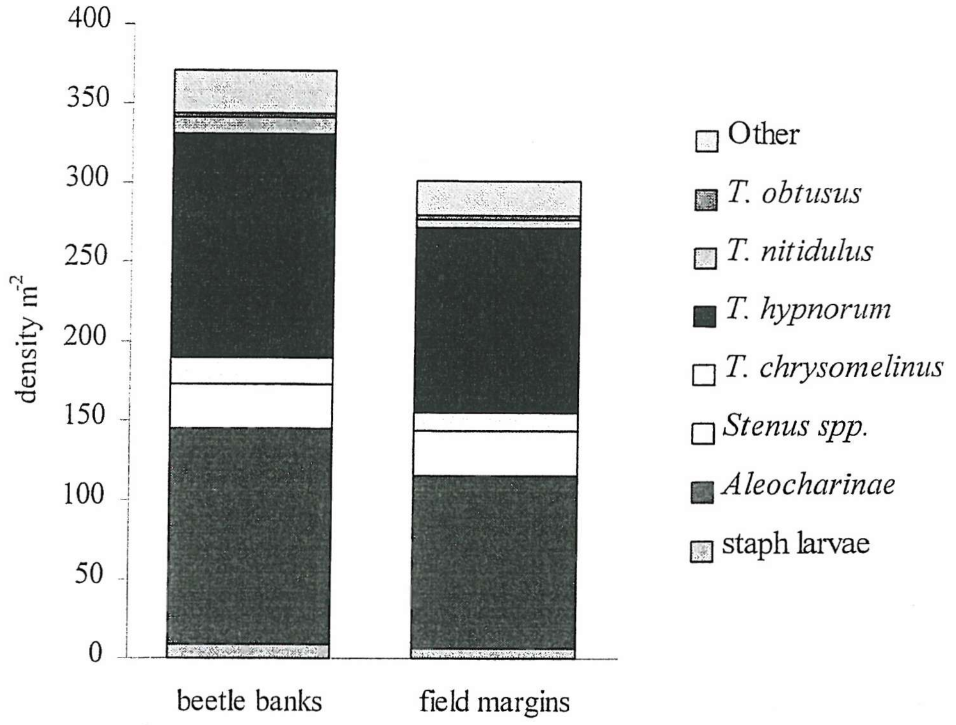


Figure 3.14 *Araneae densities in refuge habitats, sampled spring 1998*

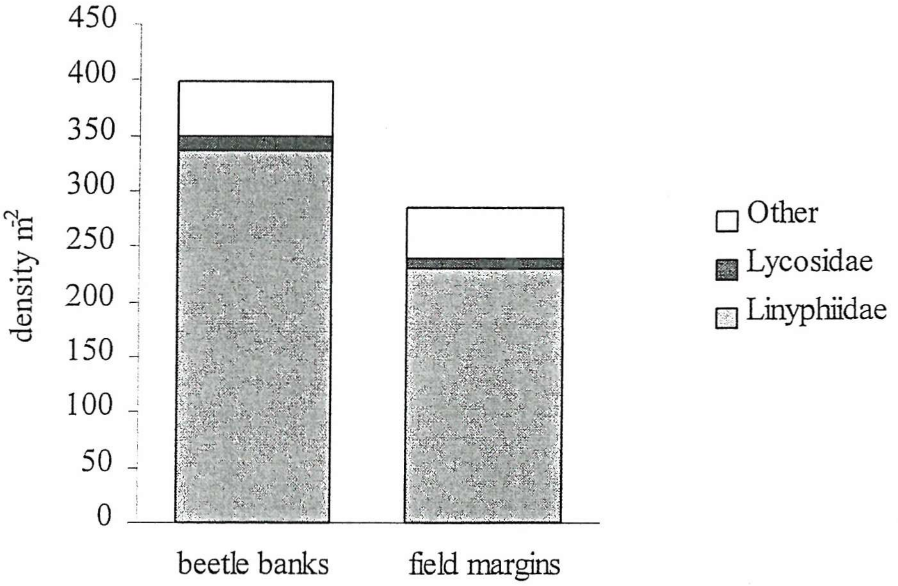
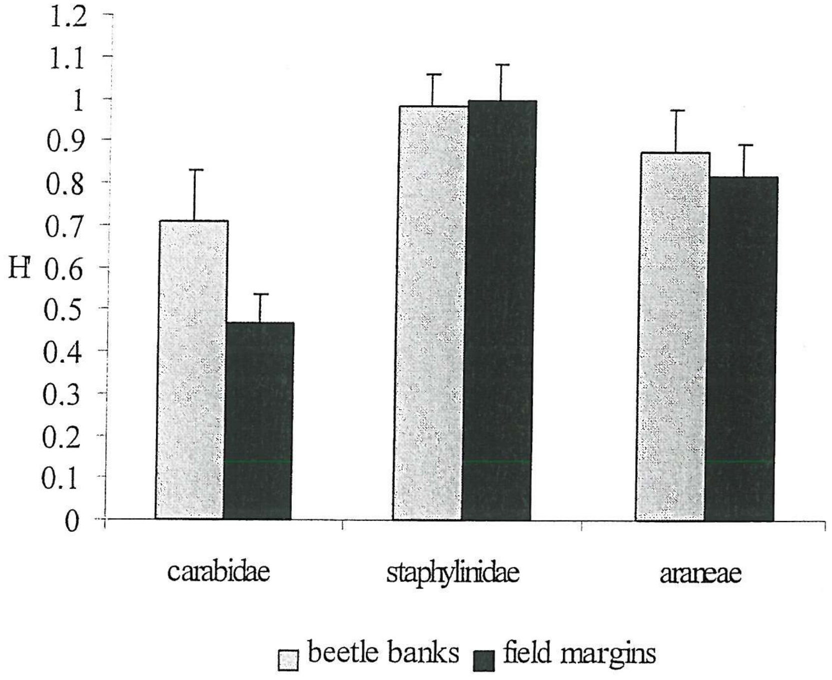


Figure 3.15 *Mean (+ SE) Shannon-Wiener diversity of predators in refuge habitats, sampled summer 1998*



3.5 Discussion

3.5.1 Overwintering predators

3.5.1.1 Density & diversity

Beetle banks were designed to provide optimal microclimatic conditions for the survival of high densities of overwintering beneficial predatory invertebrates; although previously only relatively newly established sites had been examined. Densities of predators found in the present study were equivalent to or higher than those obtained by similar work carried out in previous years (Thomas, Wratten & Sotherton, 1992c; Dennis & Fry, 1992; MacLeod, 1994; Collins, 1999). The current study found that for most taxa there were no striking differences in either predator densities or diversities between the beetle banks and conventional field margins. The field margins selected for assessment usually contained dense and well-established vegetational cover, representing exceptional field margin quality compared to many farms (personal observation). Had the study compared predator densities with other field edge habitats, such as where farm tracks immediately adjoined the crop, or evaluated predator densities of poorly managed hedgerows, the value of beetle banks may well have been more pronounced. Calculated values of H' usually range from 1.0 to 3.5 (Magurran, 1988). Low diversity may reflect that many species overwinter as larvae rather than as adults, and as larvae were pooled because of the difficulty of identification, true species diversity was probably underestimated in this study. Low values may also indicate that only a limited number of species were available for potential spring biocontrol. Thus it is important that overwintering conditions encourage maximum survival of these species. It was interesting to discover that species richness on these Hampshire beetle banks was analogous to that found in Leicestershire by Collins (1999), despite climatic and soil differences, suggesting that the suite of predators available for biocontrol is similar across regions and conclusions about them may be broad-reaching.

Thomas *et al.* (1992c) detected an increase in the proportion of 'boundary' to 'open-field' species of carabids in beetle banks, and ascribed the change to succession. Similar trends in data collected by Collins (1999) further supported this observation. However, MacLeod (1994) suggested that the compositional change could be attributed to a temporal rather than a successional process, i.e. more 'boundary' carabids will encounter a beetle bank the longer that it is *in situ*. It seems likely that both are influential factors.

The small number of sites sampled for overwintering invertebrates restricted finding distinct relationships between predator densities or diversities and age of beetle bank, but was an inevitable result of effort and time constraints. Beetle banks appear to be rapidly colonised soon after establishment (Thomas *et al.*, 1992c), with the predator populations found overwintering within them perhaps depending more on the cropping and management history of the surrounding area than on subtle successional differences in vegetational structure resulting from age. The other studies described often involved the sampling of a single site for a few years following establishment, with again only patchy evidence for increasing numbers of predators as they aged (MacLeod, 1994; Collins, 1999). In most cases, populations were highest after two or three years, but there was not evidence to suggest that they were always sustained beyond this. This study has shown, however, that older banks may continue to be good quality sites, and so should not be removed on grounds of age alone. Only if dense cover has become degraded should re-seeding or replacement be considered, as a means of ensuring adequate overwintering conditions to support invertebrates. Carabidae densities were positively correlated with *D. glomerata* density in an examination of field boundary structure (Thomas *et al.*, 1992a). Luff (1965) found that grass tussocks of *D. glomerata* thrive for up to ten years, but eventually the amount of new growth declines, and the structure of the tussock disintegrates. A well-formed tussock structure is important for creating optimal buffered-temperature overwintering conditions (Desender, 1982). It might be expected that densities of predators would increase as the tussocky habitat develops, but decline over a longer time period, if there was loss of ground cover or favoured microclimate. An examination of a wider range of banks of different ages might give more conclusive evidence for age trends. Clearly, it would be important to continue to assess these sites in the future, and extend the data set.

There was considerable variability in the densities of invertebrates sampled in beetle banks and field margins from different fields. The background population density of invertebrates present may be dependent on a number of inter-related factors. These include the management history of the field, such as which crops have been grown previously, their sowing dates, varieties used, densities of plants, the input regime of the field, and the fields' weed populations, which in turn depends on these factors plus the soil seed bank. Invertebrate densities may be very heterogeneous as a result. (Holland *et al.*, 1994b & 1999)

In summary, beetle banks clearly add to the amount of overwintering refuge available to predators of crop pests, especially where other field margins are lacking or have poorly managed bottom flora because of close ploughing, herbicide drift or misplacement of fertiliser. Hedgerows need considerable care and expense in establishment and management, and have rigorous guidelines that must be adhered to relating to removal or re-positioning (Watt & Buckley, 1994; Sotherton & Page, 1998). In contrast, beetle banks are easy to establish, inexpensive, and yet provide habitat of similar value for beneficial invertebrates, and thus are an ideal means of increasing the cover of such habitat on arable land.

3.5.1.2 Comparison with other reported overwintering densities

Thomas (1991) carried out similar destructive sampling in *D. glomerata* stands on newly established beetle banks, to calculate densities of overwintering polyphagous predators within them. The densities of individual species varied considerably, with Araneae and Carabidae showing changes from pioneer to more specialised species as the newly created habitats matured. Densities of overwintering invertebrates of more than 1000 per square metre were recorded during the initial three years. Further estimates of predator densities were made in the banks during the fifth and sixth winters after establishment, but the initial high densities reported during the second winter were not found to have been sustained

(MacLeod, 1994). Using a similar destructive sampling methodology as these researchers, Collins (1996, 1999) examined a beetle bank in another location, to represent a heavier soil type, and found yet more variation in densities per m^2. Recent work by Hughes (1999) duplicated this earlier sampling to establish whether the beetle bank prescription could be as successful on a range of soil types on Scottish farms under different cropping patterns. There are no consistent relationships indicated through time in any of these studies, with predator densities highly variable from year to year (Figures 3.16 and 3.17).

Predator densities found overwintering in the banks at the Manydown Estate in 1997-98 and in 1998-99, are comparable with those of these other researchers, although the very high numbers especially of the Thomas / MacLeod second year, 1989-90, were not seen, and it appears that this was exceptional. Suggestions that these high densities can develop regularly in well structured beetle banks, such as has been put forward by Sotherton (1995), were not supported. Manydown appears to contain a higher polyphagous predator population than on other farms (Holland & Thomas, 1997b) probably because of its conservation-aware history, and so it would be expected that beetle banks on more typical, conventionally run farms would rarely achieve the densities of predators that were recorded here.

Thomas & Marshall (1999) suggest that sown field margin strips were colonised within 11-15 months of establishment, after studies of overwintering densities sampled by soil sampling. Densities may increase after this time, as the habitat structure matures, though there is no evidence that extremely high densities can be expected unless the farm environment normally supports this. A reproductive response to high prey densities may boost predator densities in outbreak years, giving unexpectedly high numbers.

The densities of Araneae found in the Manydown Estate sites are higher than those found by the researchers previously mentioned, indicating local differences in abundance probably related to factors such as pesticide inputs and climate. Bayram & Luff (1993b) found extremely high densities of Araneae, predominantly lycosids and linyphiids, when examining overwintering densities in *D. glomerata* tussocks, but this may be a result of sampling in permanent undisturbed grassland, rather than in commercially managed agricultural fields.

Figure 3.16 *Mean densities of Carabidae per m² in beetle banks of varying age, calculated by researchers within different studies*

(**srt**: S.R. Thomas, this thesis; **aml**: A. MacLeod, 1994; **mbt**: M.B. Thomas, 1991; **klc**: K.L. Collins, 1999; **jph**: J.P. Hughes, 1999)

$R^2 = 0.014$, $F_{1,38} = 0.38$, $P = 0.54$; $y = 10.191x + 246.86$

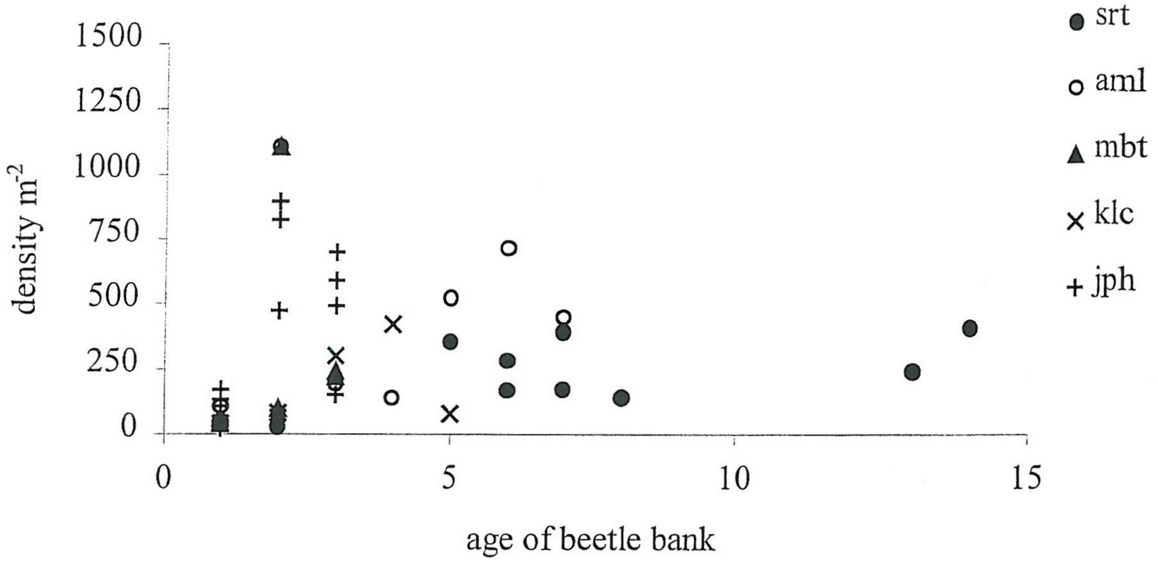
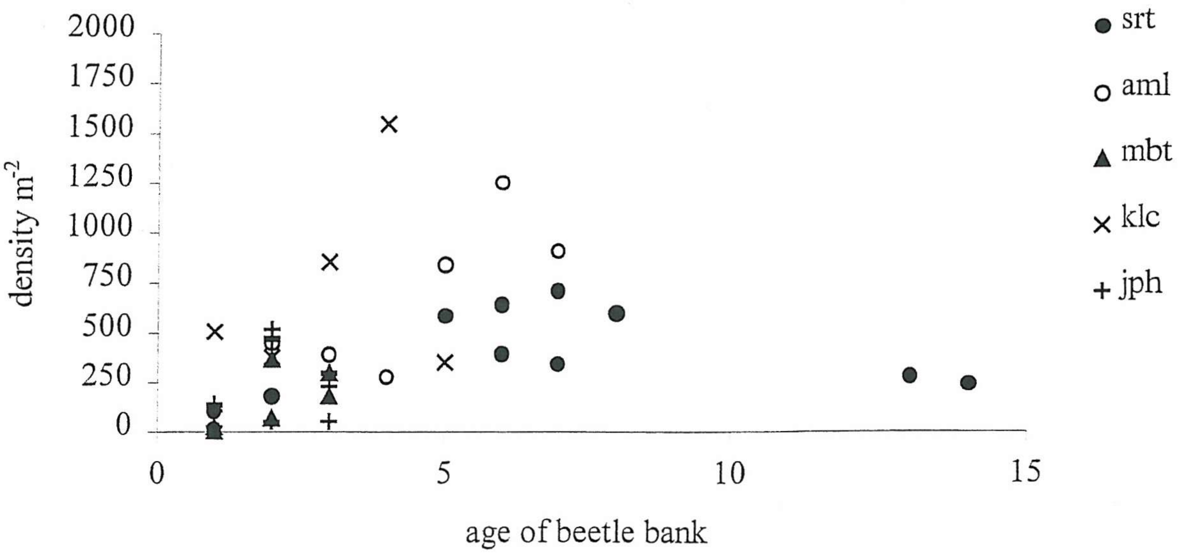


Figure 3.17 *Mean densities of Staphylinidae per m² in beetle banks of varying age, calculated by researchers within different studies*

(abbreviations as above)

$R^2 = 0.051$, $F_{1,38} = 1.39$, $P = 0.25$; $y = 24.88x + 347.02$



3.5.2 Predators in spring and summer

Whilst the winter data measured a source population of predators that may potentially re-invade the crop, the spring data gives an indication of densities of those invertebrates that survived the winter, many of which may already be active and dispersing into the field. Differences in composition between soil samples from each season do indicate such activity; for example, *B. lampros* abundance was considerable lower in spring compared to winter. The summer sampling assessed densities of those predators that had not left the edge habitat, and so they are either permanent residents in the refuge area, or they may invade the crop later in response to increased prey (pest) densities. There was little difference between the habitats. Few previous studies have attempted to quantify this possible 'reservoir' of predators, and the results obtained may relate to potential further re-invasion following eradication of already dispersed predators in the field by insecticide applications.

Kromp & Steinberger (1992) sampled Carabidae in a grassy margin adjacent to a biologically farmed (pesticide and mineral N-fertiliser free) field, and found a high mean H' of 4.3, as well as a total of 61 species. They compared their data with that from a conventionally managed sugar beet field, in which mean H' was only 3.1, although this is still considerably higher than that found in the study described here. Diversity may be higher in eastern Europe because of a lower degree of farming intensification. They noted that there was a large number of species found there exclusively, but with low abundance, which indicated the habitat may have been used as a transitional refuge or corridor. Thomas & Marshall (1999) calculated a value for Carabidae H' of 2.25 in sown field margins in mid-summer, although species richness ranged from 8 to 20, depending on exact position of traps within the margins. Again, the highly abundant *Pterostichus melanarius* skewed capture considerably, an effect also found by Asteraki (1994) when measuring species richness in sown conservation strips. In all these cases, sampling was carried out using pitfall traps, in which capture is strongly influenced by activity. Some species can be caught in high numbers as a response to aggregation behaviour or chemical cues, or because of high localised prey densities (Luff, 1986). In effect, the individuals caught may have come from a very large area, indicating the difficulties of interpretation of capture results with this methodology (Lang, 2000). In this study a sampling method was selected that would provide an absolute density measure at a single time, although only a very small area was measured, which no doubt contributed to lower diversity values measured. In addition, differences between results from these other studies and that here probably relate to the isolated 'island' nature of beetle banks within conventionally farmed, species impoverished landscape. Botanical diversity in these simple grass strips was considerably lower than that recorded by Asteraki (1994), for example. Differences could also be partially attributable to greater precision in species identification carried out in such studies.

3.5.3 Criticisms of methodology

The method used to sample invertebrates in and on the soil could allow some inaccuracies in estimates of absolute abundance per unit area. Bayram & Luff (1993b) took entire tussocks away in one movement with a turf cutter, when estimating population densities of spiders in grass tussocks. The present study used a method of cutting by spade, which being slower may have allowed some escape of the more surface active species, especially spiders, accounting for the densities found here being greatly lower than those of Bayram & Luff. The use of the suction-sampler was designed to rapidly collect mobile arthropods at the start of the sampling procedure, and should have compensated for limitations with the turf removal. Even this process may encourage some invertebrates in the soil to escape, as the vibration and disturbance may make them move rapidly away from the area being sampled (MacLeod *et al.* (1994) reported that a Ryobi vac operates at 98dB at full velocity).

Sampling from a range of farms, covering a wider geographic area, would have made the conclusions more general, but as the methodology was extremely laborious, this was considered beyond the scope of the study. Although the results would be interesting to analyse, they would require a multivariate approach because of the range of confounding factors, such as differences in farm management history and background predator populations. Farms in different regions may have widely differing predator populations (Holland *et al.*, 1994b).

3.6 The beetle bank microclimate for polyphagous predators

3.6.1 Background and aim

Previous work by M. B. Thomas (1991) examined the temperature buffering conditions that could be provided by the dense tussock vegetation in a well-established beetle bank over winter, which could facilitate the survival of predatory invertebrates (see Chapter 1). My aim was to corroborate these findings, thus to test the null hypotheses that the mean and range of temperature would be identical both within and without the beetle bank, and that there would be no difference in conditions between a typical beetle bank and hedgerow. I also aimed to extend the previous work by considering whether potential temperature buffering might continue into the summer. Conditions on the soil might be too hot for some invertebrates, which might prefer to shelter within ground cover to avoid desiccation.

3.6.2 Methods

Temperatures within and adjacent to the beetle bank and hedgerow bank of a winter wheat field, on a north Hampshire estate, UK (map reference: SU 593534), were recorded from November 1997 to August 1998. An electronic 8-bit "Squirrel" datalogger (Grant Instruments, Cambridge, UK) was used to take measurements in three positions within each of these two locations. One thermoprobe was inserted into the beetle bank or hedgebank soil to approximately 5cm depth, to record temperature where invertebrates might be buried. A second probe was inserted into a *Dactylis glomerata* tussock, or equivalent densely clumped vegetation in the hedgebank, where invertebrates are known to shelter. The third thermoprobe was positioned to record air temperature on the soil surface, at approximately 0.5m from the bank. The datalogger was set to store hourly recordings, allowing the daily mean, minimum and maximum values to be calculated. Occasional unexplainable mechanical failures, and a theft of one of the dataloggers towards the end of the monitoring period meant that temperature data collected in the two habitats had to be pooled, so that a comparison between habitat types became impossible. Little difference between recordings taken in each location had been apparent, and was considered reasonable justification for allowing pooling. The mean weekly temperature and mean weekly range (between max and min) was plotted using pooled data.

3.6.3 Results

There was little difference between mean temperatures in each of the positions where thermoprobes were placed (Figure 3.18). Over the winter, the mean temperature was often slightly lower on the soil surface than within the vegetation or soil, although by no more than 3°C. Conversely, over the summer, whilst similar patterns were shown in temperature change in all positions, those measured on the soil surface were consistently a few degrees higher than those within the plants and soil. However, marked differences were found in calculated temperature range (Figure 3.19). There was least fluctuation between maximum and minimum values recorded by the within-soil probe. Over the winter period, temperature varied by only 1-2°C each week. The greatest range, of only 5°, was recorded in spring, but declined again in summer. The probe positioned within the vegetation had an intermediate range. The probe on the soil surface showed considerable temperature fluctuations of up to 18° in a single week. Clearly conditions within the soil, and to a slightly lesser extent within the beetle bank/hedgerow vegetation were being buffered.

A predator trapping programme was in progress in the beetle bank whilst temperature was being recorded, and methodology details are described in section 4.2.2.2. There were strong significant positive regressions between both weekly mean surface air temperature recorded on the soil surface adjacent to the beetle bank/hedgerow, and mean numbers of Carabidae caught in pitfall traps within the beetle bank, and time (Figure 3.20).

3.6.4 Conclusions

The results of temperature monitoring corroborate those found by Thomas (1991) in that conditions within the beetle bank are protected from large temperature fluctuations, thus facilitating the survival of invertebrates that have moved into the habitat to shelter over the winter. Luff (1966) found that densities of Coleoptera were highest within dense tussocky grass over winter. Edgar & Loenen (1974) and Bayram & Luff (1993a & b) also found a preference for such habitat by Lycosidae spiders, despite considerable activity at very low winter temperatures. Buffering conditions in tussocky overwintering sites have also been found by Bossenbrek *et al.*, 1977, D'Hulster & Desender (1982), and Dennis *et al.*, (1994), all of whom concluded that the winter survival of beneficial invertebrates benefited from the presence of such habitat.

However, with the exception of Luff (1965), none of these studies considered the possible shelter provided by such habitat in summer, when temperatures may be high enough to cause invertebrates to seek shelter to avoid desiccation. Buffering within the beetle bank/hedgerow also was in evidence at this time, and may be important for the survival of day active species. Reduced penetration of sunlight into the grass leaves of the tussock means that the temperature within them will not become as high as on the soil surface (Luff, 1966; Dennis *et al.*, 1994). Higher humidity within the vegetation may also be important, as well as shelter from wind. Both factors have been demonstrated as contributing to the unique microhabitat profile of *D. glomerata* tussocks (Luff, 1965).

Figure 3.18 *Mean weekly temperature recorded from three positions within beetle bank/hedgerow*

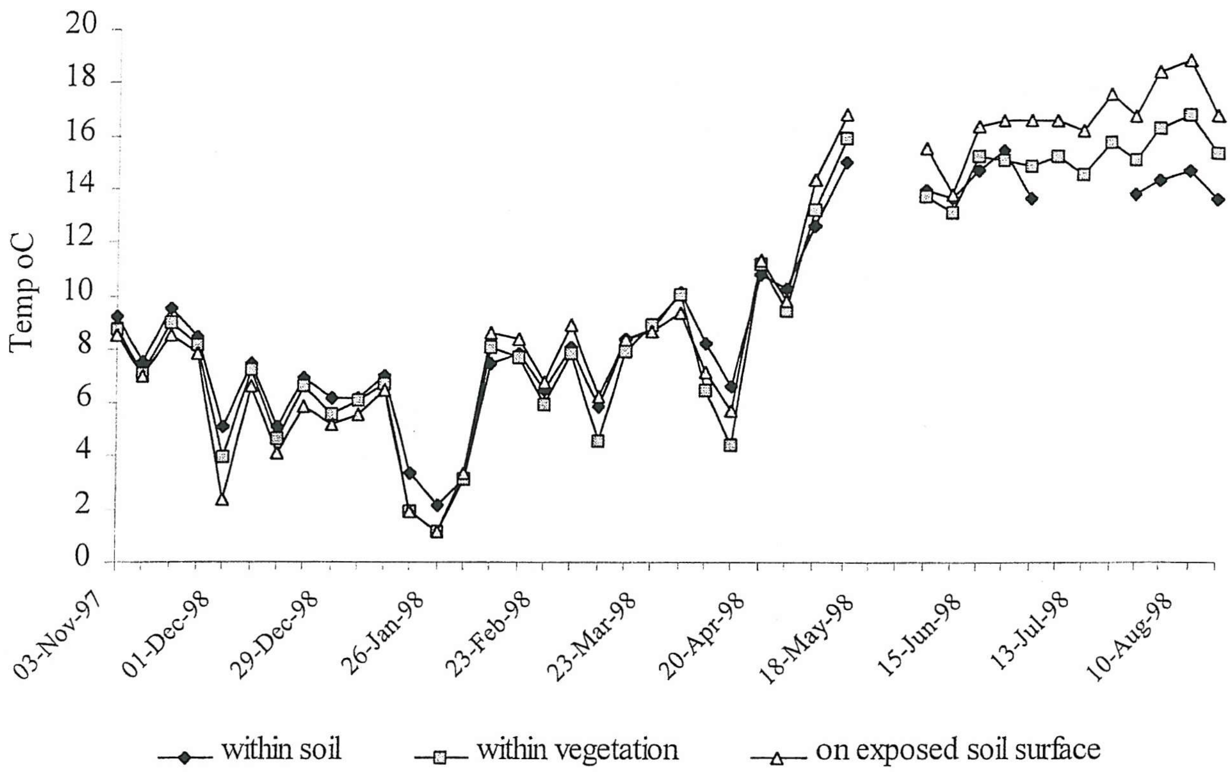


Figure 3.19 *Mean weekly range in temperature (between maximum and minimum values) recorded in three positions within beetle bank/hedgerow*

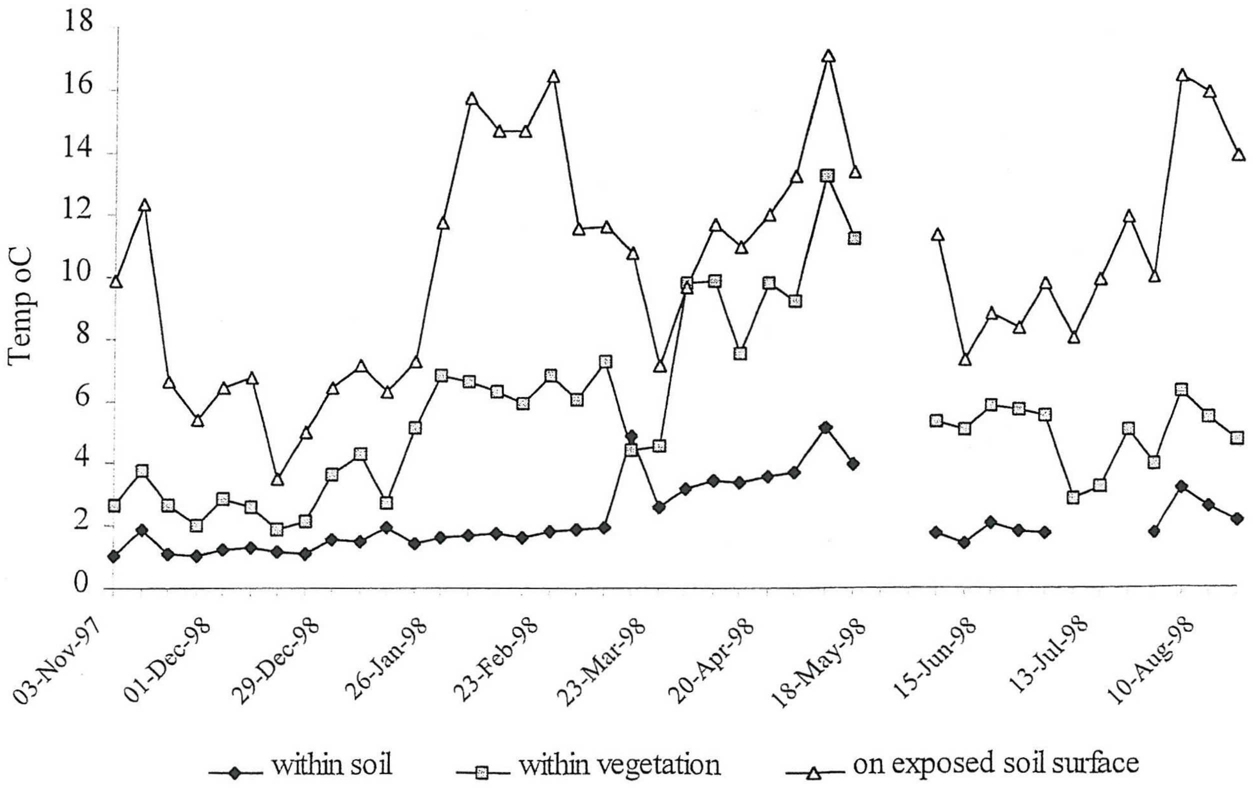
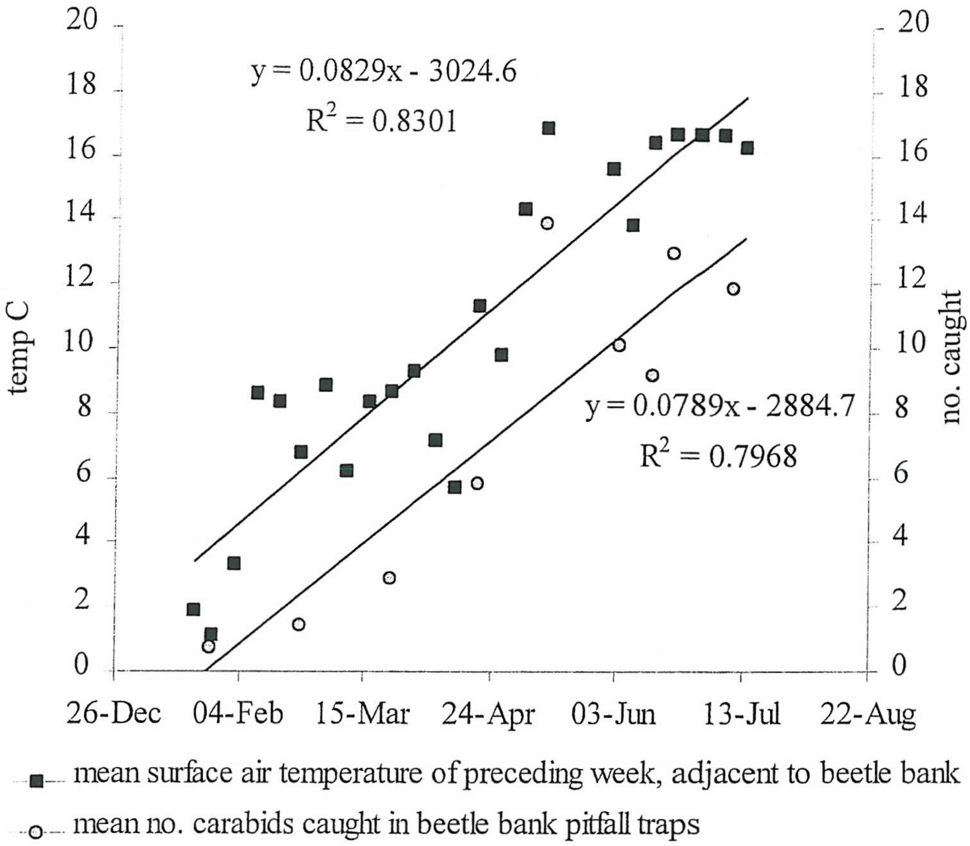


Figure 3.20 *Weekly mean surface air temperatures adjacent to the beetle bank/hedge, and mean numbers of Carabidae caught in pitfall traps within the beetle bank, against time*



Ambient temperature may directly influence invertebrate activity levels within the beetle bank, with some species hatching or emerging from the soil or from within vegetation only when the temperature is warm enough. This may account for the highly similar positive relationships between mean pitfall catch and mean weekly temperature, through the season. Patterns of invertebrate activity-density within the crop field would not necessarily be expected to show similar patterns to those within the beetle bank, notwithstanding differences in species composition and trappability through the season. Early in the season, the crop canopy is very open and so the ground is exposed, then as the crop develops, a more enclosed humid microclimate is formed. Once the crop starts to ripen and desiccate, this microclimate will change again, as the soil dries out and hardens, and causes conditions again to be potentially challenging for invertebrates moving within the field. Varchola & Dunn (1999) found considerable changes in carabid abundance and community structure in response to canopy closure in the field.

4. The contribution of beetle banks to predatory invertebrate spatio-temporal dynamics

Abridged version of chapter published as *'Spatial and temporal distributions of predatory Carabidae in a winter wheat field'*, S.R. Thomas, D. Goulson & J.M. Holland (2000). *Aspects of Applied Biology*, **62**, 55-60.

Aspects of chapter presented as poster '*Spatial and temporal distributions of predatory invertebrates within, and dispersing from, overwintering refuges in UK cereal fields*', S.R. Thomas, D. Goulson & J.M. Holland, at the XXI International Congress of Entomology, Iguaçu Falls, Brazil, 20-26/8/2000.

Also presented as poster '*Spatial and temporal distributions of predatory Carabidae in a winter wheat field*' at the Association of Applied Biology Conference: Farming Systems for the New Millennium, Cambridge, 18-20/12/2000.

Findings outlined in '*The impact of beetle banks on predator distributions within fields*' S. Thomas (2001). *The Game Conservancy Review of 2000,* **32**, 79-80.

Additional results from this work published as '*Overwintering populations of beetle larvae (Coleoptera) in cereal fields and their contribution to adult populations in the spring*' R. Noordhuis, S.R. Thomas, D. Goulson. (2001). *Pedobiologia*, **45**, 84-95.

4.1 Abstract

The within-field spatial distribution of predatory Carabidae was investigated from late winter through to summer in winter cereal fields, to evaluate coverage over the period when biocontrol of pest outbreaks is most valuable. Differences in activity-densities between those species that disperse from boundary habitats and species that are known to be permanently resident within the field were assessed. Capture was compared between areas beside two different overwintering refuges, sown beetle banks and a hedgerow bottom. Heterogeneity within these refuges was measured and interpreted. The use of a novel spatial clustering technique compared to conventional analysis was explored.

For boundary-overwintering carabids, significant patch-clustering was apparent alongside beetle banks and the hedge in spring, followed by a more homogeneous spatial distribution across the field later in the season. Patterns observed support the concept of a 'wave' of dispersal by key species. Populations within source habitats were largely heterogeneous throughout the season. A rapid increase in activity-density of field-inhabiting carabid species was recorded late in summer, with significant patches developing in the field centre and gaps near margins. Consequently, this group may be of limited value for the biocontrol of many developing pests unless within-field conditions receive greater consideration. Overall, results indicated that beetle banks are as valuable as conventional boundaries for aiding carabid dispersal into crops.

Patches and gaps of different carabid densities did not appear persistent through the season, although this was not formally tested. Subtle microclimate, prey distribution and edaphic factors probably account for the spatial and temporal patterns seen. The relatively novel methodology appears to be more informative than analysis of conventional mean and variance heterogeneity of capture data, and can be used further to explore associations of distributions through time or between different species. Limitations of the study are discussed with reference to similar recent investigations. An additional aspect of the study examined potential recovery of carabid populations following insecticide treatment, but found little evidence for re-invasion of boundary species from a beetle bank or hedgerow. Field species showed only a re-distributional response.

Empididae were captured by transects of sticky traps within a winter wheat field through a trapping regime extending from May until July 1998. Only species of the genera

Platypalpus and *Empis* were found. These had similar abundance within a beetle bank and a hedgerow, and a lower, fairly homogeneous abundance at a range of distances from these habitats across a winter wheat field. There was coincidence in time and position with pest species present in the wheat, including cereal aphids and orange wheat blossom midge, though these were present in only low numbers throughout the experimental period. An organophosphate pesticide application significantly reduced fly abundance, and would therefore not be good practice if these useful beneficial insects are to be encouraged.

4.2 Spatio-temporal distributions of Carabidae

4.2.1 Introduction

Information relating to the within-field spatial and temporal heterogeneity of beneficial predatory invertebrates is important for the successful implementation of integrated pest management involving the conservation and enhancement of habitat heterogeneity to maximise their impact on arable crop pests (Wratten & Powell, 1991; Powell *et al.*, 1995). A thorough cover of predators as early as possible in the season will deliver most effective biocontrol, with financial benefits from reduced pesticides inputs as a consequence. Despite considerable research on the value of field margins for the overwintering of predators (Sotherton, 1985; Wallin, 1985; Riedel, 1995; Andersen, 1997), information on the dispersal of these predators into crop fields is limited. Specific aspects of predator dispersal that need further investigation include: the distances into fields that predators may disperse from boundary overwintering sites; the time scale of such dispersal; its coincidence with the population development of pests; and whether the entire field, even if very large, receives equal penetration. Finally, the proportion of beneficial species that live year-round within the field, rather than having to move into the field from winter sheltering habitat, needs further examination. Whilst boundary species are moving into the field, field species already present may be increasing in abundance. If so, conditions within the field itself may be as important as the provision of quality edge overwintering habitat.

Pests such as wheat blossom midges and bulb flies may have patchy distributions depending on particular soil characteristics, crop variety and soil temperature. Aphid populations in cereal fields have been found to be non-randomly distributed, often with greater numbers towards field centres (Chambers *et al.*, 1982; Winder *et al.*, 1998 & 1999).

In contrast, most predators were more abundant in areas near field margins in summer (Dennis & Fry, 1992). It has been suggested that predation can remove, or at least delay, the need for insecticide application, if predators are present at high enough levels early on in aphid population development (Chambers *et al.*, 1982; Dennis & Wratten, 1991). However, it is also important that densities remain high later in the season, when they may have a greater impact on pests such as cereal midges (Holland, Thomas & Hewitt, 1996; Holland & Thomas, 1997a). Midge return to the soil to diapause, after the crop has ripened, and at this stage they have been found to be vulnerable to predation by carabids and staphylinids (Holland & Thomas, 2000).

Large fields have developed through intensification of production. As a result it may take too long for invading predators to reach field centres, allowing aphid populations to reach damaging levels. Source populations of predators may also be inadequate because of low edge: field area ratios. Beetle banks were designed to provide high quality overwintering habitat across the middle of large arable fields, reducing the distance that predators need to cover to achieve a thorough distribution (Thomas *et al.*, 1991; Thomas *et al.*, 1992b; Sotherton, 1995). Temperature buffered, well-drained conditions within them facilitate maximum survival of Carabidae, Staphylinidae and Araneae. Inserting beetle banks across large arable fields may actually increase, rather than merely redistribute, predator populations available for biocontrol. However, if predator distributions are still found to be heterogeneous across the field, this may suggest that even with the addition of such features, field sizes remain too large for maximum potential biocontrol.

Additionally, an uneven distribution of predators at source within the overwintering habitat may contribute towards a heterogeneous distribution within the field, following subsequent dispersal.

Two types of dispersal of predatory species have been described (Coombes & Sotherton, 1986). A 'slow wave' of ground-active species such as the carabids *Agonum dorsale*, *Bembidion lampros* and *Demetrias atricapillus* may result in potentially limited penetration. The rapid dispersal of highly mobile species such as the staphylinids *Tachyporus chrysomelinus* and *T. hypnorum* penetrate fields mainly by flight and may come from greater distances than just the surrounding margins. Linyphiidae spiders, which disperse by aerial ballooning, also belong in this second group, and are the most important numerically.

Most studies on the dispersal of predators in arable fields carried out to date have suffered limitations. The use of only a small number of traps across fields (Coombes & Sotherton, 1986; Collins, 1999; Jensen *et al.*, 1989), the evaluation of bait predation to assess predator presence, which provides only inferential evidence (Thomas, 1991) and the comparison of mean activity-densities at only a few set locations from which patterns of movement have been extrapolated, have not explicitly described predator spatial patterns through the season. More recently, intensive studies tending to focus on individual species have been particularly informative (Thomas, Parkinson & Marshall, 1998).

This study attempts to:

a) discover whether Carabidae activity-density is patchy or uniform across fields, and whether this is achieved early enough in the season to cope with pest outbreaks;

b) compare Carabidae distributions in areas of the field beside a beetle bank and a hedgerow;

c) examine heterogeneity within these linear habitats.

4.2.2 Materials and methods

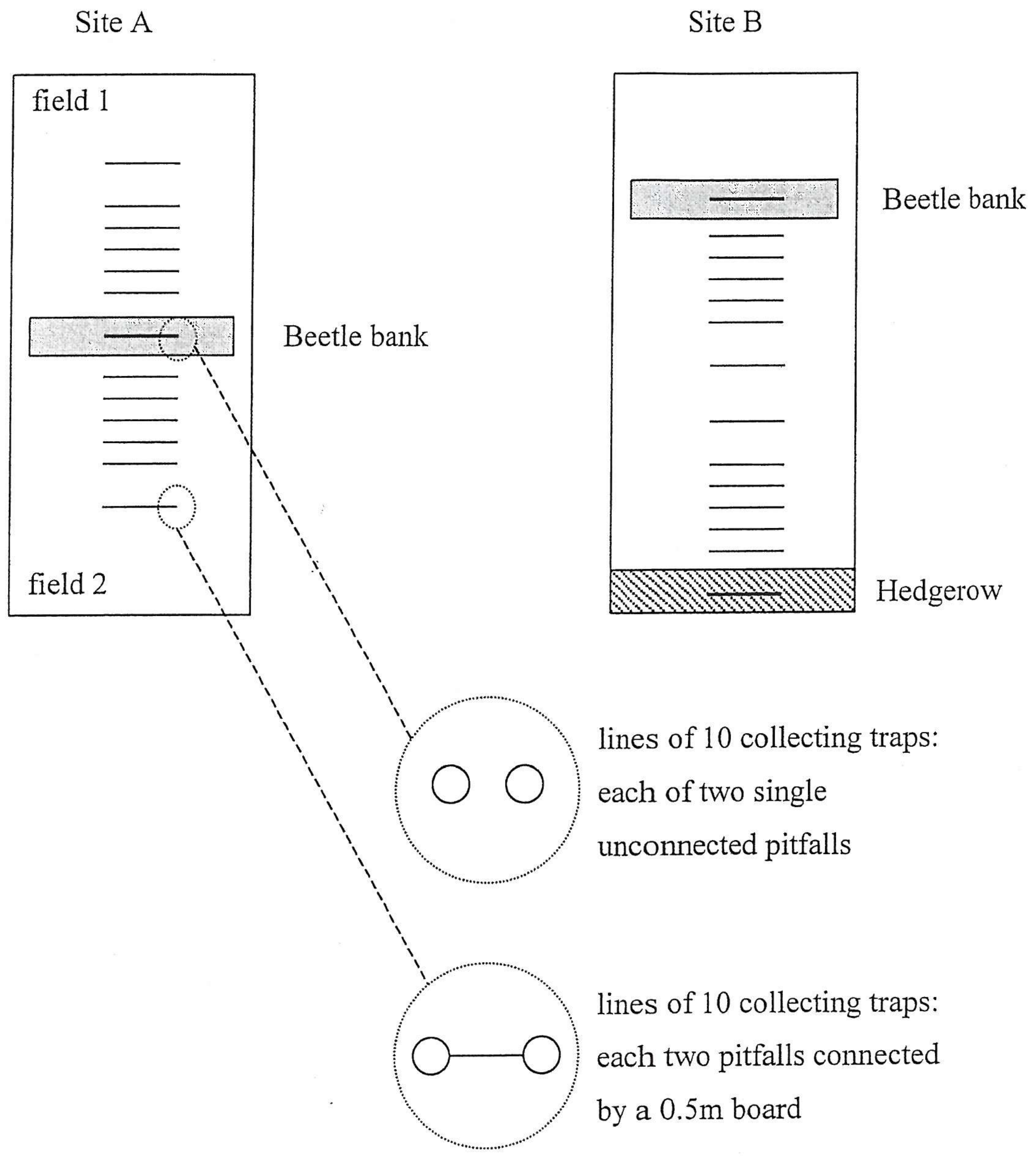
4.2.2.1 Spatial distributions of Carabidae within the field

Predatory invertebrates were sampled from two sites within an estate in north Hampshire (map reference: SU 593534) in 1998. Autumn sown crops were selected to avoid detrimental effects of cultivation on beetle emergence (Fadl *et al.*, 1996). In site A, two winter barley fields (var. Regina, 16 and 17ha respectively) were separated by a 4.2m wide *Dactylis glomerata*-sown beetle bank. Sampling grids were located in each field. These consisted of ten transects at 10m intervals, each containing collecting traps at 5, 25, 50, 75, 100 and 150m distances into the field perpendicularly from the beetle bank edges. Each collecting trap was formed of two pitfalls (6cm diameter beakers, partly filled with water and detergent) connected by a 50cm board set into the ground to enhance capture (Durkis & Reeves, 1982; Wallin, 1985) (Figure 4.1). Sampling was carried out each month from March until the end of July, and consisted of opening the pitfalls for a 72-hour collecting period. The use of double traps was also chosen to lessen inter-trap variability, and the possibility of accidentally increasing observed grid heterogeneity of catch (Powell *et al.*, 1995). Traps were re-set flush with the ground on each occasion. In site B, two sampling grids were located within a winter wheat field (var. Buster, 27ha), one extending from a *D. glomerata* sown beetle bank and the other extending from a hedgerow parallel to the beetle bank on the other side of the field. Layouts were as above, with a 50m gap between the two 150m lines of collecting traps (Figure 4.1). At this site, collecting started in February and finished in June.

Six-metre conservation headlands surrounded each field on all sides, including alongside the beetle banks.

Following identification of Carabidae catch to species, 'boundary-overwintering' (migrating into fields in spring) and 'field-inhabiting' (resident in fields year-round) categories were used in the subsequent analysis of distributions (Table 4.1).

Figure 4.1 *Diagram of experimental sites, indicating layout of sampling grids in each of the fields*



4.2.2.2 Carabidae homogeneity within overwintering habitats

At each site, transects of pairs of pitfall traps were established within the boundary habitat. These were not connected by boards because of the density of the vegetation. They were placed at 10m intervals, in the beetle bank at site A, and in both the beetle bank and hedgerow bottom at site B. These traps were opened concurrently with the within-field traps.

Additionally, fifteen 20 × 20 × 20cm destructive turf samples were removed from each beetle bank and hedgerow in early January, to measure absolute overwintering Carabidae densities on or within the soil and turf.

Identification of catch was carried out as before.

Table 4.1 *Carabidae identified in pitfall trap samples*

Other species caught were found extremely infrequently, and were recorded as either e.g. '*Bembidion* spp.' or 'other Carabidae' and not used in the current analysis.
(Sourced from Thiele, 1977; Sunderland & Vickerman, 1980; Luff, 1982; Coombes & Sotherton, 1986; Sotherton, 1984; Wallin, 1985; Thomas, 1989; Pullen *et al.*, 1992; Kennedy, 1994; Kromp & Steinberger, 1992)

Boundary-overwintering species:	**Field-inhabiting species:**
Agonum dorsale	*Amara eurynota*
Agonum muelleri	*Amara apricata*
Amara familiaris	*Amara ovata*
Amara plebeja	*Amara similata*
Asaphidion flavipes	*Bembidion obtusum*
Badister bipustulatus	*Calathus fuscipes*
Bembidion lampros	*Harpalus aeneus*
Demetrias atricapillus	*Harpalus rufipes*
Loricera pilicornis (sometimes field)	*Nebria brevicollis*
Pterostichus niger	*Notiophilus biguttatus*
	Poecilus cupreus
	Pterostichus madidus
	Pterostichus melanarius (sometimes boundary)
	Trechus quadristriatus (sometimes boundary)

4.2.2.3 Analysis

Within-field distributions: For each sampling grid, a repeated measures ANOVA (SPSS Inc., 1993) was performed on ln (x+1) transformed data, using distance from the boundary as a fixed factor and date as the repeated measure. Boundary-overwintering and field-inhabiting species groups were analysed separately in this way.

A relatively new SADIE (Spatial Analysis by Distance IndicEs) technique, originally described by Perry (1995 & 1998) and further developed (Perry *et al.*, 1999), was used. Statistical measurement of heterogeneity of the distribution of arthropods has been difficult until the recent development of such methods to measure spatial pattern in spatially referenced count data (Perry, 1998). SADIE computes indices I_a and J_a, based on distances to regularity and crowding. To determine whether predatory invertebrates caught were clustered in patches of higher than average activity-density, or in gaps of lower than average activity-density; and whether these changed across the fields at increasing distance from the beetle bank through time, the 'Red-Blue' method was used (Perry *et al.*, 1999). This measures the degree to which the observed count at each sample point contributes to the overall aggregation. Predatory invertebrates in patches of higher than mean density at each location sampled are calculated by the indices vi, with the mean value $\bar{v}i$, or in gaps of lower than mean density calculated by the indices vj, with mean value of $\bar{v}j$. Values of $vi > 1$ indicate greater patchiness and values of $vj < -1$ indicate greater gappiness than would be expected by chance alone (Perry *et al.*, 1999). Values around unity indicate the data is spatially random.

Distributions of invertebrates within the above groupings, plus numerically dominant individual species, were presented as contour maps using the SURFER package (Golden Software Inc., 1997), to indicate where clustering or gappiness was found that was greater than would be expected by chance.

Within overwintering habitat: Chi-squared tests were used to assess whether the carabid distribution was homogeneous along the habitats, by comparing observed numbers caught against the mean for all ten trap-pairs. These were carried out for all sample dates. The analysis was repeated for the turf samples.

4.2.3 Results

Analysis of variance indicated that capture of both boundary-overwintering and field-inhabiting species changed significantly through time in all sampling grids (Table 4.2). Capture was also significantly different by distance in all fields except within the grid adjacent to the hedgerow (H) in site B. All interactions between date and distance into the field were significant. Carabid beetles were caught in steadily increasing numbers, from very low capture in winter, to peak capture in May, followed by a decline and then a second rise to high numbers again in later summer.

Table 4.2 *Summary of ANOVA results for pitfall trap capture*

(where * P<0.005, ** P<0.01 and *** P<0.001)

	Boundary-overwintering spp.			Field-inhabiting spp.		
	d.f.	F	*P*	d.f.	F	*P*
Site A – field 1						
Date	5, 270	214.79	***	5, 270	106.35	***
Distance	5, 270	9.91	***	5, 270	7.57	***
Date × Distance	25, 270	5.96	***	25, 270	3.27	***
Site A – field 2						
Date	5, 270	244.81	***	5, 270	149.63	***
Distance	5, 270	8.62	***	5, 270	3.30	*
Date × Distance	25, 270	3.34	***	25, 270	5.34	***
Site B – adjacent to BB						
Date	5, 270	375.36	***	5, 270	483.04	***
Distance	5, 270	10.37	***	5, 270	4.48	**
Date × Distance	25, 270	2.47	***	25, 270	4.14	***
Site B– adjacent to hedgerow						
Date	5, 270	246.43	***	5, 270	526.42	***
Distance	5, 270	1.60	n.s.	5, 270	1.96	n.s.
Date × Distance	25, 270	4.26	***	25, 270	9.50	***

4.2.3.1 SADIE results from Site A

Spatial patterns changed through time in site A. Initially, aggregation was indicated in the first field but not in the second, and dissipated. Later in the season, significant values of I_a emerged, in both fields and for both carabid groups (Table 4.3).

Low activity-densities of boundary-overwintering carabids were found in the first field, predominantly clustered beside the beetle bank on the first sampling date (Figure 4.2). Over the next two months, their activity-density increased, whilst $\bar{v}\,i$ declined, indicating a greater spread across the field. However, at the end of May densities were lower, and strong clustering into patches was again in evidence. Once more, this was concentrated along the edge of the field adjacent to the beetle bank. Capture increased for a second time over the last two dates. Activity-densities in the second field followed similar patterns, with initial low capture increasing over the first three months (Figure 4.3). Patches formed towards the field edge beside the beetle bank at the end of May, when again activity-densities were somewhat lower than earlier. Capture rose over the last two dates, but there was no clear edge effect shown, with patches of high activity-density at a number of distances into the field as well as near the boundary. *Bembidion lampros* and species of *Amara* were mainly responsible for the early peak in captures, with *Agonum dorsale* and *Loricera pilicornis* dominating capture in the second peak.

The activity-density of field-inhabiting carabid species showed similar patterns in both fields, with fairly uniform capture through the early part of the season with some localised patches or gaps in changing locations in either field (Figures 4.4 and 4.5). However, over the last two sampling dates, capture increased considerably, in a wave from the centre of either field. There was gappiness adjacent to the beetle bank boundary with the exception of the fourth sample date, when high activity-density was seen there. *Pterostichus* species and *Trechus quadristriatus* dominated capture and were largely responsible for this pattern.

4.2.3.2 SADIE results from Site B

Significant overall spatial clustering was exhibited throughout the experimental period in site B, for both carabid groups (Table 4.3).

Although few were caught initially, boundary-overwintering carabid species were present in strong patches in the area of the field adjacent to the hedgerow on the second sampling date (Figure 4.6). By the third date, a strong patch was evident by the beetle bank, and this area increased to high activity-density on the fourth date. *Bembidion lampros* was dominant in the catch and thus mostly accounted for the pattern, with *Agonum dorsale* also abundant. As with the other site, activity-density was lower at the beginning of June, with a more uniform distribution across the field shown by $\bar{v}\,i$, with some scattered patches.

In contrast, field-inhabiting species were present in moderate numbers at the start of sampling, mostly towards the field centre (Figure 4.7). There was little increase in activity-density, although more patches in the grid adjacent to the hedgerow, over the following two months. Densities are higher near the beetle bank on the fourth date, but then there was a sudden large increase in activity-densities in the following month. Highest densities appear to have emerged within the middle of the field, and by the last date had spread across the field resulting in a scatter of clusters of high and lower density. *P. melanarius* strongly dominated catches towards the end of sampling, with considerable capture of *Nebria brevicollis* and *T. quadristriatus* also accountable for the pattern found.

Table 4.3 *Summary statistics indicating overall degree of clustering of carabids in the experimental fields, as indices* I_a *and associated probability* P_a

(Bold type indicates significant I_a *values > 1, where* $P < 0.05$*)*

Site A		date	1	2	3	4	5	6
			Mar	Apr	May	early Jun	late Jun	Jul
field 1	Boundary spp.	I_a	**2.421**	0.902	0.913	**1.948**	1.345	**2.085**
		P_a	**0.001**	0.650	0.620	**0.001**	0.062	**0.001**
	Field spp.	I_a	**1.866**	1.324	1.245	0.789	**2.267**	**2.194**
		P_a	**0.001**	0.075	0.10	0.876	**0.001**	**0.001**
field 2	Boundary spp.	I_a	1.244	1.335	**1.479**	**1.572**	**1.573**	**1.438**
		P_a	0.129	0.069	**0.027**	**0.016**	**0.011**	**0.034**
	Field spp.	I_a	1.028	1.073	**1.357**	**1.395**	**1.644**	**3.429**
		P_a	0.367	0.291	**0.045**	**0.042**	**0.012**	**0.001**
Site B	Boundary spp.	I_a	0.726	**2.802**	**3.534**	**3.98**	1.184	1.564
		P_a	0.870	**0.001**	**0.001**	**0.001**	0.209	0.066
	Field spp.	I_a	**3.376**	1.63	**1.963**	**3.369**	**1.94**	**2.644**
		P_a	**0.001**	0.052	**0.019**	**0.001**	**0.016**	**0.001**

4.2.3.3 Homogeneity within boundaries

Densities of overwintering carabids were found to depart significantly from a regular distribution along all three boundaries, when numbers found in turf samples were examined. However, those caught in pitfall traps were much more variably distributed, with homogeneous capture in some sites on sampling dates from winter through the spring and summer (Table 4.4). There was no consistent pattern apparent in the results.

Table 4.4 *Chi-square test statistics for homogeneity of carabid capture in boundary habitats*

(where * P<0.005, ** P<0.01 and *** P<0.001)

	Turf samples	Pitfalls							
		Jan	Feb	Mar	Apr	May	early Jun	late Jun	Jul
	χ^2_{14} =	χ^2_{9} =							
Site A – BB	99.20 ***	-	-	10.00 n.s.	10.00 n.s.	13.91 n.s.	20.81 *	28.52 ***	23.15 **
Site B – BB	41.83 ***	8.33 n.s.	11.34 n.s.	46.14 ***	53.51 ***	7.90 n.s.	16.56 n.s.	33.50 ***	-
Site B – hedge	49.24 ***	11.86 n.s.	4.35 n.s.	22.20 **	40.90 ***	8.20 n.s.	51.73 ***	39.17 ***	-

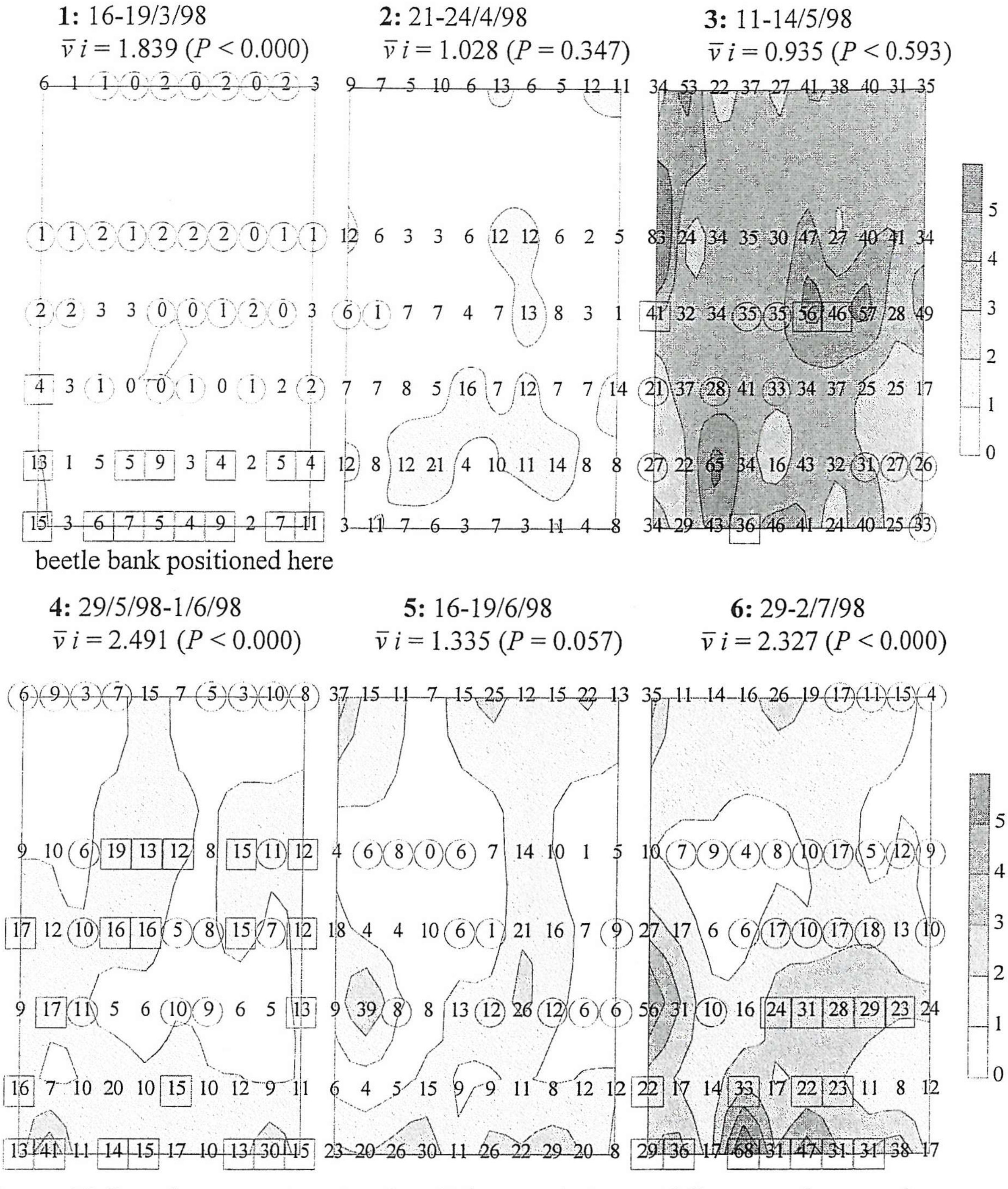
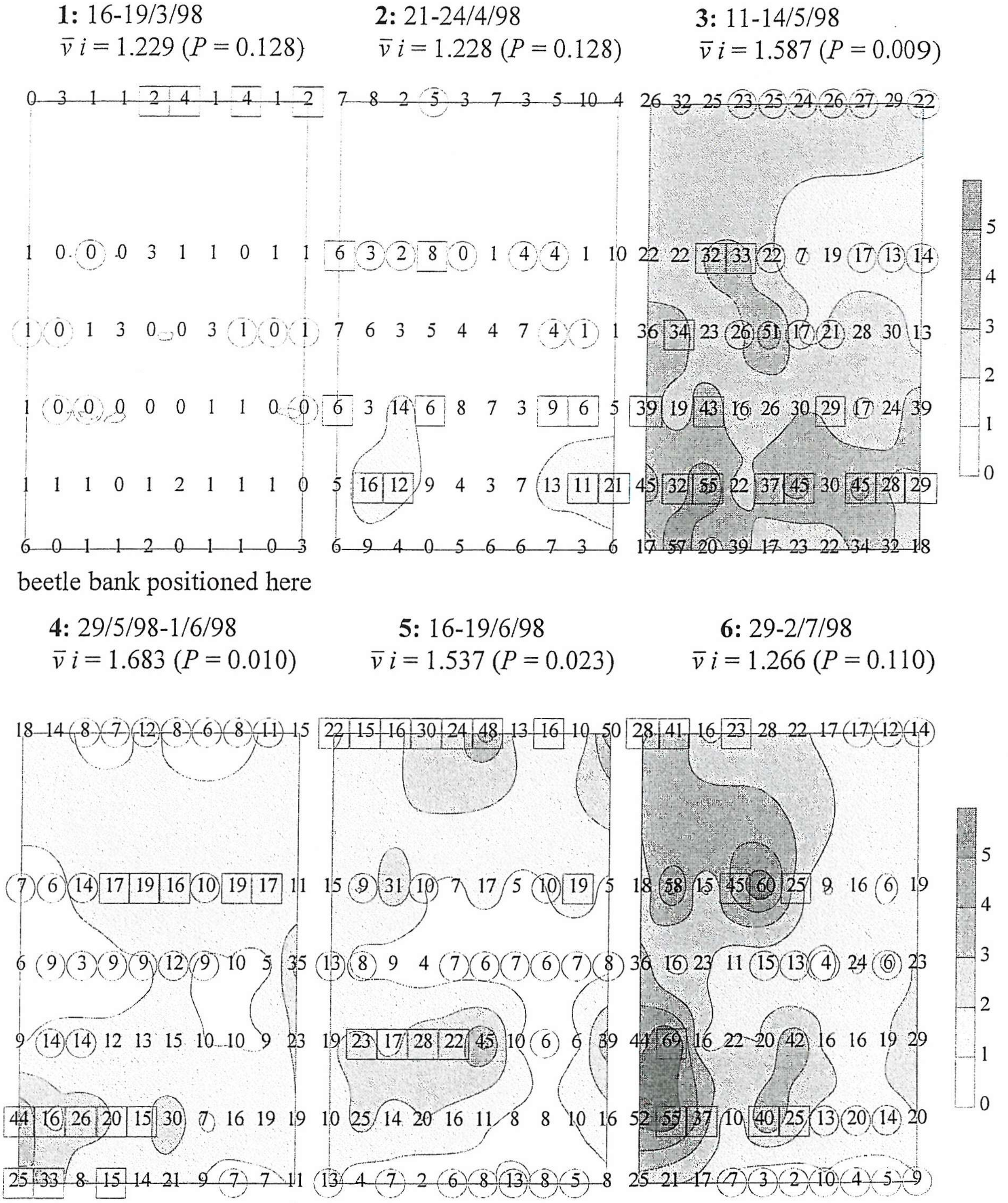


Figure 4.2 *Boundary-overwintering Carabidae caught in a pitfall trap grid across the first winter barley field, Site A, at intervals through spring 1998, categorised by interpolated contouring into equally spaced shaded density classes*

At each sampling point, above-average clustering into patches of greater than average neighbouring counts is measured by the clustering index vi. Counts strongly exceeding the mean, where vi > 1.5, are surrounded by a square. Below average clustering causing gaps of less than average neighbouring counts is measured by the clustering index vj. Strong indication of gaps is indicated by values surrounded by circles, where vj < -1.5. The average patch clustering value for the entire sample, vi, is given above the map, with its statistical significance on the null hypothesis that the observed counts were arranged randomly amongst the sample units.



1: 16-19/3/98
$\bar{v}_i = 1.229$ ($P = 0.128$)

2: 21-24/4/98
$\bar{v}_i = 1.228$ ($P = 0.128$)

3: 11-14/5/98
$\bar{v}_i = 1.587$ ($P = 0.009$)

beetle bank positioned here

4: 29/5/98-1/6/98
$\bar{v}_i = 1.683$ ($P = 0.010$)

5: 16-19/6/98
$\bar{v}_i = 1.537$ ($P = 0.023$)

6: 29-2/7/98
$\bar{v}_i = 1.266$ ($P = 0.110$)

Figure 4.3 *Boundary-overwintering Carabidae caught in a pitfall trap grid across the second winter barley field, Site A, at intervals through spring 1998, categorised by interpolated contouring into equally spaced shaded density classes*

Notation, symbols and methodology follow Fig. 4.2. i.e. O: significant gap-clustering, □: significant patch-clustering.

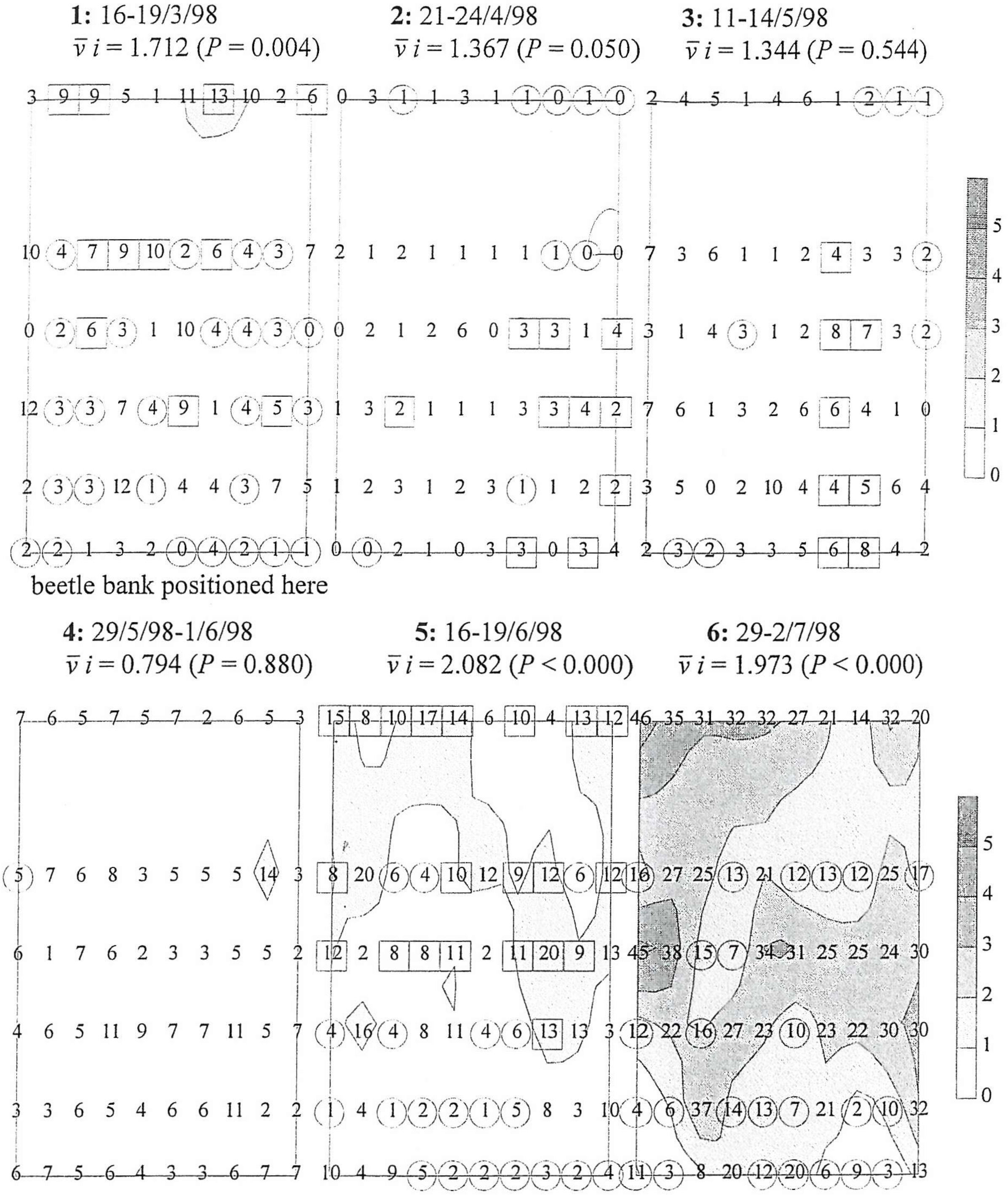


Figure 4.4 *Field-inhabiting Carabidae caught in a pitfall trap grid across the first winter barley field, Site A, at intervals through spring 1998, categorised by interpolated contouring into equally spaced shaded density classes*

Notation, symbols and methodology follow Fig. 4.2. i.e. O: significant gap-clustering, ☐: significant patch-clustering.

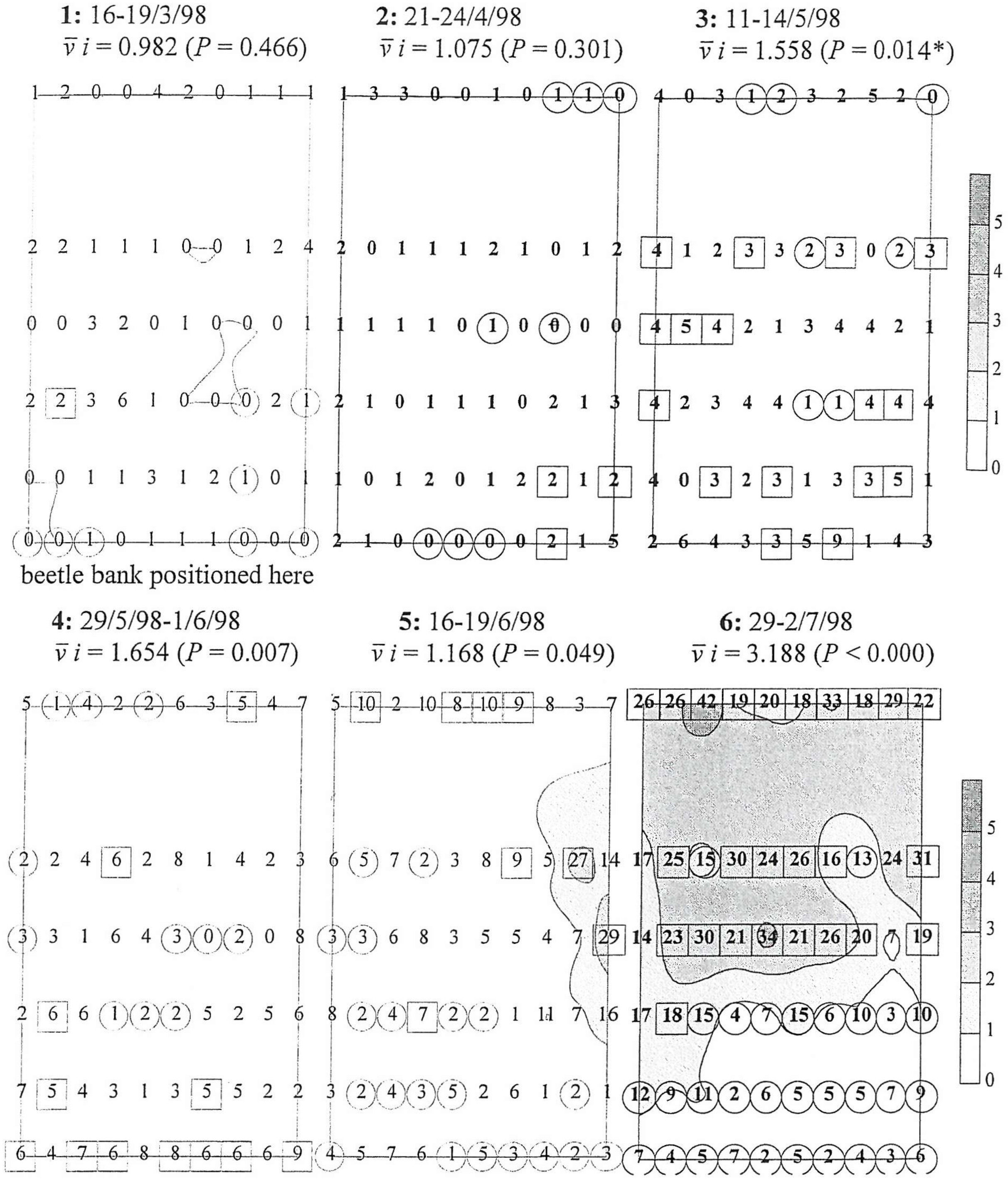


Figure 4.5 *Field-inhabiting Carabidae caught in a pitfall trap grid across the second winter barley field, Site A, at intervals through spring 1998, categorised by interpolated contouring into equally spaced shaded density classes*

Notation, symbols and methodology follow Fig. 4.2. i.e. O: significant gap-clustering, ☐: significant patch-clustering.

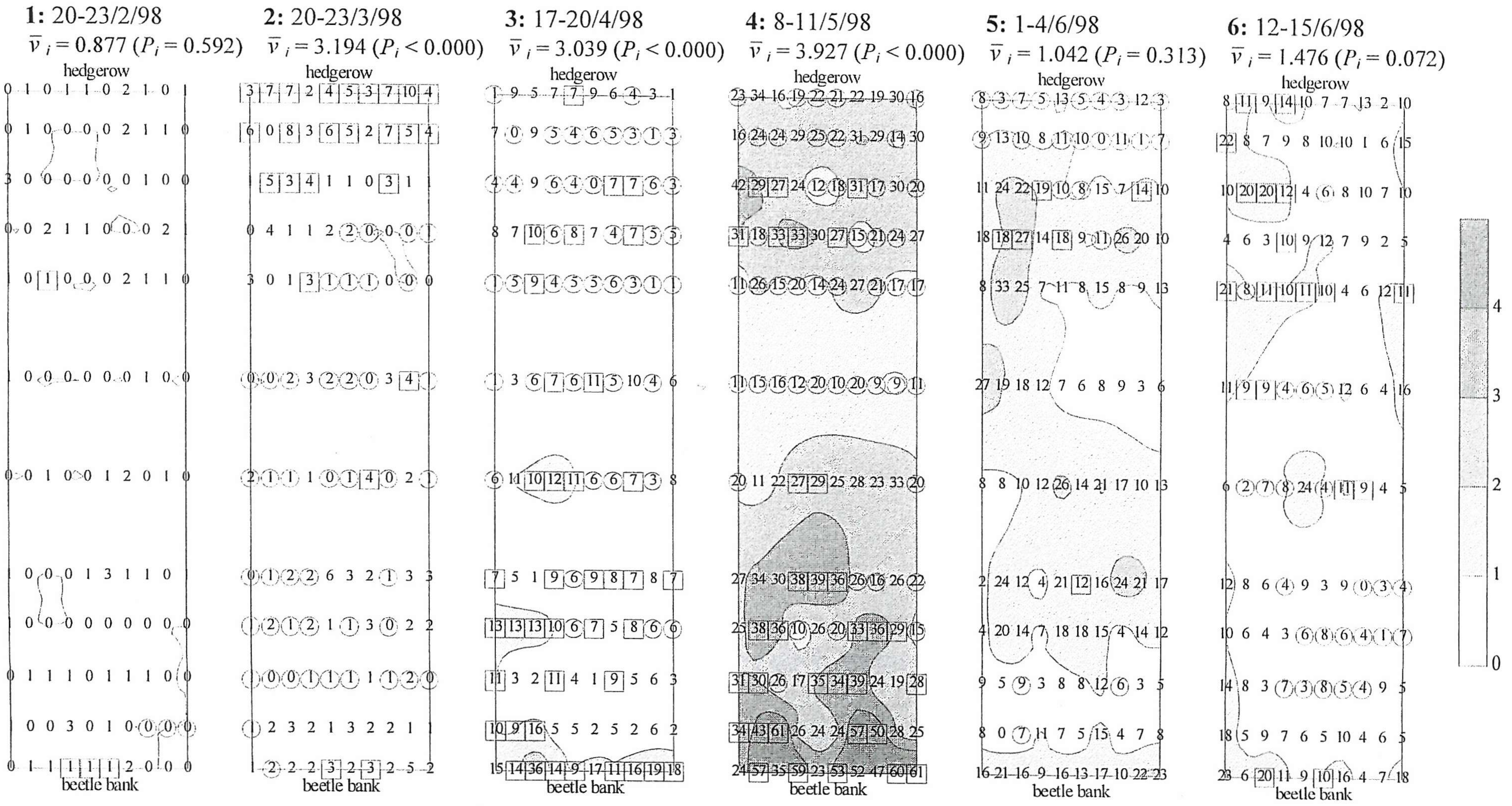
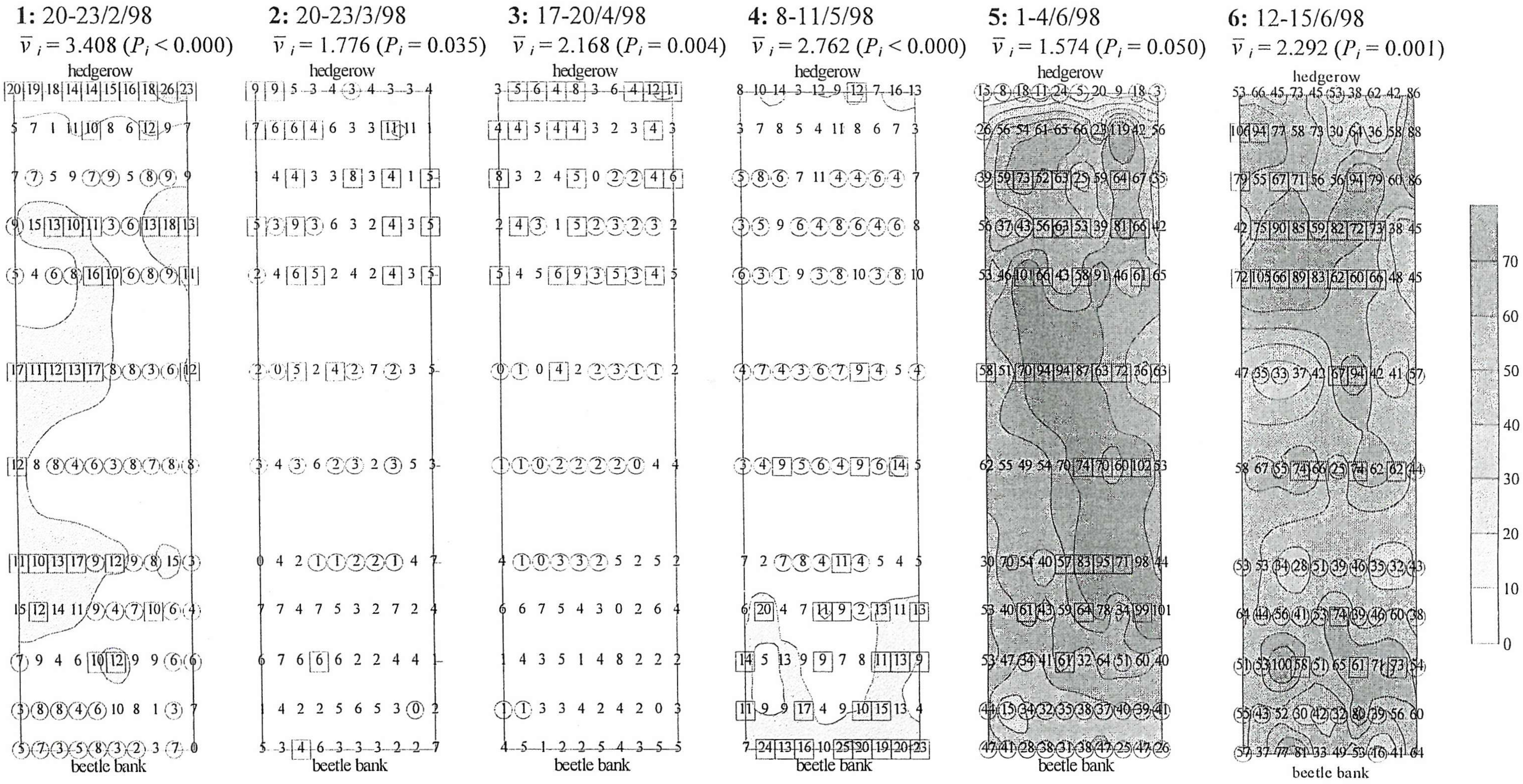


Figure 4.6 *Boundary-overwintering Carabidae caught in a pitfall trap grid across the winter wheat field, Site B, at intervals through spring 1998, categorised by interpolated contouring into equally spaced shaded density classes*

Notation, symbols and methodology follow Fig. 4.2 where O: significant gap-clustering,□: significant patch-clustering.



1: 20-23/2/98 $\bar{v}_i = 3.408$ ($P_i < 0.000$)

2: 20-23/3/98 $\bar{v}_i = 1.776$ ($P_i = 0.035$)

3: 17-20/4/98 $\bar{v}_i = 2.168$ ($P_i = 0.004$)

4: 8-11/5/98 $\bar{v}_i = 2.762$ ($P_i < 0.000$)

5: 1-4/6/98 $\bar{v}_i = 1.574$ ($P_i = 0.050$)

6: 12-15/6/98 $\bar{v}_i = 2.292$ ($P_i = 0.001$)

Figure 4.7 *Field-inhabiting Carabidae caught in a pitfall trap grid across the winter wheat field, Site B, at intervals through spring 1998, categorised by interpolated contouring into equally spaced shaded density classes*

Notation, symbols and methodology follow Fig. 4.2 where O: significant gap-clustering,□: significant patch-clustering.

4.2.4 Discussion

As the experiment occupied an extended period of carabid emergence, considerable variation in temporal-spatial distribution was both expected and found. This result conforms to previous studies of spatial pattern (Thomas, Parkinson & Marshall, 1998; Holland *et al.*, 1999). The simplistic groupings used here were justified despite the considerable difference in phenology between many species. An understanding of the overall distribution of predators is as valuable as information relating to individual species when considering the siting, quality and influence of overwintering edge habitats, and within-field farming practices. Cereal aphids were only present at very low densities throughout the season therefore the direct biocontrol benefit to farmers of establishing beetle banks across arable fields could not be confirmed. However, because the value of polyphagous predators that utilise beetle banks has been demonstrated (Holland & Thomas, 1997a & b), it can be assumed that beetle banks make a useful contribution to pest control.

The strong patch clustering seen alongside the beetle bank further support the concept of a wave of boundary overwintering predators, predominantly of species such as *B. lampros* and *A. dorsale*, dispersing over a short period, supporting the findings of Kromp & Nitzlader (1995), Coombes & Sotherton (1986) and Jensen *et al.* (1989). However, densities of field-emerging species remained very low until late in the season in this study, and thus may be less valuable for the control of developing pests. This would suggest that within-field conditions might need further improvement if this second group is to be encouraged. Undersowing, inter-cropping and conservation headlands, techniques which increase vegetation levels within the field, have all been shown to increase the diversity of beneficial arthropods (Thomas, 2000a); indeed Holland *et al.* (1999) describes how some carabids, notably most but not all spermophagous species, were positively associated with percentage weed cover. These techniques may warrant greater consideration for future integrated pest management. Pest control may not be adequate if it relies principally on early inward-dispersing species. Within-field habitat quality for carabids was considered to be a crucial factor for their population densities by Kromp & Nitzlader (1995), who found evidence for migration between edge habitats and the field only with a few species, the majority being field resident.

In other studies often a small number of transects have been used, primarily because of labour demands, with the presentation of only statistical mean and variance heterogeneity across fields. Interactions between the effects of distance and time may be seen, but as here, are difficult to interpret. SADIE includes the spatial information at all sampling locations in the analysis. It quantifies the spatial pattern in a sampled population by measuring the total effort, in terms of the distance moved, that the individuals in the observed sample must expend to move to extreme arrangements, such as where they are spaced as regularly as possible. Thus SADIE provides a means of assessing the significance of clusters, which may not always be apparent visually, and is a valuable tool. An additional benefit of the method is that it is able to work on irregularly spaced grids such as within this experimental set-up (Perry, 1998).

The distributions of Carabidae were clearly heterogeneous in their temporal-spatial arrangement, with patches of high and low activity-density not stable from one sample date to the next. There were no persistent 'hot-spots' of activity in any of the fields following visual inspection of the data. The use of SADIE to calculate indices of association, to test for spatial stability of aggregation pattern through time, would be an interesting future extension to this study. Thomas *et al.*, (1998) found positive, significant associations between spatial distributions of *Pterostichus melanarius* through consecutive weeks. However, associations between the first and last sampling periods, a month or more apart, were not significant. As sampling was carried out only monthly in the experiment described here, it is also unlikely that there would be strong associations between patterns, as this allows too long a time for redistribution of beetles in response to subtle prey density, microclimate or edaphic factors in the field.

Although the results of the spatial analysis indicated that there was significant heterogeneity in distribution, there were no gaps across the field that were truly depleted of carabids. Insecticides were not required through the spring and summer, suggesting that adequate natural regulatory control was taking place, despite climatic conditions in spring that might have been expected to favour pest outbreaks. Regular monitoring found negligible levels of cereal aphids across the field, precluding tests of association between them and activity-densities of predators. Winder *et al.* (1999) evaluated aphid spatial patterns, finding them relating to scale of sampling and the field edge, although ephemeral overall. In follow-on experiments it would be valuable to be able to overlay the spatial patterns of predators and pests, to determine if lower pest densities are directly related to locations where there are higher densities of predators or whether other biotic and abiotic factors contribute to such distributions. Holland *et al.* (1999) were not able to demonstrate associations between carabids and aphids but this has since been achieved (Winder *et al.* in prep).

Subtle differences in crop density, weed presence, distribution of preferred prey, soil topology and drainage are known to be responsible for the location preferences of individual carabids (Thiele, 1977), characteristics that are difficult to map accurately. However, such factors, alongside the question of patch persistence, would be interesting to investigate with respect to longer-term management to enhance populations of predatory Carabidae in arable fields.

The minor differences in distribution patterns between the barley fields at site A, or between grids in the same field at site B, are difficult to explain. Characteristics of crop density, weed presence, soil topology and drainage were extremely similar in each place, and so few differences in invertebrates would be expected. However, invertebrate distributions within fields are known to depend upon subtle microclimate differences, and can be highly species-dependent. Many autumn breeding species are active at night, preferring locations of higher humidity, whereas the more frequently day active spring breeders may be found in warmer, sun-exposed areas of a field (Wallin, 1985). Spermophagous species prefer increased weed cover, other species select areas where they can shelter under stones, and small localised differences in humidity, exposure and the distribution of preferred prey (Bryan & Wratten, 1984; Wallin, 1986; Honêk, 1988; Holland *et al.*, 1999) may influence the abundance of many carabids. Whether there is interaction between such factors or not for individual species is also not clear. For example, following the dispersal of *A. dorsale* into the crop, Jensen *et al.* (1989) found capture correlated with percentage weed cover, and were also probably in aggregations of highest prey availability, as the prey was found mostly within areas of early developed plant communities. Other species captured did not correlate with weeds. The measure of such variables across an entire field is immensely laborious, and the degree of variation that might be expected would require untenable replication of the experimental design used here.

An examination of how patches of high predator densities persist through time would be informative with respect to longer-term management of fields, and would require the continuation of a study such as carried out here for a number of years within the same sites. Luff (1982) found that some field-inhabiting carabids did not vary much in abundance in an arable field over a study spanning nine years, although in another study examining carabid distributions in arable fields, Wallin (1985) suggested that fluctuations were likely from year to year. These probably relate to the individual microclimates within different crops, although field topography may be responsible for the similarity of patterns over longer time periods.

There was considerable variation in the distribution of overwintering Carabidae found by turf sampling within the boundary habitats. This result corroborated work by Coombes & Sotherton (1986), who found that early spring suction sample densities of the most common Carabidae species recorded, *D. atricapillus* and *B. lampros*, were significantly heterogeneous in the boundary. In comparison, levels of activity-density found in the pitfall traps around the same time were homogeneous. This suggests that although there was clumping of those beetles sheltering within the turf, those individuals actually surface-active and thus trappable in activity-dependent pitfalls were dispersed fairly evenly within the habitats. However, later in the season, when warmer temperatures mean greater Carabidae activity, distribution patterns were very variable and followed no particular trend in any of the habitats sampled. Thus there was little evidence to suggest that areas of high carabid activity-density in the field later in the year were influenced by 'hot-spots' within immediately adjacent boundaries.

One question remaining is whether Carabidae activity-densities measured in pitfall traps set within the beetle banks and hedgerow correlate with the activity-densities found out in the field traps. Coombes & Sotherton (1986) found significant correlations between overwintering densities per m^2 of *A. dorsale* and *B. lampros* measured by soil sampling in the boundary, and their respective densities caught in pitfall traps at 10m distance from the boundary. They also took suction samples at 5m into field in spring and found these correlated with overwintering densities in the soil taken earlier, and also spring suction samples in the boundary. However, in a more intensive part of the study, soil densities of Carabidae in boundaries and their spring densities at 5m into the adjacent field were not found to show any correlations at any point during the month of sampling, the dispersal period of these species. It was suggested that as numbers in the field did not reflect overwintering densities in immediately adjacent habitats, then there was probably a 'rapid fanning out from local boundary foci' (Coombes & Sotherton, 1986).

Here, it was not possible to examine formally overwintering densities of Carabidae with those caught within the field in spring, as the sampling points were not directly aligned. Certainly visual observation of the data did not suggest that carabid capture in the pitfalls set within the beetle banks and hedgerow showed any association with those caught in neighbouring field traps, on any particular date. However, capture within dense vegetation is known to be very different from that within the more open stand in a cereal crop (Honêk, 1988; Melbourne, 1999), so that the two data sets are not comparable.

Pitfall traps have been criticised considerably because they provide a composite measure of abundance and activity of invertebrates caught. Capture rates may thus vary according to species, sex, hunger, prey availability and also temperature, habitat structure and terrain, trap visibility, spacing and other factors (Luff, 1975; Adis, 1979; Honêk, 1988; Topping & Sunderland, 1992; Digweed *et al.*, 1995; Hawthorne, 1995; Sunderland *et al.*, 1995). However, other sampling methods would have been too laborious and disruptive to the experimental layout, and not necessarily comparable with other similar published work. Identically and carefully installed traps at all sampling points within the grids, as suggested by Holopainen (1995), probably minimised capture differences. In fact, despite limitations, this trapping method could be considered as suitable for comparative work within a single habitat type, as measuring activity-density is a better measure of the level of predation than absolute measures of population density. Movement patterns of polyphagous predators influence the rate of prey encounters (Thiele, 1977), and so pitfall catch more realistically represents what biocontrol may be occurring across the field. Arguments such as proposed by Lang (2000) that where epigeal invertebrates are to be studied on arable land, then absolute density estimates should be calculated using a range of sampling methods, are not necessarily valid or feasible. Holland & Smith (1999) found that capture composition in unfenced pitfall traps was often very similar to that recorded in fenced traps, although the latter technique is labour-intensive and has yet to be standardised.

One problem observed during this study, and also recorded by others (Thomas *et al.*, 1998; Powell *et al.*, 1995) is that of soil fissure formation in very dry weather. After prolonged sun, many clay soils contract. The deep cracks that form in the surface may act both as pitfalls themselves, limiting the efficiency of the existing traps, or increase the overall surface area of the field such that the movement of predators is slowed and encounter rates with traps decreased. These effects have yet to be quantified by anyone, although Thomas *et al.* (1998) suggest that they should be considered, especially if compounded with treatment effects and intermittent sampling regimes, and can result in potentially spurious activity-density data. In fact, they considered the production of such spurious data a major problem. In their regime, sampling occurred every other day, in contrast to most studies including this present one, where only infrequent sampling was used. As a consequence, they concluded that this would provide only low resolution of true time-related activity-density patterns.

4.3 Effects of insecticide on Carabidae dispersal patterns

4.3.1 Background and aims

The process and rate by which predators can re-invade insecticide-treated crops has been examined in small within-field plots by Thacker & Jepson (1993) and Duffield & Aebischer (1994). Results indicate that the time taken for invertebrates to re-invade and recover to pre-treatment levels in the centre of treated plots was directly correlated with plot size, thus predator re-invasion from field margins into large treated fields may take many weeks. As a consequence, field scale applications of broad-spectrum insecticides have been shown to result in aphid resurgence as a result of reduced predator pressure (a product of limited predator re-colonisation) at the field centre (Duffield & Aebischer, 1994). In theory, the presence of beetle banks dividing large fields into smaller units should allow a faster re-invasion of depleted invertebrate populations in pesticide-treated fields, therefore preventing pest resurgence and the need for further pesticide applications. However, this assumes that there is a 'reservoir' population of predators that continue to disperse into crops, responding to resurgent prey levels, which may not be the case. Following the main experiment on carabid dispersal, I aimed to compare the activity-density of carabids within the field pre-spray and post-spray, and assess whether there was evidence for population recovery from either the boundary habitats or from within the field. I also looked for indications that dispersal was still occurring into the field from the boundary using a mark-release-recapture method.

4.3.2 Methods

Dimethoate, an organophosphate pesticide (BASF Dimethoate 40) was applied at full field rate (850ml a.i. in 200 litres water per hectare) to the winter wheat field, site B, on 16th June. This chemical was chosen as it has known detrimental effects on non-target invertebrates, whilst having less influence on invertebrate behaviour than pyrethroid insecticides.

The pitfall grid was opened for two further trapping sessions following application, on 18-21/6/98 and 6-9/7/98. Further trappings had been planned but were not possible because of the approaching harvest. The SADIE technique was used as previously to see if the activity-density of Carabidae was significantly clumped alongside the boundaries initially after the application, and whether this was sustained at a later date.

Additionally, carabids were collected by dry trapping and surface searching from the boundaries, marked, and released back at the capture sites, to establish whether there was recapture at distances out into the field within the subsequent pitfall trap openings. Four hundred each of *Nebria brevicollis* and *Pterostichus madidus* were collected from the beetle bank and hedgerow base within site B. Rapid-drying white correction fluid was applied to the elytra, and 20 beetles of each species were released back at 10m intervals along each of these habitats on 17/6/98, a day after the insecticide application. A second collection of 500 *P. madidus* was made in the boundaries, marked on a different part of the elytra, and released on 1/7/98, also at 10m intervals in the habitats. Pitfall trap catch was recorded and percentage recapture and average distance travelled per day calculated for each species. These two species were selected as they were abundant in the boundaries, and sufficiently large to allow rapid elytral marking.

4.3.3 Results

There was only low capture of boundary-species of Carabidae in the field immediately prior to insecticide application, although these were fairly randomly distributed. From 2-5 days following the spray, there was depletion of these beetles, although there were some patches of high activity-density immediately adjacent to the beetle bank and in the area of the field near to the hedge. Overall, there was no significant aggregation across the field (Table 4.5). At 20-23 days later, there were higher levels of activity-density near the hedge, but significant gappiness close to the beetle bank. Although capture exceed pre-spray levels by this time, the whole field was shown to be significantly more heterogeneous in boundary carabids (Table 4.5; Fig. 4.9).

Prior to the spray, there was high capture of field-species of Carabidae, in a significantly heterogeneous distribution (Table 4.5), containing several patches of high activity-density. The treatment caused a substantial depletion of catch, but also resulted in a more homogeneous spatial pattern overall. After three weeks, the carabids were significantly heterogeneously distributed again, with most significant patches adjacent to the hedgerow and strong gappiness near to the beetle bank (Table 4.5; Fig. 4.10).

Table 4.5 *Summary statistics indicating overall degree of clustering of carabids in Site B, as indices I_a and associated probability P_a*

(Bold type indicates significant I_a values > 1, where $P < 0.05$)

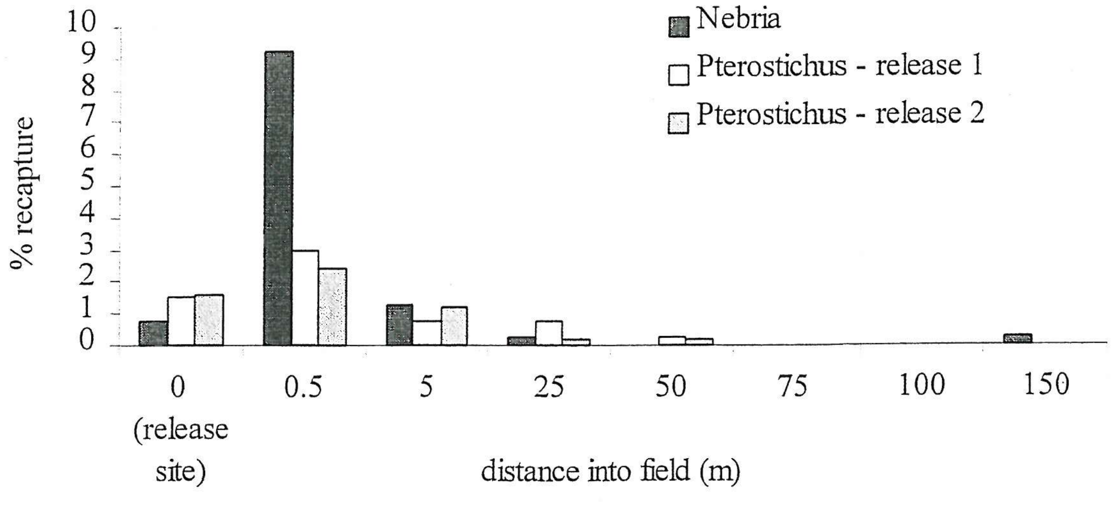
	date	6 - pre-spray	7 - post-spray	8 - post-spray
Boundary spp.	I_a	1.564	1.233	**2.223**
	P_a	0.066	0.168	**0.004**
Field spp.	I_a	**2.644**	1.5	**2.853**
	P_a	**0.001**	0.081	**0.001**

There was 11.8% recapture (47 individuals) of *N. brevicollis* recaptured on the first trap opening, four days following release. Three-quarters of these were caught in the traps 0.5m from the release sites, although one was found in a trap at 150m into the field. Beetles had moved an average of 4.7m since release, giving an average of 1.2m per day (Fig. 4.8).

There was 6.3% recapture of *P. madidus* (25 individuals), with half of these caught in the 0.5m located traps. None was recovered further than 50m into the field, and overall, the average distance covered was 5.8m in the four days, with an average of 1.5m per day. Following the second release of *P. madidus*, only 5.6% were recaptured, with a mean distance moved of 4m over the eight days preceding trap opening. This gave a daily mean displacement of 0.5m (Fig. 4.8).

Only a single *N. brevicollis* from the first release was recaptured in the second pitfall trap opening, with this individual caught at 0.5m. No *P. madidus* from the first release were recovered in the second pitfall trapping.

Figure 4.8 *Percentage recapture of marked beetles at each distance into the field*



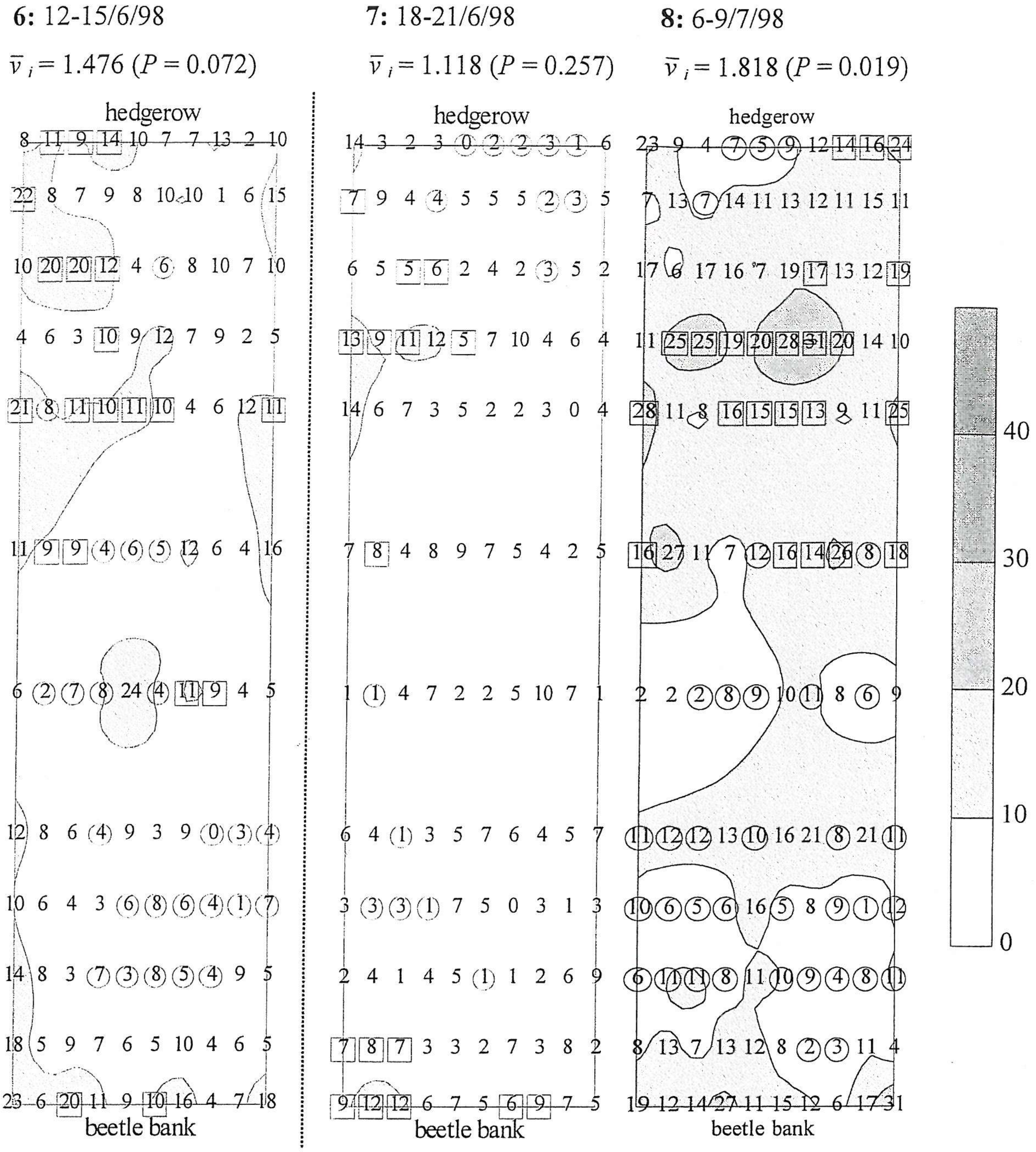


Figure 4.9 *Boundary-overwintering Carabidae caught in a pitfall trap grid across a winter wheat field, spring 1998, before and after an organophosphate application*

Dashed line indicates dimethoate application. Notation, symbols and methodology follow Fig. 4.2 where O: significant gap-clustering,☐: significant patch-clustering.

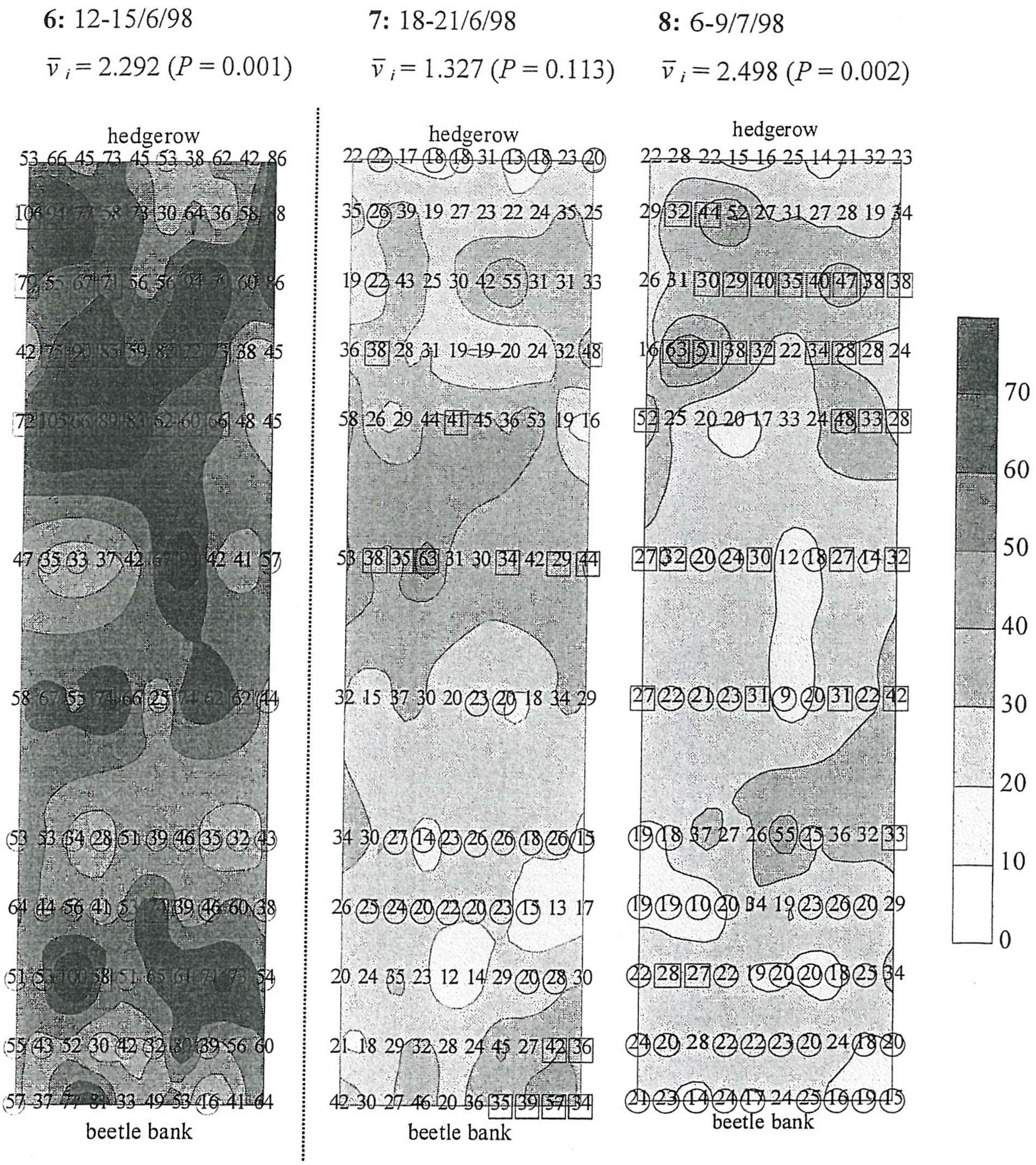


Figure 4.10 *Field-inhabiting Carabidae caught in a pitfall trap grid across a winter wheat field, spring 1998, before and after an organophosphate application*

Dashed line indicates dimethoate application. Notation, symbols and methodology follow Fig. 4.2 where O: significant gap-clustering,□: significant patch-clustering.

4.3.4 Conclusions

This assessment of spatial distribution patterns following insecticide application did not provide evidence for edge-mediated recovery of boundary-species of Carabidae. However, there was a considerable increase in activity-density from the first to the second post-treatment sampling events, and the time interval between these samples was over two weeks, thus any increase in predators by the edge habitats may not have been recorded. The significant patches seen especially around 75m into the field from the hedgerow may have resulted from dispersal from that source, but the interval was too great to allow confirmation. The much more numerous field species appeared to redistribute only in response to the treatment, and it is not clear why this may have happened. One factor that may have been responsible is that of increased activity of beetles following depletion of prey. Hungry carabids are known to be more active, potentially resulting in greater and more homogeneous patterns of capture across the field (Wallin & Ekbom, 1994). Any resurgence of aphids following the insecticide may then bring about the more clumped distribution of carabids on the second trapping, resulting from aggregation at such prey sources.

High levels of spatial heterogeneity of predator species are recognised as limiting the interpretation of insecticide effects (Mead-Briggs, 1998), as were found with the pre-spray distribution of field species. The full effects of an insecticide are also difficult to interpret where only small areas of a field are monitored (Mead-Briggs, 1998), and so although the experimental area covered the full width of the field from boundary to boundary, it only represented a slice of the total area and restricted a full appraisal of the spray impact.

Dimethoate is a systemic insecticide with some contact action operating by cholinesterase inhibition. It had been expected that a much stronger depletion of carabid activity-density would have been seen following application, but it is possible that the late timing of application had an impact. The wheat was at an advanced growth stage, and its dense canopy may have restricted deposition to the soil surface, where most species abundant at this time are active. It had been hoped that the application could have been made at an earlier stage of crop development, giving a more usual reflection of common farm practice to insurance spray against summer aphids. Unfortunately, this was precluded by inclement weather and crop lodging.

The small-scale mark-recapture experiment provided little evidence for net movement of carabids into the crop from the untreated boundary following insecticide application. Most recapture was near to the area of release, although more occurred at the edges of the field rather than in the source habitats themselves. However, results should be treated with caution, as it is possible there are several reasons why this limited dispersal may have occurred. The disturbance effect of capturing and handling the beetles has been shown to cause increased activity levels after release (Greenslade, 1964). Also, it might be expected that amongst a large number of beetles, there will always be some atypical movements by individuals, and the very small number caught out in field traps may have represented only such unusual individuals, rather than what happened with the majority. Finally, recapture within the source habitats may have been restricted because of the difficulties of movement within the denser vegetation. Permeability has been demonstrated as lower in grassy banks than within the crop (Frampton *et al.*, 1995). Recapture rates were much lower than the 40-60% found by Thomas *et al.* (1998), although more in keeping with the very low percentages found by Coombes & Sotherton (1986) and Jensen *et al.* (1989) for *Agonum dorsale.* A more extensive mark-release programme may have been more revealing.

Thomas *et al.* (1997) found that 60% of *P. melanarius* and *Harpalus rufipes* travelled only 0-2.5m per day, more in agreement with the results from the present study. However, the high probability of recapture at release sites probably underestimated true dispersal. The closure of traps for a period following release was suggested as a partial solution (Thomas *et al.*, 1997). Although in the present experiment traps were not opened for at least four days after release, most recapture occurred adjacent to release sites. Particularly in the case of *N. brevicollis*, this could actually have been a result of activity levels diminishing as the beetles approach diapause, which usually occurs in July and August (Penney, 1969). *P. madidus* was more mobile than *N. brevicollis*, as measured by average distances moved from source.

It is most likely that for both species, there was considerable loss of markings through the experiment. The longer the beetles were active before capture, i.e. the greater distances they were likely to have moved, the more chance that the markings became lost such as through abrasion with plants. Those within the source habitats may also have been more liable to lose markings. Carabid marking methods have been extensively assessed (e.g. Southwood, 1978; Frampton *et al.*, 1995), with the conclusion that painting methods are seldom persistent. Painting was chosen because of simplicity, rapidity, and availability of materials; however, it would have been preferable to use an alternative such as inscribing elytral abrasions with a model-makers drill, a recently developed innovative and successful technique (Thomas, 1995).

The difficulty of interpreting the results from this study mean that the validity of the results is questionable, although they provide insight into how the experimental design could be improved in a future study. The most important improvement would be to have run the experiment at an earlier stage in crop development. Then, penetration of the insecticide would have been more likely to reach the soil and eradicate a greater proportion of the predators in the field, and while dispersal was still expected from the edge habitats. Several more trap openings more closely spaced in time may also have provided better recapture rates.

4.4 Predatory Diptera

4.4.1 Introduction

Concerns about the widespread use of pesticides in agriculture, both in the UK and world wide, have led to the development of biological control programmes, to encourage and manipulate the numbers of predatory arthropods found naturally within farmland, to assist in the control of crop pests (Dent, 1990). Many groups of arthropods, such as beetles, spiders and parasitoids have been thoroughly studied (for example, Vickerman & Sunderland, 1975; Wratten *et al.*, 1984; Sunderland *et al.*, 1986; Wratten & Thomas, 1990; Powell *et al.*, 1995). However, despite being frequently recorded in arable fields, the Empididae family of predatory flies has received limited attention from researchers.

Most interest has focused on the many species that form mating-swarms, giving rise to the common name 'dance flies' for the Empididae; but little attention has been paid to the Tachydromiinae subfamily. Atypically, these are most frequently found walking on plants, only using short periods of flight for dispersal (Chvála, 1976). There are many species in this subfamily; for instance over 200 species of *Platypalpus* have been recorded in Europe (Grootaert, 1983), but much of the published literature is concerned only with description and classification.

Early studies were not always well quantified, but suggest that there is a high abundance of empids in arable crops. Crop type and locality may influence numbers (Potts & Vickerman, 1974). Some research indicates the potential of these insects for biological control. Stark & Wetzel (1987) recorded high population densities, up to 40-60 m^{-2}, of *Platypalpus* species within cereal crops. Adult Empididae densities from 18-43 m^{-2} were found by Heynen & Wuebbeller (1990). Brunel *et al.* (1989) found *Platypalpus* species dominated dipteran catch in rape field water traps, with the highest abundance near the plot borders and a fairly homogeneous distribution of catch at increasing distance across the fields. Seasonal trends in abundance in a wheat field were found by Longley (1997) in a study to determine efficient sampling methods.

Feeding habits are still not fully understood. Early observations suggested feeding occurs on pests such as *Oscinella frit* L. (frit flies) (Jones, 1969), *Sitodiplosis mosellana* Géhin, *Contarinia tritica* Kirby (wheat midges), *Chlorops* species (gout flies) and aphids (Potts & Vickerman, 1974). *Platypalpus* predated on species of greenhouse pests though avoided aphids in one study (Kuehne & Schrameyer, 1994), but in the open field, immuno-assay techniques indicated that this genus had consumed cereal aphids (Crook & Sunderland, 1984). Predation on frit flies and wheat midges has been reported more recently (Stark & Wetzel, 1987) in cereal crops.

Larvae of these flies live in the soil over the winter and emerge in spring, making them susceptible to mortality by soil cultivation techniques (Overgaard-Nielsen *et al.*, 1994). It was only recently discovered that they too are predatory (Cumming & Cooper, 1993) and may also assist with biological pest control, particularly of soil-living organisms such as other dipteran larvae. Spatial distributions of larvae, such as whether densities are different between crop edges and mid-field, have not been studied.

Within the agricultural landscape, hedgerows may provide shelter for adult empids and development sites for their larvae (Morvan *et al.*, 1994), although this may only be the case for selected genera such as *Hilara*. Other non-crop areas such as grass edges and beetle banks, which are protected from direct pesticide inputs and cultivation, may also be important in helping to maintain predatory fly populations. Larvae may survive more successfully in such undisturbed areas than within fields, and nectar and pollen feeding species may benefit from flowers present in field boundary habitats. *Platypalpus* may be seen on flowering plants (Chvála, 1976) where there may be associated increased prey densities. Beetle banks primarily provide overwintering refuges for polyphagous predators, compensating for reductions of suitable habitat such as hedgerow bottoms, by providing a simple, inexpensive alternative (Sotherton, 1995). Unlike field margins, with flowering species providing pollen and nectar resources, beetle banks are comprised mainly of sown grass species. It is currently not known how useful they might be to other invertebrates such as predatory flies.

This study examined the spatial and temporal distribution of empid predatory flies across a wheat field, and compared their abundance in relation to distance into the field from a hedgerow or beetle bank boundary. Densities of potential prey species were also evaluated to see if they coincide in time with the predatory flies. The effect of a summer pesticide application on these invertebrates was investigated.

4.4.2 Materials and methods

4.4.2.1 Study site and procedure

Empididae were monitored using sticky traps in a 25.4 ha field of winter wheat, variety Buster, sown in autumn 1997, on a Hampshire estate, UK (map reference: SU 593 534).

The sticky traps were constructed of 15 × 15 cm squares of transparent, odour-free adhesive film (Rentokil fly control film, Agrisense-BCS Ltd., West Glamorgan, UK.), which were curved into a cylinder, with a resulting diameter of approx. 4.8 cm. These were mounted onto transparent supporting plastic cylinders, vertically attached to bamboo canes, which were set into the ground. The sticky trap cylinders were placed so that they were always at flag leaf height of the developing crop, where maximum capture was previously found to occur (Longley, 1997).

More efficient capture has been demonstrated for cylindrical traps compared to flat section traps (Lewis, 1959; Longley, 1997). Though often used, flat traps tend to be blown so that they present only their edge to the prevailing wind direction, and the cylindrical design used here has been found to be optimal for minimising the effects of wind direction on trap position (personal observation). Empididae are attracted to yellow traps (Longley, 1997). The transparent traps used here allowed easier interpretation of capture from different field positions, by passively capturing insects flying within that area, rather than actively attracting them from unknown distances, depending on trap visibility.

Transects of sticky traps were positioned across the wheat field; two extending into the field at 90° from a *Dactylis glomerata* sown beetle bank and another two extending 90° from a woody hedgerow with established complex grassy bottom flora. Both boundaries were oriented N-S, with the beetle bank on the eastern side of the field and the hedgerow on the west. Traps were placed within these boundaries, and at distances of 5, 10, 25, 50, 75, 100 and 150 m from them along each of the transects. Trapping commenced on the 29th of May 1998, at approximately G.S. 49 (ear formation) (Zadoks *et al.*, 1974) and stopped on 27th

July, G.S. 93 onwards (when the crop was desiccated and nearing harvest), giving a total of nine weeks of capture. All sticky traps were replaced each week after a 5-day trapping period, when they were removed from their support cylinders and spread onto clear polythene. Samples were frozen and examined by light microscope. Species of predatory fly, Opomyzidae (cereal flies), Oscinellidae (frit flies), Chloropidae (gout flies), Cecidomyidae (orange wheat blossom midge) and cereal aphids were recorded.

4.4.2.2 Pesticide treatment

Dimethoate, an organophosphate pesticide (BASF Dimethoate 40) was applied at full field rate (850ml a.i. in 200 litre water per hectare) to the wheat on 16th June.

4.4.2.3 Analysis

Capture of abundant insects was analysed by repeated-measures ANOVA on log (x + 1) transformed data, with week as the within-subject factor, beetle bank or hedgerow as a between-subject factor, and distance into the field as a covariate. If capture of a species was infrequent, all weeks were pooled to carry out an ANOVA on log (x + 1) transformed data, with adjacent habitat and distance as between-subject factors.

Numbers caught on traps immediately before and after the dimethoate application were transformed as before. A repeated-measures ANOVA, with date pre- and post-spray as within-subjects factor, and adjacent edge habitat as between-subject factor, was performed to examine the impact of the treatment on abundance across the field.

4.4.3 Results

Empididae of the genus *Platypalpus* dominated capture throughout the trapping period. Species of the genus *Empis* were caught infrequently, and no other predatory fly species were seen.

4.4.3.1 Platypalpus species

Numbers of *Platypalpus* species caught increased greatly between the first and second weeks and were reduced in the fourth week following pesticide application. Numbers recovered in the area bordered by the beetle bank, though not in the area by the hedgerow. Capture was lower in both areas for the remainder of the sampling period (Figure 4.11).

A significant interaction was found between week and type of adjacent field boundary habitat ($F_{8, 224} = 5.02$, $P < 0.001$), though not between week and distance ($F_{8, 224} = 1.96$, $P =$

0.053). There was a significant difference in weekly capture of *Platypalpus* species ($F_{8, 224}$ = 14.9, $P < 0.001$), and in capture with respect to distance across the field ($F_{1, 28}$ = 17.7, $P <$ 0.001). Greater numbers of flies were caught within the edge habitats, than with the field (Figure 4.12). Overall, there was no difference between numbers caught from the two areas with different adjacent habitat ($F_{1, 28}$ = 0.64, $P = 0.43$), and no interaction between distance and habitat ($F_{1, 28}$ = 1.12, $P = 0.3$).

There was a significant decrease in mean numbers of *Platypalpus* species post dimethoate treatment ($F_{1, 28}$ = 38.8, $P < 0.001$). Interactions were not significant between pre/post spray date and adjacent habitat ($F_{1, 28}$ = 1.17, $P = 0.29$), between date and distance ($F_{1, 28}$ = 1.37, $P = 0.25$) or between date, distance and habitat ($F_{1, 28}$ = 0.99, $P = 0.33$).

Figure 4.11 *Mean number of* Platypalpus *species captured per trap (+ SE) in each sampling week, in areas with different adjacent field boundary habitat*

Data pooled for all distances into the crop. (Arrow denotes sample after pesticide application).

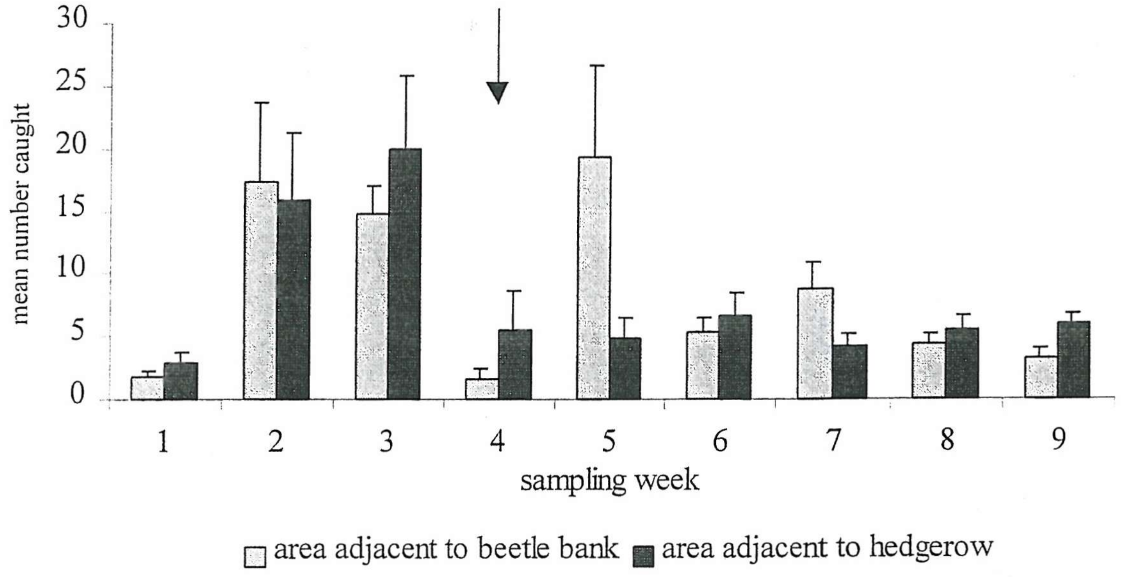
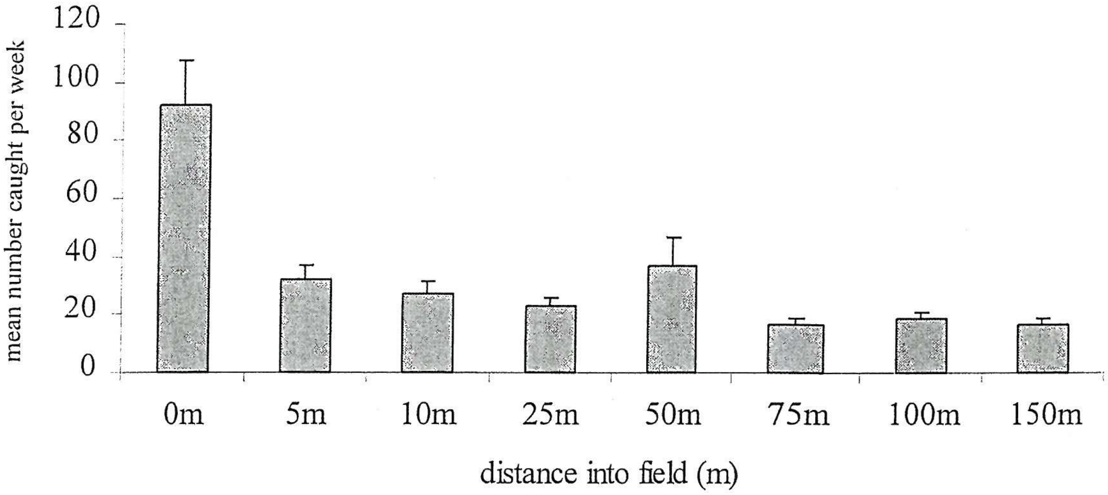


Figure 4.12 *Mean weekly number (+ SE) of* Platypalpus *species captured at each distance into the field, pooling transects from different adjacent field boundary habitat*

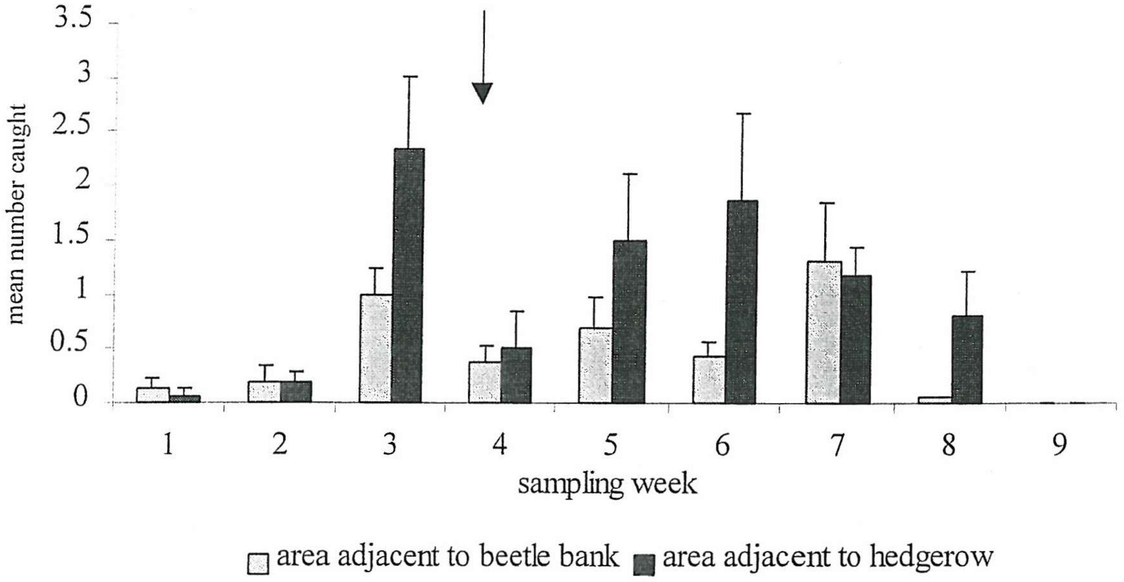


4.4.3.2 Empis species

Numbers of *Empis* species increased in the third week of sampling, were reduced in the week following pesticide application, and were higher again in the following week, although had virtually disappeared by the final week (Figure 4.13). Overall, greatest capture occurred in traps within the hedgerow itself, with numbers on the beetle bank traps and at all other distances across the field being low. All weeks were combined to examine the relationship between capture and distance across field in each of the two areas. There was a significant difference according to distance ($F_{7, 16} = 4.92$, $P < 0.01$), but not between capture in each of the habitat types ($F_{1, 16} = 0.11$, $P = 0.75$). The interaction between the factors was also non-significant ($F_{7, 16} = 2.12$, $P = 0.10$). Numbers were too low to examine the effects of the pesticide spray.

Figure 4.13 *Mean number of* Empis *species captured per trap (+ SE) in each sampling week, in areas with different adjacent field boundary habitat*

(Arrow denotes sample after pesticide application).



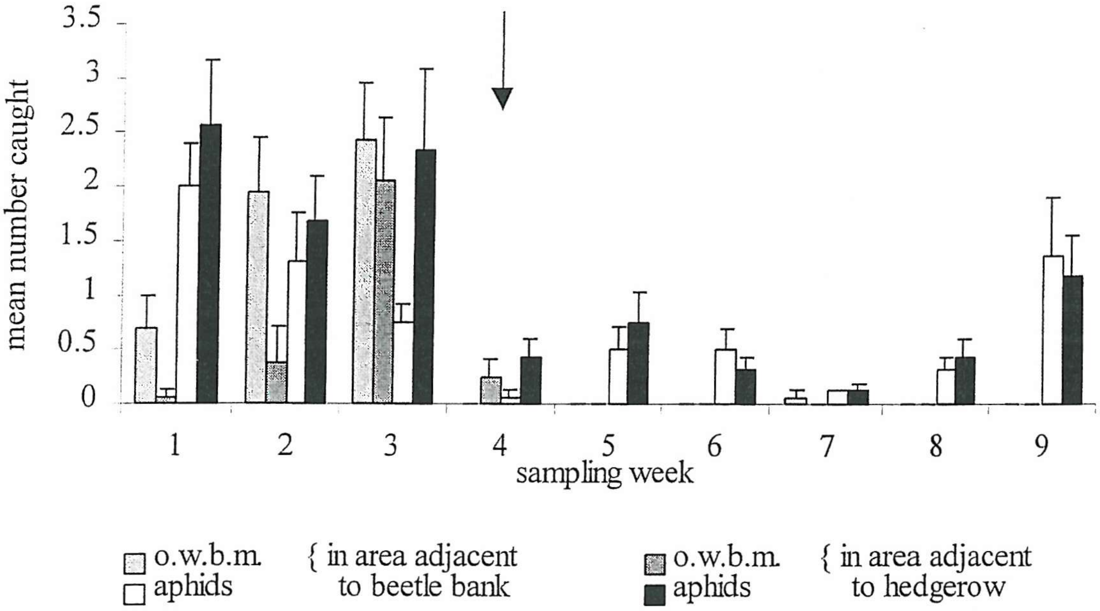
4.4.3.3 Pest (prey) species

Catches of cereal, frit and gout flies were negligible and so were not analysed. Orange wheat blossom midge showed very low abundance, especially after the pesticide application (Figure 4.14). The aphid population remained low before the spray, and although clearly reduced after, remained present at low levels in the crop throughout the trapping period (Figure 4.14), with a trend for increase at the end of the experiment. When weekly capture was pooled, capture by the edge of the field was significantly higher than elsewhere ($F_{7, 16} = 4.43$, $P < 0.01$), though there was no difference between habitats ($F_{1, 16} = 0.34$, $P = 0.57$). The interaction between habitat and distance into the field was not significant ($F_{7, 16} = 1.63$, $P = 0.20$)

There was a significant decrease in cereal aphids post dimethoate ($F_{1, 28} = 8.65$, $P < 0.01$). Interactions were not significant between pre/post spray date and adjacent habitat ($F_{1, 28} = 0.001$, $P = 0.98$), between date and distance ($F_{1, 28} = 1.60$, $P = 0.22$) or between date, distance and habitat ($F_{1, 28} = 0.02$, $P = 0.90$).

Figure 4.14 *Mean capture per trap (+ SE) of orange wheat blossom midge (o.w.b.m.) and cereal aphids each week*

(Arrow denotes sample after pesticide application).



Sticky traps are considered an unsatisfactory method for assessing aphid densities, as they may be blown onto the traps (Winder, 1990) or may be knocked onto them during collection. However, tiller observations during the course of the experiment supported these trends in aphid number.

4.4.4 Discussion

High numbers of between 1 to 20 flies were caught passively on small, non-attractive traps across the field. These results are comparable with the high densities given by other researchers who used coloured, attractive traps, drawing flies in from a possibly extensive area (Stark & Wetzel, 1987; Heynen & Wuebbeller, 1990; Stark, 1990). The flight period of *Platypalpus* species was also in accord with that of other researchers (such as Grootaert, 1981), extending through the period of crop development. Three weeks later, suction samples taken within the vegetation of the beetle bank and hedgerow found that empids were no longer present (data not presented).

Increased numbers at the edges of the field may have been in response to greater prey availability there. *Platypalpus* species were most probably feeding on the elevated prey densities at the field edges, which may be associated with more complex vegetation even in the florally impoverished beetle bank. *Empis* species, known to be at least partially flower-feeders (Chvála, 1976), may have been utilising increased pollen and/or nectar resources in the hedgerow.

Farmers may be reluctant to reconstruct expensive field boundaries, but may consider low-cost habitat such as beetle banks, and this study indicated that these may support as many *Platypalpus* as a hedgerow. More such habitat on farmland is undoubtedly beneficial for increasing invertebrate diversity, especially of these predatory flies. When higher pest numbers develop within the crop, such predators may respond by increasing penetration into the field from the margin to feed on them, easier where field sizes are effectively reduced by the insertion of beetle banks.

Platypalpus numbers recovered within and near the beetle bank, after the pesticide spray, which was not the case at the hedgerow location. Wind direction may have been a contributory factor, being mostly towards the hedge through the experimental period, which may have led to unintended drift and more active ingredient depositing into the hedgerow. There also may have been greater soil emergence of empids within the beetle bank. Further work to investigate the suitability of such habitats as reproduction and pupation sites would be useful, especially to evaluate whether there was greater survival of predatory flies within them compared to the open field or other field margins.

Such summer pesticide applications are not desirable because of the risk to populations of beneficial insects, such as these flies (Holland, 1998). Pests such as cereal aphids may produce a reproductive response to decreased predation pressure; even within the short time scale of this experiment, there were indications of resurgence even within such low aphid populations. Predatory flies may have been partly responsible for these low levels of aphids and orange wheat blossom midge in the summer studied, alongside factors such as unsuitable conditions for population development. The use of broadspectrum pesticides is currently being discouraged, with the use of pest-specific treatments within threshold-set monitoring regimes now promoted by farming advisory bodies, to protect beneficial invertebrates. However, organophosphates such as dimethoate, with broad toxicity, are still often used in June and July for cereal aphids because of their lower cost compared to aphid-selective treatments (Oakley, 1994). Long term prophylactic application of pesticides is known to have a detrimental effect on Empididae populations: the Boxworth project found serious declines in the abundance of predatory flies in full insurance-sprayed areas compared to integrated low input plots (Vickerman, 1988).

The results of this experiment would support suggestions that these predatory flies may be potentially important contributors to the suite of biological control invertebrates present in arable crops, principally through their high abundance through the season. Further work to demonstrate positive impacts on pests is needed, which may suggest that measures to increase and protect their populations become essential.

5. The value of beetle banks for farmland biodiversity in summer

First section of chapter published as '*Resource provision for farmland gamebirds: the value of beetle banks*'. S.R. Thomas, D. Goulson & J.M. Holland (2001) *Annals of Applied Biology*, **139**, (1), 111-118.

Second section of chapter published as *'The contribution of beetle banks to farmland biodiversity'*, S.R. Thomas, D. Goulson & J.M. Holland (2000). *Aspects of Applied Biology*, **62**, 31-38.

Aspects of chapter presented as oral paper *'The contribution of beetle banks to farmland biodiversity'* at the Association of Applied Biology Conference: Farming Systems for the New Millennium, Cambridge, 18-20/12/2000.

Also presented as a poster at the School of Biological Sciences Geoffrey Taylor Postgraduate Symposium, University of Southampton, 3-5/4/00; and at the Royal Entomological Society Insect Conservation Special Interest Group meeting, 6/12/00.

5.1 Abstract

Severe declines have occurred in the populations of wild game birds in Britain. This has been attributed to agricultural intensification, leading to the loss of invertebrates vital within chick diets, fewer feeding resources for adults, and inadequate provision of nesting and brood-rearing habitat. In the first part of this chapter, I explored the potential value of simple sown grass strips in providing these resources, comparing results with functionally similar conventional field margins. The data indicate that beetle banks can contribute useful, albeit lower, densities of chick-food than conventional margins. These resources are more abundant later in the season, which may have implications for early hatched chicks. Beetle banks provide considerable quantities of nesting cover for adults, although sheltering conditions may never be as satisfactory as in well managed hedgerows. Given the ease and low cost of establishment of beetle banks, I suggest that they may be valuable components within a range of game management techniques on the farm, as a 'spin-off' to their primary role as overwintering habitat for polyphagous predators. They may be important particularly where resources for game birds are impoverished, but clearly cannot substitute for suitably managed field margins.

In the second parts of this chapter, I describe experimental work to evaluate whether beetle banks may contribute a useful extra habitat resource for two different representative arthropod groups, of potential conservation importance. Species richness of Orthoptera was similar between beetle banks and adjacent field margins, although there were compositional differences in capture. Grasshopper species favoured mid-field beetle banks, whereas bushcrickets tended to prefer field margins such as hedgebottoms. Some species were much more frequently encountered than others were, although limited measurement of site vegetational characteristics did not allow for explanations of why this was the case. Older beetle banks were more speciose, which may reflect either degradation of the dense sward or merely a slow rate of colonisation from a poor source.

Contrasts between species richness and composition of Lepidoptera in beetle banks and hedge banks were made. As expected, fewer butterflies were recorded in beetle banks, although even in hedge banks the number of individuals and species seen was low in comparison with similar studies. There was considerable seasonal variation in the abundance of key families. Butterfly presence was related to the floristic species richness and diversity of the habitats. Further detailed study would be essential to measure the exact use made of

beetle banks by butterflies, and whether vegetational change within them gives positive benefits. It would appear important to evaluate whether improving management practices, such as incorporating conservation headlands alongside beetle banks, would aid populations to make greater use of such simply created grass swards.

5.2 Forage and shelter resources for farmland gamebirds

5.2.1 Introduction

5.2.1.1 Game birds

Perdix perdix (grey partridge) abundance has declined drastically over the last few decades. In the 1950s, densities of around 25 pairs per km^2 could be found, whereas fewer than 5 pairs per km^2 were recorded by the mid-1980s (Potts, 1986). Consequently, this species was entered into the UK Red Data Book (Batten *et al.*, 1990). Only large-scale reared bird releases are responsible for maintaining stable populations of *Alectoris rufa* (red-legged partridge), but their wild populations are in jeopardy (Hill & Robertson, 1988). More recent work, in particular by the British Trust for Ornithology, has revealed further decreases (e.g. Chamberlain & Fuller, 2000; Gregory *et al.*, 2000). Such population declines parallel what is also happening to many other, often less thoroughly studied, birds associated with farmland. In all cases, the reason has been clearly related to loss of biodiversity, attributed to the intensification of farming practices in recent decades (Potts, 1997; Wilson *et al.*, 1999). Increased herbicide usage, the summer use of foliar insecticides, and a loss of undersowing, have all been implicated in causing increased chick mortality, by decreasing the available invertebrate food (Rands, 1986, 1988). Grey partridge and *Phasianus colchicus* (pheasant) chicks depend upon a high number of invertebrates in their diet in the first few weeks of life, to provide sufficient protein for survival (Hill, 1985; Green, 1984; Potts, 1986). The diversity of insect food within partridge chick diets is as important as overall quantity. There is evidence that an increasing proportion of aphids in cereals that has occurred since the introduction of herbicides in the 1950s has been detrimental to chick survival (Borg & Toft, 2000).

For other species such as *A. rufa*, insects are also important, though to a lesser extent (Green, 1984; Rands, 1988). The presence of weeds in and around crops as insect hosts is thus important. Additionally, the amount of plant material eaten increases as chicks mature (Ford, Chitty & Middleton, 1938), including grass and small dicotyledonous seeds, unripe cereal grains and leaves and flowers (Green, 1984). Adult game birds feed almost exclusively on plant material, with little difference in preference between species (Middleton & Chitty, 1937). Diet items consist of grain, leaves and roots of grasses and dicotyledonous plants.

Later in the season, partridges pair for breeding and claim territory, so that the area of habitat accessible for nesting and brood rearing may constrain maximum population growth (Rands, 1986; Aebischer *et al.*, 1994). Adult bird breeding success during the spring-summer has been shown to relate to the availability of nesting cover in this spring settling period, as well as being determined by nest predation (Potts, 1997). The structural characteristics of hedgerows are important for nesting. Hedge-bottoms, with some elevation for good drainage, and with high proportions of dead grass, litter and other vegetation, have been found to be important, as birds require shelter and material to make nests cryptic (Rands, 1986). Aebischer *et al.* (1994) found that several varieties of field margins and non-crop areas were preferred nesting habitat. Nests were particularly associated with species such as *Dactylis glomerata* (cock's-foot), *Urtica dioica* (nettles) and *Torilis japonica* (hedge-parsley), i.e. those with tall, more continuous canopy cover. Less preferred vegetation was more open, low and patchy. Beetle banks may also fulfil such habitat requirements. Grassy banks and hedgerows are not such preferred habitats for pheasants, which select field margins specifically adjacent to woodlands. However, these game birds do use this type of vegetation where grass is sufficiently tall and dense (Hill & Robertson, 1988). Vegetation is also important for chicks, as it must provide sufficient cover to conceal them from predators, yet permit movement of the chicks within it (Aebischer *et al.*, 1994).

More non-crop habitat and improvement in farming practice is needed for the successful survival of wild game species in the arable environment. MAFF is currently piloting an Arable Stewardship Scheme, encouraging farmers to manage their land for wildlife including game, by recommending and monitoring the use of a variety of techniques, such as grass margins, wildlife seed-sown strips, overwintered stubbles, undersown spring cereals, conservation headlands and also beetle banks (Anon., 1999a). The benefits of many such techniques, particularly of the latter, are as yet inadequately quantified.

The Game Conservancy Trust and regional Farming and Wildlife Advisory Groups now propose that beetle banks may be useful for gamebirds, providing additional nesting and feeding sites, if they are retained as permanent landscape features and protected from pesticide and herbicide drift, although there is currently little supporting literature.

5.2.1.2 Aims of study

This study was designed to quantify the resources offered by beetle banks for gamebird chicks and adults. Firstly, it aimed to measure the abundance of chick food invertebrates in beetle banks; and secondly, to quantify their vegetational value for both chicks and adult birds. The latter involved examining cover, used for nesting and brood-rearing, and plants of food value. Relationships between the invertebrates and plant cover could then be assessed. These attributes were compared with those provided in adjacent typical conventional field margins, which are also linear vegetation strips with similar functions in the agricultural landscape.

5.2.2 Materials and Methods

5.2.2.1 Chick food availability in spring and summer

Sampling took place in beetle banks on farm estates across Hampshire and Wiltshire, UK (map references: SU 593 534; SU 017 196; SU 408 488; SU 694 323; SU 585 550), all on slightly flinty, calcareous silty clay loam-based soils. Ranging from 200 - 900m long and 2.5 - 5m wide, the banks had been established between less than one and fourteen years previously by autumn-ploughing earth ridges. They were hand-sown predominately with *D. glomerata* and various other grass species. Natural regeneration has taken place within them, although there has been little active management. In all cases, adjacent established grassy hedgerow bottoms or grassy non-shrubby margins were sampled simultaneously to allow comparison with the beetle banks.

In 1998, four each of beetle banks and margins were sampled in May and five in August, to assess chickfood provision through the main chick-hatching period, on a single Hampshire estate. Fifteen 20 × 20cm areas along each beetle bank or field margin site were randomly selected. Invertebrates on the vegetation and soil surface were removed by a Ryobi RSV3100 vacuum suction-sampler (Stewart & Wright, 1995). Samples were frozen prior to hand sorting to remove invertebrates, which were stored in 70% alcohol before identification. All invertebrate taxa on which game chicks most commonly feed were identified (following Ford *et al.*, 1938; Green, 1984; Moreby & Southway, 1999; Moreby, Southway & Boatman, 1999). Mean total numbers of these chickfood invertebrates were compared between beetle banks and field margins, for the two sampling periods, using repeated measures ANOVA, following log (x + 1) transformation to increase homogeneity of variance.

In 1999, twenty-two beetle banks/margins from five estates were assessed, to extend the data set and include farm variation as a factor. Sweep-netting was carried out over June and July to facilitate rapid insect collection from a large number of sites during peak chick hatch. A 50cm diameter net was swept immediately above the ground within the vegetation, taking approximately one second to collect from an area of around 50cm^2 each sweep. Fifteen sweeps were pooled to form a sample, with fifteen samples being taken randomly along each site. Samples were again stored frozen and hand-sorted to remove all invertebrates, and were identified as previously. The relative abundance of invertebrate prey available for chicks to feed on was compared between beetle banks and field margins, and between different farms, by two-way ANOVA following log (x + 1) transformation of the data. Site means were again used to avoid pseudoreplication. Additionally, Shannon-Wiener Diversity indices were calculated for each sample of chickfood invertebrates, and used to compare between habitats and farms, by two-way ANOVA. Being normally distributed when calculated from a number of samples, this index does not require data transformation (Magurran, 1988).

5.2.2.2 Vegetation cover and food plant provision in beetle banks

The vegetation within twenty randomly selected sampling points on nine beetle banks or field margins was assessed in July 1998, and in February/March 1999. This was repeated for twenty-two beetle banks/margins in late June/July 1999. Each species present and its percentage cover within a 0.71m × 0.71m (= 0.5m^2) quadrat placed on the ground was recorded. Overall plant cover, the amount of live/dead tussock, and cover of other grasses and dicotyledonous plants, was compared between habitats by two-tailed t-tests. Mean values from each site were used, following logit transformation.

5.2.3 Results

5.2.3.1 Spring and summer chick food

In 1998, chickfood invertebrate densities were not significantly different between field margins and beetle banks ($F_{1,6} = 0.02$, $P = 0.89$). There was a significantly higher prey density per m^2 in August compared to May ($F_{1, 6} = 7.03$, $P = 0.04$), caused by increases in most taxa, although the interaction between habitat and date was non-significant ($F_{1, 6} = 0.00$, $P = 0.99$). In May, mean chickfood densities were 657.5 per m^2 for beetle banks and 564.17 for field margins (s.e.d. = 232.7). In August, densities were 1547.31 and 1434.23 for banks and margins, respectively (s.e.d. = 450.2). Prey densities showed high variability between the fields sampled, on both of the sampling occasions.

Small flies were very frequently caught, and as might be expected, were predominant in the summer catch (Table 5.1). Small species of staphylinid beetles, homopteran bugs and linyphiid spiders were also very abundant at this time. Hymenopteran larvae, regarded as important chick food components (Moreby & Aebischer, 1992), were infrequently caught, and were most numerous in field margins in May. Beetle banks contained more carabid beetle and heteropteran bugs in both seasons, and more coccinellid beetles in spring, when compared with the fields margins (data not presented). Only ants and lepidopteran larvae were consistently more abundant in field margins. Overall, many invertebrate groups were similarly abundant both early and late in the season (Table 5.1).

In 1999, sweep capture of mean total chick-food invertebrates was significantly higher in permanent field margins compared with beetle banks ($F_{1, 34} = 7.20$, $P = 0.01$). A mean of 46.65 chickfood invertebrates was caught per 15 samples taken in beetle banks, with a mean for field margins of 64.70 (s.e.d. = 8.73). Catch did not differ between the farms sampled ($F_{4, 34} = 2.30$, $P = 0.08$), and there was no significant interaction between habitat and farm ($F_{4, 634} = 0.59$, $P = 0.67$). As in the first sampling year, there was considerable variability between sampling sites.

Small species of dipterans, heteropterans and aphids were most numerous in the sweep-net catch (Table 5.2). Beetles were frequently caught, and chiefly did not differ in abundance between habitat type. Field margins contained significantly greater numbers of cantharid beetles, heteropterans, other auchenorrhynchan bugs, flies and some spider families. There was no difference in the abundance of infrequently caught sawfly or lepidopteran larvae between the two habitats (Table 5.2).

The diversity (H′) of chickfood invertebrates was significantly higher in field margins ($F_{1, 34} = 5.20$, $P = 0.03$), with a mean index of 1.51 compared with 1.40 in beetle banks (s.e.d. = 0.08). However, it did not differ significantly between farms ($F_{4, 34} = 0.56$, $P = 0.69$), nor was there any significant interaction between these habitat and farm factors ($F_{4, 34} = 1.39$, $P = 0.29$).

Table 5.1 *Mean chickfood invertebrate densities per m*^{2} *in margin habitats sampled by Ryobi suction sampling in May and August 1998.*

Results of t-test on $\log_{10}$ (x + 1) transformed data. (*$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

	May mean (SE)	**Aug mean (SE)**	
Carabidae	18.75 (7.01)	29.04 6.28)	$t_{16} = 2.12$ n.s.
Staphylinidae	81.46 (25.39)	157.69 (37.14)	$t_{16} = 2.12$ n.s.
Chrysomelidae	9.58 (3.28)	25.58 (8.34)	$t_{16} = 2.12$ n.s.
Curcurlionidae	3.75 (1.50)	14.62 (8.47)	$t_{16} = 2.12$ n.s.
Elateridae	2.11 (0.69)	0	$t_{16} = 2.12$ **
Coccinellidae	26.67 (17.80)	3.08 (1.19)	$t_9 = 2.26$ n.s.
Nitidulidae	0.42 (0.27)	0	$t_{16} = 2.12$ n.s.
Heteroptera	35.83 (17.45)	44.62 (21.93)	$t_{16} = 2.12$ n.s.
Homoptera - Aphidae	15.94 (5.78)	15.38 (8.85)	$t_{16} = 2.12$ n.s.
Delphacidae	84.08 (41.70)	119.04 (22.02)	$t_9 = 2.26$ n.s.
Cicadellidae	10.20 (3.12)	58.85 (13.35)	$t_{16} = 2.12$ n.s.
Other Auchenorrhyncha	0	1.15 (0.82)	$t_{16} = 2.12$ ***
Small diptera	84.79 (12.07)	670.19 (150.44)	$t_{16} = 2.12$ ***
Hymenopteran larvae	9.38 (7.84)	2.50 (0.81)	$t_{10} = 2.23$ n.s.
Formicidae	34.38 (13.63)	40.19 (10.04)	$t_{16} = 2.12$ n.s.
Lepidopteran larvae	0.49 (0.33)	3.46 (1.18)	$t_{16} = 2.12$ *
Dermaptera	10.01 (7.01)	0.19 (0.19)	$t_8 = 2.31$ *
Linyphiidae	154.38 (26.09)	251.73 (48.03)	$t_{16} = 2.12$ n.s.
Other Araneae	31.04 (8.42)	42.88 (5.81)	$t_9 = 2.26$ n.s.
Opiliones	4.98 (3.29)	10.58 (2.32)	$t_{16} = 2.12$ *

Table 5.2 *Mean chickfood invertebrate catch, per 100 samples, in beetle banks (bb) and field margins (fm) sampled in June/July 1999.*

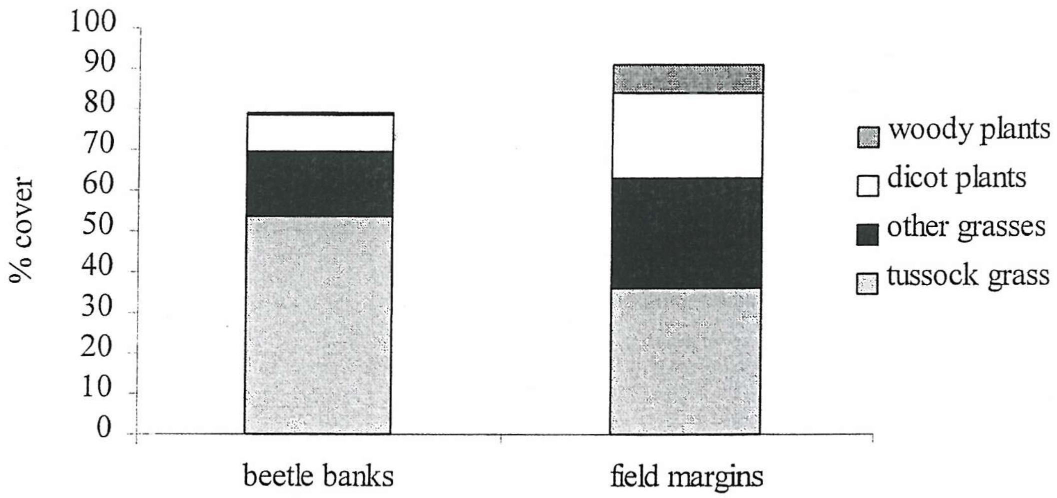
Results of t-test on $\log_{10}(x + 1)$ transformed data. (*$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$)

	bb mean (SE)	**fm mean (SE)**	
Carabidae	0.68 (0.22)	1.22 (0.42)	$t_{35} = 2.03$ n.s.
Staphylinidae	0.59 (0.17)	1.06 (0.30)	$t_{36} = 2.03$ n.s.
Chrysomelidae	13.16 (8.87)	10.36 (4.14)	$t_{42} = 2.02$ n.s.
Curcurlionidae	12.33 (7.36)	7.58 (3.37)	$t_{35} = 2.03$ n.s.
Cantharidae	2.84 (1.26)	6.66 (1.54)	$t_{42} = 2.02$ *
Elateridae	1.65 (0.47)	1.50 (0.41)	$t_{42} = 2.02$ n.s.
Coccinellidae	1.79 (0.47)	1.70 (0.70)	$t_{42} = 2.02$ n.s.
Nitidulidae	19.72 (10.21)	36.41 (12.59)	$t_{42} = 2.02$ n.s.
Heteroptera	78.51 (13.33)	112.05 (12.59)	$t_{37} = 2.03$ *
Homoptera - Aphidae	90.61 (23.41)	77.44 (32.69)	$t_{42} = 2.02$ n.s.
Delphacidae	4.29 (1.39)	7.48 (19.41)	$t_{42} = 2.02$ n.s.
Cicadellidae	10.62 (1.79)	15.24 (3.81)	$t_{42} = 2.02$ n.s.
Other Auchenorrhyncha	2.37 (0.68)	7.95 (1.34)	$t_{36} = 2.03$ ***
Small diptera	57.82 (7.82)	110.85 (13.78)	$t_{42} = 2.02$ *
Hymenopteran larvae	3.52 (0.75)	3.24 (1.21)	$t_{42} = 2.02$ n.s.
Formicidae	0.55 (0.28)	5.82 (2.23)	$t_{24} = 2.06$ *
Lepidopteran larvae	2.49 (1.20)	3.38 (1.21)	$t_{42} = 2.02$ n.s.
Dermaptera	0.65 (0.26)	0.67 (0.48)	$t_{37} = 2.03$ n.s.
Linyphiidae	2.05 (0.88)	3.90 (1.11)	$t_{42} = 2.02$ n.s.
Other Araneae	4.37 (0.87)	16.39 (3.01)	$t_{35} = 2.03$ ***
Opiliones	0.38 (0.23)	0.45 (0.16)	$t_{42} = 2.02$ n.s.

5.2.3.2 *Summer plant provision*

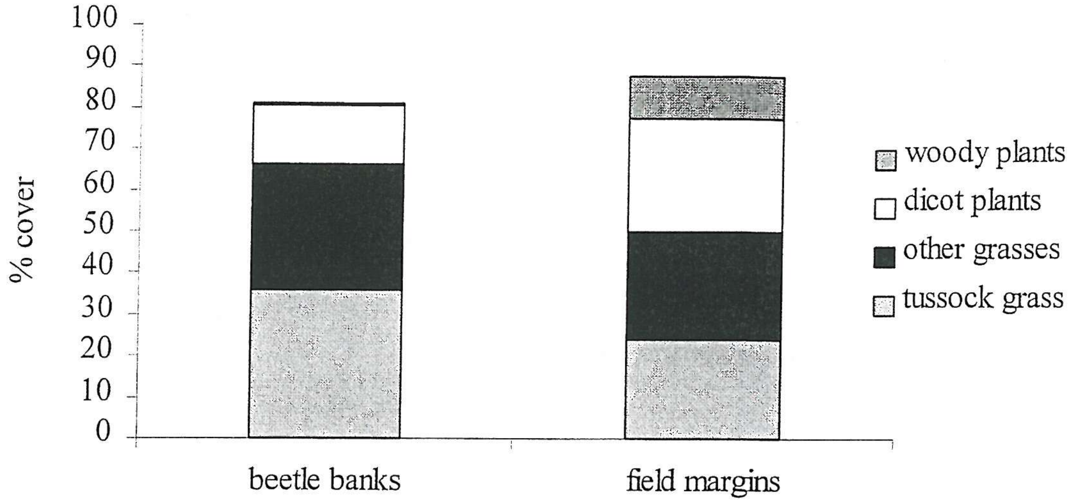
1998 sampling revealed that there was more cover in the field margin bases compared to beetle banks ($t_{16} = 1.75$, $P = 0.003$) (Figure 5.1); however, cover provision was high in both kinds of habitat, with no less than 67% cover, and a maximum of 97%. There was no significant difference in the percentage of tussocky-structured grass present in beetle banks and field margin ($t_{12} = 1.78$, $P = 0.14$). Other grass and herbaceous plant cover, fed on by adult game birds, was not significantly different overall ($t_{16} = 1.75$, $P = 0.10$, grasses; $t_{10} = 1.75$, $P = 0.07$, dicots) (Figure 5.1). Field margin bases contained small amounts of woody plants, the presence of which was negligible in beetle banks (Figure 5.1). There was considerable variation in the abundance of these plant categories between individual fields.

Figure 5.1 *Mean percentage cover of plant categories (+ SE) in beetle banks and field margins, summer 1998 assessment; n = 18.*



In 1999, there was no significant difference between overall vegetational cover in field margins and beetle banks ($t_{37} = 1.69$, $P = 0.10$), and levels of both tussocky grass and other grass species were no different either ($t_{42} = 1.68$, $P = 0.11$, tussock; $t_{34} = 1.69$, $P = 0.69$, grass). As expected, field margins contained significantly more dicotyledonous and woody plants than beetle banks ($t_{26} = 1.71$, $P < 0.001$, dicots; $t_{42} = 1.68$, $P < 0.001$; Figure 5.2). In the majority of vegetation categories, there was considerable variation between farms.

Figure 5.2 *Mean percentage cover of plant categories (+ SE) in beetle banks and field margins, summer 1999 assessment; n = 44.*

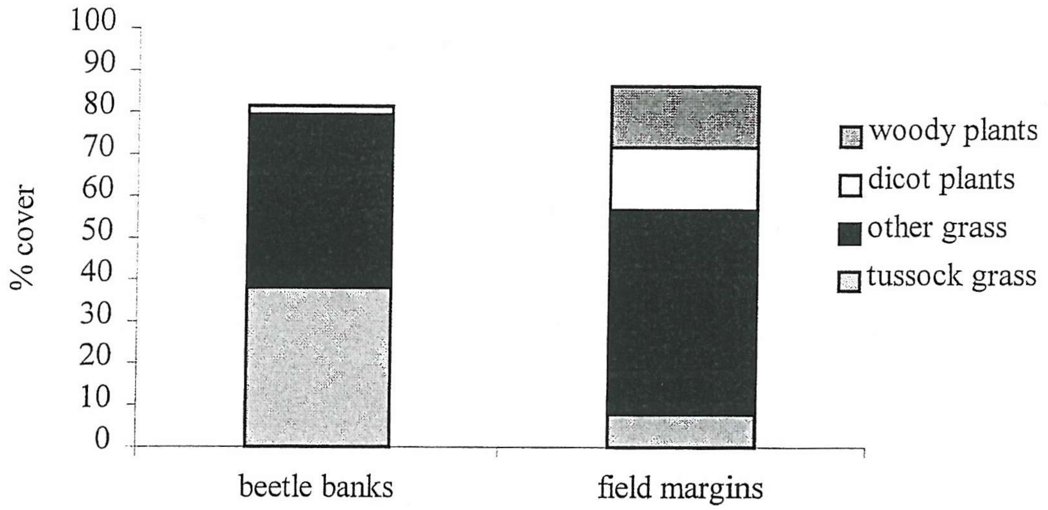


5.2.3.3 Winter plant provision

There was no significant difference in total vegetation cover between beetle banks and field margins ($t_{16} = 1.75$, $P = 0.33$) (Figure 5.3). Cover had been maintained with a very similar range to the summer, at between 62 – 97 %. However, when mean percentage of tussocky live and dead grass cover was examined, there was significantly more present in beetle banks than in field margins ($t_{16} = 1.75$, $P = 0.01$). Mean proportion of other grass growing in the habitat was not different ($t_{16} = 1.75$, $P = 0.12$), but there was significantly more dicotyledonous plant material in field margins ($t_{16} = 1.75$, $P = 0.01$), as well as more woody plants ($t_8 = 1.86$, $P = 0.02$) (Figure 5.3).

Plant litter, dead grass and tussock were combined into a single category and was compared between habitats. These vegetation types are important for providing camouflaged nesting material in the spring (Rands, 1988). Beetle banks contained significantly more of this material ($t_{16} = 1.75$, $P = 0.01$) with a mean of 61 % compared to 27%.

Figure 5.3 *Mean percentage cover of plant categories (+ SE) in beetle banks and field margins, 1998-99 winter assessment; n = 18.*



5.2.3.4 Relationships between plants and invertebrates

As the ages of the beetle banks assessed in this study were known, it was possible to assess whether abundance and diversity of chick food invertebrates and plant cover showed age-related changes. Data from the second sampling year was used, which represented a greater sample size of beetle banks. The two newly sown banks were excluded, as being less than a year old, they contained only annual species that had germinated through the ploughing disturbance whilst creating the bank, prior to grass establishment. Regression analysis was performed between age in years and mean invertebrate catch in beetle banks, but no relationship was evident ($r^2 < 0.001$, $F_{1, 18} = 0.015$, $P = 0.905$). However, a regression between age and invertebrate diversity index showed a highly significant positive relationship ($r^2 = 0.335$, $F_{1, 18} = 9.084$, $P = 0.008$). This undoubtedly results from the increasingly complex plant communities that develops in the beetle banks (Thomas *et al.*, 2000). Plant diversity was also calculated, and had a highly significant positive relationship with invertebrate diversity, both in beetle banks ($r^2 = 0.559$, $F_{1, 18} = 22.790$, $P < 0.001$) and in field margins ($r^2 = 0.260$, $F_{1, 18} = 7.027$, $P = 0.015$).

5.2.4 Discussion

The results of this study strongly support the view put forward by Aebischer & Blake (1994), who suggested that grass strips, and in particular beetle banks, may be valuable for game birds as well as properly managed hedgerows. Although beetle banks are simple landscape features, it was found that they could develop high densities of the preferred invertebrate prey of game chicks, approaching equivalent values to those of more complex established hedgerows and other permanent field boundaries. Despite overall chickfood densities being lower in beetle banks, the numbers of many key groups sampled often did not differ significantly. This was particularly so for invertebrates considered nutritionally important, such as sawfly larvae and caterpillars, found by Moreby (1988) to be especially numerous in chick faecal samples. Faecal analysis, although known to under-represent softer-bodied species, also found plant bugs, plant hoppers, ground beetles, leaf beetles, and weevils to be important dietary items. These groups were also similar in relative abundance within beetle banks and the conventional field margins sampled here.

Invertebrate catch from the beetle banks and field margins varied considerably between the different fields, and also between farms. It is likely that previous field management, including differences in cropping and agrochemical inputs over a number of years, influenced catch. Increased replication in the experimental design would be necessary to evaluate such factors, although complications such as the frequent growing of different crops on either side of beetle banks, or the presence of other features such as woods and roads adjacent to margins, would have to be taken into account. In the first sampling year, the farm used had well maintained field margins and hedgerows following a history of environmentally conscious management to encourage game, including the use of conservation headlands around all margins. This may explain why invertebrate densities were similar in the habitats examined. However in the second year, when more farms with different management histories were compared there was a greater variability in chickfood densities. Barker & Reynolds (1999) also found significant variation between farms when examining chickfood abundance in grass margins.

Suctioning has been described as an inefficient sampling method (Green, 1984), as chrysomelid beetles, sawfly and lepidopteran larvae, highly preferred dietary choices, may be scarce in suction samples though common in sweep net samples. More recently, sweep-netting has been preferentially selected technique for chickfood capture (Barker & Reynolds, 1999; Itamies *et al.*, 1996), Beetle banks are established to enhance ground-active fauna

(Thomas *et al.* 1991 & 1992), for which suction-sampling may be a more appropriate assessment method.

Peak partridge chick hatch occurs in late June to early July, coinciding with high insect abundance, although it may be any time from April to September (Green, 1984; Anon., 1995). Although there was a lower catch of chickfood in beetle banks, the difference between the habitats was consistent and small in both spring and summer, i.e. food availability may remain adequate for chick survival throughout the hatching season. The abundance of many invertebrates did not significantly differ from May to August. Chicks may fare better later in the season, when there is greater overall food abundance, with conventional field margins providing improved food resources. However, the addition of beetle banks to a monoculture of cereals may enhance game chick survival, especially considering the increasing invertebrate diversity that appears to develop within the maturing habitat structure. Once established, beetle banks have a dense grassy structure, and are probably at least as good as many other marginal habitats for the provision of camouflaged shelter for both adult game birds and their chicks, though may never be equivalent to that provided by well managed hedgerows. Plant cover was high throughout all sites, and beetle banks were found to be valuable for the supply of nesting material, in late winter and early spring. Many field margins are frequently observed to have exposed bases, with little material of value for either forming a nest or allowing shelter from harsh weather and predators, and so any additional resources in fields may be important. The farms used in this study tended to manage margins sympathetically for wildlife and thus usually had fairly well maintained hedgebases, inevitably linked to the desire to also create beetle banks.

Foraging gamebirds tend to avoid vegetation that is difficult to penetrate (P. Thompson, personal communication). It may be that some of the sites developed cover that actually became too impenetrable as the season progressed, a factor that may merely inconvenience adult birds, yet jeopardise the survival of chicks. Where plants are too densely spaced, chicks may become so wet from the vegetation that unless they can dry off quickly they may chill and die. Barker & Reynolds (1999) considered that many planted grassy margins, including beetle banks, could be less than ideal habitat for birds, although they reported that some farmers had experimentally cut channels within such habitats for birds to move around and dry out following rain. The provision of a sterile strip alongside field boundaries and features such as beetle banks has been suggested as useful for game chicks, as it provides an open area for drying out (Bond, 1987). Such solutions may be essential where vegetation has become especially dense. It was observed that where tussocky cover had developed patchily, often because many beetle banks are hand sown (Thomas, 2000b), not only did this allow some other plants to develop, but allowed some degree of permeability for the benefit of game. There is a clear trade-off between managing beetle banks for the dense tussock cover to enhance maximum predatory invertebrate survival, their primary aim, and allowing some patchy alternative plant cover for the benefit of game species.

Herbaceous and grass species that may be fed on by adult birds were only present at low levels in beetle banks, although this has been found to increase through time following establishment (Thomas *et al.*, 2000). Many seed-producing dicotyledons known to be preferred specifically by game birds, are more usually found within the field itself rather than in boundary habitats. These include plants such as *Stellaria media* (chickweed), *Polygonum* spp. (knotgrasses.), *Myosotis arvensis* (forget-me-not), *Chenopodium album* (fat hen) and *Fumaria officinalis* (fumitary) (Ford *et al.*, 1938; Middleton & Chitty, 1937; Green 1984. Boatman & Wilson, 1988). However, with the development of more efficient herbicides and low tolerance of weeds within fields by farmers, weed seed availability may be low, and thus any extra food resources within the habitat in which adult birds may be nesting can only be seen as beneficial.

Game birds with chicks were observed within banks during the course of the study, indicating that the habitat was being utilised. Overall, it appears that beetle banks make a valuable contribution to game habitat on farmland, with their low cost and ease of construction adding further positive points. They may be especially invaluable when combined with spring brood-rearing and winter cover crops within set-aside strips, such as recommended by Boatman & Bence (2000), a methodology shown to significantly increase wild pheasant populations, as well as the nationally declining skylark, on conventionally managed farmland on UK lowland. Although beetle banks may add chickfood invertebrates and nesting shelter to arable fields, and may be useful where such resources are lacking, appropriate good management of conventional field margins may be much more important for the continuing survival of game bird species on farmland.

5.3 Orthoptera

5.3.1 *Introduction*

The Orthoptera are found in a large variety of habitats, with their success dependent on temperature, solar radiation, relative humidity and biotope structure (Fischer *et al.*, 1996). Most species are polyphagous herbivores or predators, so that food does not usually play an important role in habitat preference. The Acrididae in particular choose habitats according to species-specific body thermoregulation requirements (Willott, 1997), drought tolerance and temperature requirements of egg development (van Wingerden *et al.*, 1991). In the spring and summer, short swards tend to have higher soil temperatures than long swards (Luff, 1965, Bossenbroek *et al.*, 1977), and therefore certain thermophilic species only live in short swards (van Wingerden *et al.*, 1991; Willott, 1997). The average temperature during one season can affect the overall success of Acrididae in both that season and in that of the next (Willott & Hassall, 1998; Willott, 1997). Unlike the Acrididae, tettigoniids are fairly specific in choice of oviposition sites.

Stenoecious species are now in decline with many threatened by habitat fragmentation and destruction, and high pesticide and nitrogen use (Fischer *et al.*, 1996; van Wingerden *et al.*, 1991 & 1992). Euryoecious and vagrant species still thrive in meadows and other areas of little disturbed grassland, as well as on roadsides and waste ground (Marshall & Haes, 1988; Port & Thompson, 1980).

Grasshoppers have been found to be one of the most preferred food choices of grey partridge and pheasant (Potts, 1986; Martin *et al.*, 1996) and are also important in the diet of songbirds such as corn bunting, tree sparrow and skylark (Brickle, 1999; Anon., 1995b). However, grasshoppers are now rarely found in UK cereal fields (Green, 1984; Potts, 1986), although they are present in central and southern Europe where there has been considerably less agricultural intensification. Consequently they are rarely now found in partridge chick diets (Green, 1984).

On intensively managed land, marginal habitats may be increasingly important sources of grasshoppers, whether considered as important dietary components for game or other birds, or as invertebrates deserving conservation. Here, I aimed to assess the relative composition and abundance of Orthoptera in beetle banks, in order to evaluate their value compared to other linear biotopes within arable fields.

5.3.2 Materials and methods

In the summer of 1999, 22 beetle banks, paired with 22 adjacent field margins, from five conventionally managed farm estates were sampled to evaluate the presence and abundance of Orthoptera. Fifteen sweep-net samples, each of 15 sweeps, were taken within the dense vegetation of each site, sampling close to the ground and using a 50 cm diameter net (Refer to section 5.2.2 for full details of the procedure). Species richness was compared between beetle banks and field margins by t-test, using means of each site. The number of sites occupied by different species, and their mean capture per sample was also examined. Any relationships between mean capture or mean species richness and vegetational characteristics of the sites were explored using linear regression.

5.3.3 Results

Six species of Orthoptera were recorded through sweep net sampling: *Chorthippus bruneus* Thunberg (common field grasshopper), grasshopper *C. parallelus* Zetterstedt (meadow), *Omocestus viridulus* L. (common green grasshopper), *Conocephalus discolor* Thunberg (long-winged conehead), *Pholidoptera griseoaptera* Degeer (dark bushcricket) and *Leptophyes punctatissima* Bosc (speckled bushcricket). In additional, *Metrioptera roeselini* Hagenbach (Roesel's bushcricket) was noted in a beetle bank and *Meconema thalassinum* Degeer (oak bushcricket) in a hedgebottom during the course of the experiment.

There was no significant difference between the mean number of orthopteran species found in the two habitat types (t = 2.02, d.f. = 42, P = 0.29). Although species of bushcricket were more likely to be found in the more species-rich field margins, grasshoppers and *C. discolor* were more often encountered in the mid-field, less botanically diverse beetle banks (Figure 5.4). In all, 68 individual Acrididae were captured in beetle banks, with only 19 in field margins. Of the Tettigoniidae, 55 individuals were captured in beetle banks and 145 in field margins. *L. punctatissima* was the most abundant species overall (Figure 5.5).

Figure 5.4 *Percentage of sites in which different orthopteran species recorded*

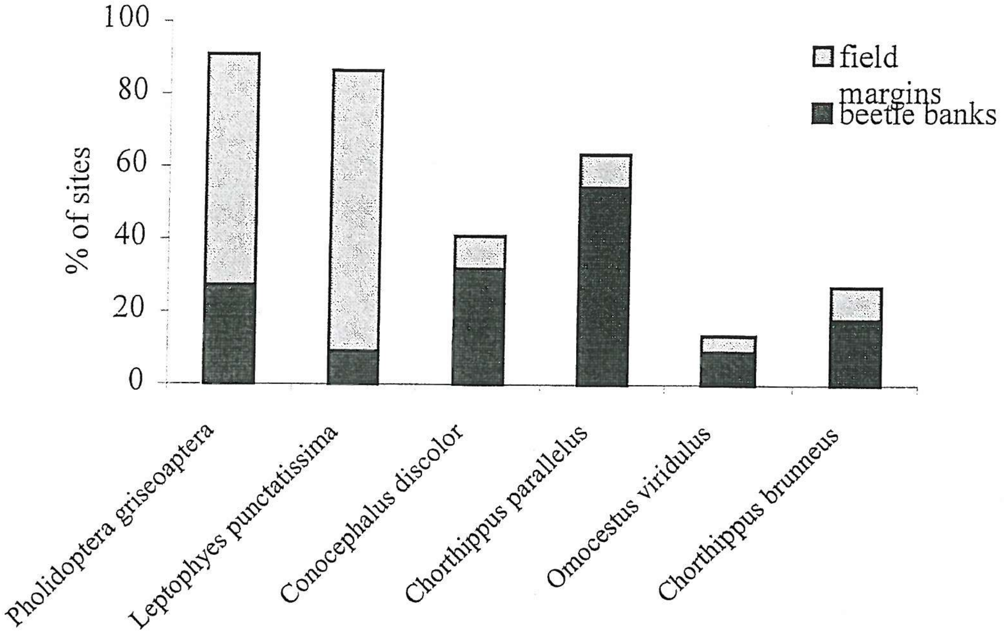


Figure 5.5 *Mean capture of Orthoptera caught in beetle banks and field margins per sample (15 sweeps)*

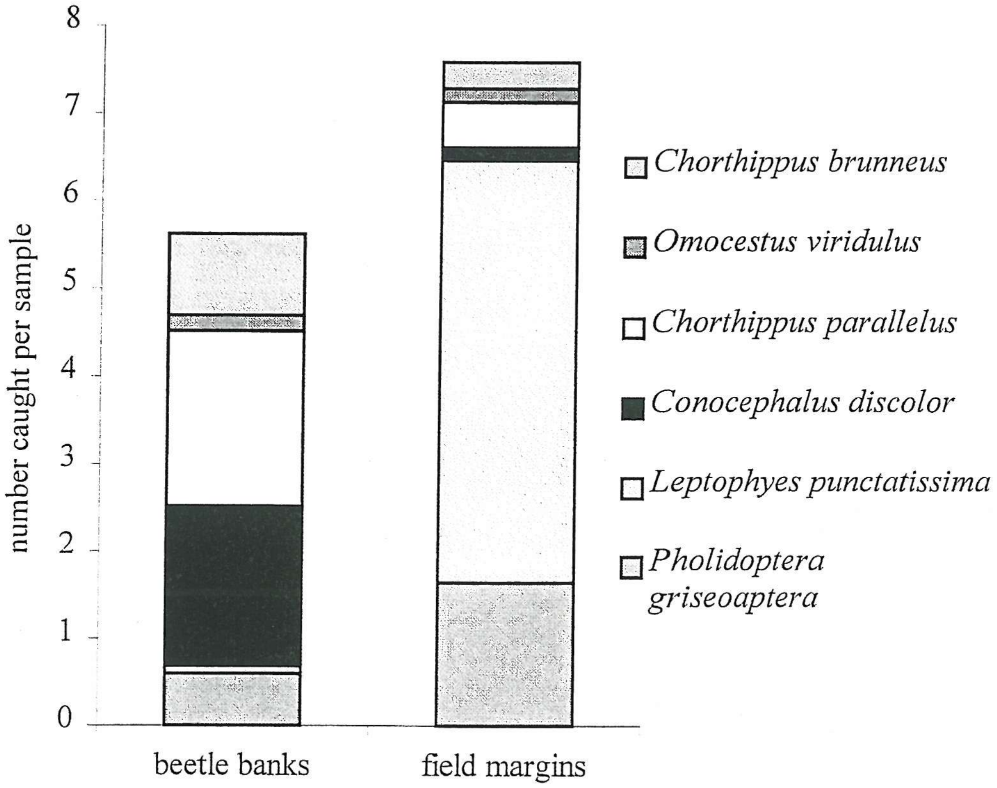


Table 5.3 *Relationships between Orthoptera capture and characteristics of sample sites*

	Total orthopteran capture	Orthopteran spp. richness
Site age (BB only)	**$r^2 = 0.22$, $F_{1,21} = 5.72$, $P = 0.03$**	**$r^2 = 0.25$, $F_{1,21} = 6.67$, $P = 0.02$**
% total cover	$r^2 = 0.01$, $F_{1,43} = 0.36$, $P = 0.55$	$r^2 = 0.07$, $F_{1,43} = 3.35$, $P = 0.07$
% grass cover	$r^2 = 0.01$, $F_{1,43} = 0.21$, $P = 0.65$	$r^2 < 0.01$, $F_{1,43} = 0.06$, $P = 0.80$
Floral spp. richness	$r^2 < 0.01$, $F_{1,43} = 0.03$, $P = 0.87$	$r^2 = 0.05$, $F_{1,43} = 2.05$, $P = 0.16$
Floral H′	$r^2 = 0.01$, $F_{1,43} = 0.31$, $P = 0.58$	$r^2 = 0.09$, $F_{1,43} = 4.02$, $P = 0.05$

The only factor indicating a significant positive relationship with both numbers of species and number of individuals caught was age of the beetle bank (Table 5.3). Other factors, such as the amount of grass or total vegetational cover, or composition of the sites did not appear to have any influence on the Orthoptera captured (Table 5.3).

5.3.4 Discussion

Orthopteran capture was infrequent in this experiment, and lower than had been anticipated, which may reflect that either the conventionally managed farms visited do truly have poor population levels, or that the sampling methodology was inaccurate or inefficient. Certainly there was considerable acoustic evidence for grasshopper presence in the habitats, although no attempts were made to quantify this in the limited time available for the study. From the results, beetle banks appear to be a reasonably valuable habitat in terms of overall presence and species richness of Orthoptera. They may also represent a slightly different physical sward more suited to grasshoppers when compared to grassy hedge bottoms, which bushcrickets appear to prefer. Mid-field grass strips may be favourable areas for grasshoppers because the high grass in summer can provide adequate shelter for nymphs and adults, whereas often field margin vegetation, although better for egg hatching, may be too low and open.

The vegetational composition of the sample sites was somewhat simplistically classified, probably accounting for the lack of relationships with orthopteran capture. In a more thorough investigation, it would be more relevant to consider how the vegetation is physically structured, in relation to temperature, humidity and soil conditions of the sites. It is likely that aspect is the factor having the greatest impact on which grasshoppers may be found in any one site, rather than necessarily what plants are present. This information might indicate why there were such obvious differences in the frequency of encounter and mean abundance of certain species. Also, colonisation of new sites may be limited initially. Beetle banks may actually present too dense a grass stand in their early years, but as other plants develop and tussocks deteriorate, there may be greater penetration of sunlight, and conditions on the ground may become warm enough for grasshoppers to settle and reproduce. Increasing capture and diversity of Orthoptera in older beetle banks indicates this may be supported.

Chorthippus parallelus and *C. brunneus* and the bush cricket *Metrioptera roeselii* are euryoecious species, tolerating a wide range of temperature and moisture differences (Monk, 1985; Fischer *et al.*, 1996; Willott, 1997). *C. brunneus* is the more vagrant of the two and has the ability to colonise marginal habitat quickly (Monk, 1985). It would have been informative to discover if there was increased abundance of any individual species following time from bank establishment, but because capture rates were found to be so low, this would require sweep-netting of a much larger number of sites. It also indicates that a more thorough sampling regime is necessary to ensure all species present were actually being noticed. For example *M. roeselii* is able to survive at very low densities on small patches of suitable habitat in a complex landscape (Kindvall *et al.*, 1998); and so although none was caught during sweep-netting, it may not mean that the species was not subsisting on any of the habitat strips visited. In future study, it would be important to use a range of trapping and recording techniques to ensure all species were being observed, and allow population estimates to be made. Acoustic scanning is a useful tool for recording adult densities (Fischer *et al.*, 1997). An extended sampling season would allow capture of nymphs, which would provide evidence that breeding was occurring in the sites visited, and obviously more than one season of sampling would indicate survival rates.

In North America, several species of grasshopper can be found in cereal fields, in high abundance, and some of these are agricultural pests (O'Lesks *et al.*, 1997; Gillespie & Kemp, 1996). Control in the USA is carried out using broadspectrum insecticides, such as the pyrethroid deltamethrin, the organophosphates chlorpyrifos and dimethoate and the carbamate carbofuran (Martin *et al.* 1996 & 1998). The use of such insecticides on arable crops in Britain has increased dramatically since the early 1980s but has stabilised since the early 1990s. Little is known about pesticide effects on grasshoppers, but spray drift could have reduced their success in field margins. Longley & Sotherton (1997) have demonstrated such effects for butterflies. By their usual positioning within field centres, beetle banks are particularly vulnerable to unintentional insecticide exposure, and some means of protection would appear essential to protect such Orthoptera. Conservation headlands were introduced to increase invertebrate densities in headlands to improve partridge and pheasant reproductive success (Sotherton, 1991, 1992), and the reduced spray drift into margins and beetle banks with conservation headlands adjacent to them could benefit Orthoptera on arable farms.

It would be informative to sample within the adjacent crop, both in the field centre and in the headland, relating any capture to the farming regime, crop type, inputs and agronomic history, in future work. This would both give a better background as to why capture was high or low in certain habitats, and indicate the possible importance of havens such as beetle banks and field margins for the continuing survival of the Orthoptera on arable land.

5.4 Lepidoptera

5.4.1 Introduction

Arable farmland currently supports a relatively impoverished butterfly fauna. The crop itself is an unsuitable habitat for all but the butterfly pests of brassicas (Thomas, 1984) and consequently movement and activity of butterflies in the agricultural landscape is largely restricted to non-cultivated areas (Dover, 1990; Hill *et al.*, 1995). Hedgerows and field margins, woodland, grassland and damp or marshy ground are therefore considered to be very important in maintaining butterfly biodiversity on farmland (Thomas, 1986; Dover, 1996). Hedgerows are the most widely available habitat and provide shelter, larval host plants and nectar sources for butterflies. They are also thought to act as wildlife corridors by facilitating movement of butterflies in the arable landscape. Some 32 species of butterfly have been recorded in field boundaries (Dover, 1996) of which at least 24 are reported to breed in arable margins and similar linear habitats in at least part of their range (Warren, 1992).

Although national extinctions have been rare in Britain, the ranges of the majority of indigenous butterfly species have declined rapidly (Thomas, 1984), with the principal factor being the loss and modification of butterfly habitat, through post-war agricultural intensification (Fry, 1991). The large-scale removal of hedgerows (Hill *et al.*, 1995) to create more efficient fields and the increased area and frequency of agrochemical applications has drastically reduced the total area of semi-natural habitats in the countryside. Close ploughing at crop edges has also eroded the width of field boundaries, making them more vulnerable to pesticide and fertiliser drift (Longley & Sotherton, 1997).

Farmland butterfly populations may be affected by intensification in other ways. Laboratory bioassays have demonstrated ecotoxicological effects of a wide range of insecticides against larvae of certain butterfly species (Davis *et al.*, 1991; Çilgi & Jepson, 1994). Lepidoptera are at risk from both direct spraying and residual deposits of pesticides and may be exposed to several applications in a lifetime. Indirect effects of agrochemical use are also thought to be significant (Dover, 1994; Feber & Smith, 1995). The use of broad-spectrum herbicides close to field boundaries encourages the production of annual grass species leading to a species poor community (Smith & Macdonald, 1992). Accidental application of fertilisers increases the nutrient status of field margins, which can reduce floral diversity and contribute to degradation of field margin habitat. Consequently, intense farming may affect butterfly populations through the substantial reduction in the quantity and quality of both adult and larval food resources (Hill *et al.*, 1995).

Removal of hedgerows results in a reduction in habitat availability and also reduces connectivity. Habitat corridors such as hedgerows are potentially very important in promoting the persistence of butterfly metapopulations in fragmented landscapes (Fahrig & Merriam, 1994). Increased fragmentation by hedgerow removal may make local populations of butterfly species with poor powers of dispersal more susceptible to local extinction, which further reduces abundance and distribution. However there is a lack of information to substantiate this claim (Hill *et al.*, 1995) as the understanding of what constitutes a barrier to butterfly movement is still poor (Fry, 1991).

The potential value of beetle banks for butterflies, if any, has yet to be quantified. Grassy strips established between the crop edge and the boundary positively influenced the abundance of *Maniola jurtina* (meadow brown) (Feber *et al.*, 1994); however, they may be too species poor to provide useful habitat for many other species. This study aimed to assess the habitat potential of beetle banks for butterflies in terms of nectar feeding, breeding and movement by comparing their communities with those of grassy hedgebanks.

5.4.2 Materials and methods

Standard 200m line transect walks (Pollard, 1977) were carried out alongside beetle banks and hedgebanks on conventionally managed farms (see ection 5.2.2 for location details) in June, July and August 1999, recording species richness and relative abundance of Lepidoptera flying along or within the habitat. All those flying within an imaginary 5m^3 box ahead of the recorder were counted whilst walking at an even pace. Where necessary, brief stops were made to use a net to temporarily catch individuals for accurate identification. A total of 186 transects were walked alongside both beetle banks and hedgebanks. Two-way ANOVAs were performed with month and habitat type (beetle bank or hedge) as fixed factors, on log (x + 1) transformed numbers of individuals and of species, and for each of the main families recorded. Any relationships between mean number of individuals or mean species richness recorded in each site, and vegetational characteristics of the sites were explored using linear regression.

5.4.3 *Results*

Although there was a significant difference in the number of lepidopteran individuals recorded in transects by month and by habitat, the interaction between factors was not significant (Table 5.4). More butterflies were seen alongside hedgebanks than beetle banks, and in both habitats, greater numbers were present later in the season (Fig. 5.6). Species richness followed similar trends, with a significant difference between months and between habitats (Table 5.4), with more species recorded along hedgebanks; however, the month × habitat interaction was significant.

With the exception of two *Polyommatis icarus* (common blue) seen in hedges, only four families were recorded. *Thymelicus sylvestris* (small skippers) and *Ochlodes venata* (large skippers) were recorded on beetle banks, with additionally *T. lineola* (Essex skippers) on hedgebanks (Hesperiidae). *Aglais urticae* (small tortoiseshells), *Vanessa atalanta* (red admirals) and *V. cardui* (painted ladies) were recorded on beetle banks, with also *Inachis io* (peacocks) and *Polygonia c-album* (commas) on hedgebanks (Nymphalidae). *Pieris rapae*, *P. brassicae* and *P. napi* (small, large and green-veined whites respectively) were recorded on beetle banks, with *Gonepteryx rhamni* (brimstones) also on hedges (Pieridae). *Maniola jurticea* (meadow browns), *Melanargia galathea* (marbled whites), *Aphantopus hyperantus* (ringlets) and *Pyronia tithonus* (gatekeepers) were recorded on beetle banks, with *Parage aegeria* (speckled woods) and *Coenonympha pamphilus* (small heaths) additionally on hedges (Satyridae). Seasonal variation was evident in the occurrence of these families (Fig. 5.6). The Hesperiidae declined in abundance from June to August, whereas Pieridae exhibited the opposite trend, and were most abundant at the end of the sampling period. The Satyridae were most abundant in the July sampling period, but the Nymphalidae were present at similar levels throughout sampling, and were the only family not to show a strong significant difference by month (Table 5.4). The overall difference between habitats could be attributed mostly to the Satyridae, with a month × habitat interaction also resulting in this family.

Butterfly species richness was positively related to the number of plants present in all habitats under study, and their diversity (Table 5.5). The number of individuals recorded also showed a positive relationship to floral diversity (Table 5.5). Other characteristics, such as beetle bank age and amount of herbaceous or nectar-providing plants present, did not significantly influence the abundance of butterflies.

Figure 5.6 *Lepidoptera recorded by standard transect walks along linear field habitats*

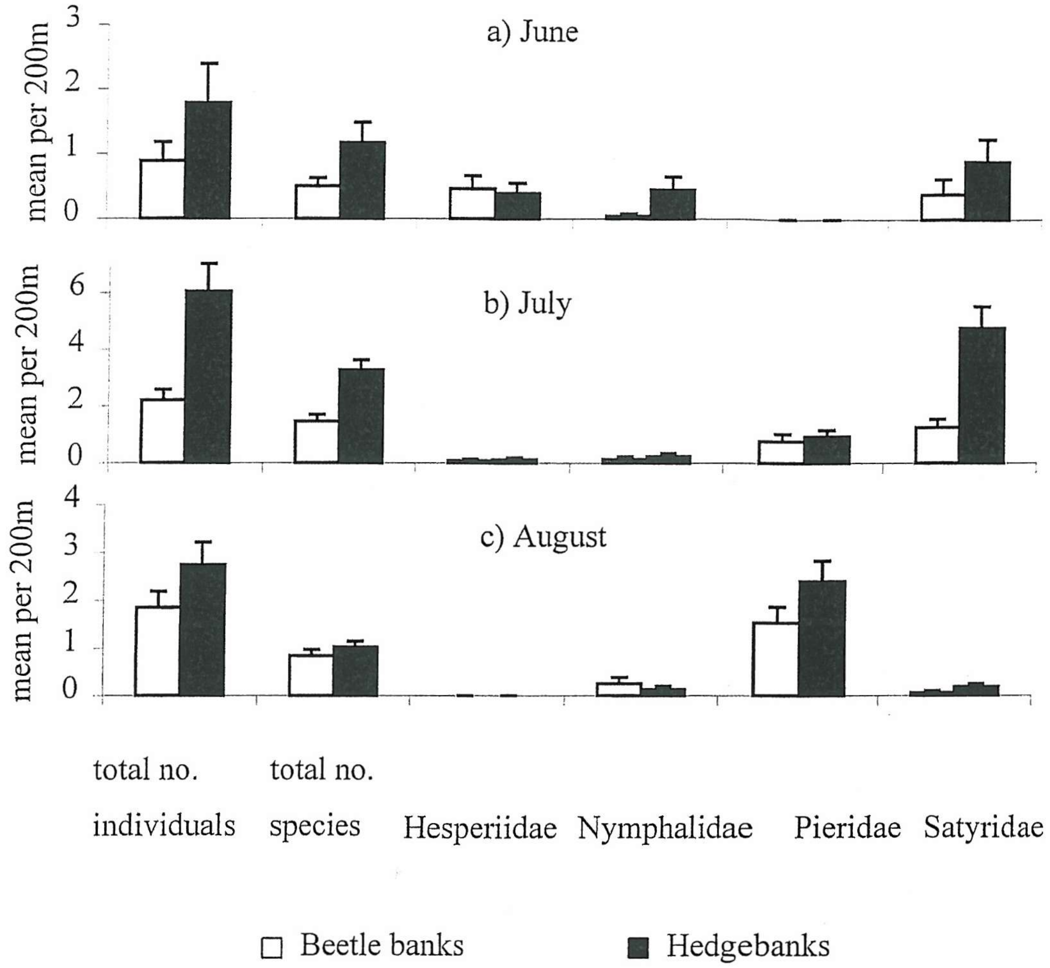


Table 5.4 *Summary of ANOVA results for 200m standard butterfly transects walks*

(indicates P<0.05, ** P<0.01, ***P<0.001)*

Factor	Month	Habitat	Interaction
Total no. individuals	$F_{1,143} = 15.63$ ***	$F_{1,143} = 13.85$ ***	$F_{1,143} = 2.79$
No. species	$F_{1,143} = 23.04$ ***	$F_{1,143} = 18.82$ ***	$F_{1,143} = 3.42$ *
Hesperiidae	$F_{1,143} = 11.15$ ***	$F_{1,143} = 0.05$	$F_{1,143} = 0.04$
Nymphalidae	$F_{1,143} = 1.04$	$F_{1,143} = 4.81$ *	$F_{1,143} = 3.00$
Pieridae	$F_{1,143} = 36.14$ ***	$F_{1,143} = 2.28$	$F_{1,143} = 0.58$
Satyridae	$F_{1,143} = 53.97$ ***	$F_{1,143} = 28.27$ ***	$F_{1,143} = 9.13$ ***

Table 5.5 *Relationships between butterfly observations and characteristics of sample sites*

	Mean no. individuals seen	Butterfly species richness
Site age (BB only)	$r^2 = 0.04$, $F_{1,21} = 0.73$, $P = 0.40$	$r^2 = 0.09$, $F_{1,21} = 1.89$, $P = 0.18$
% herbaceous plants	$r^2 < 0.01$, $F_{1,43} < 0.01$, $P = 0.99$	$r^2 < 0.01$, $F_{1,43} = 0.01$, $P = 0.94$
% cover of nectar-providing spp.	$r^2 < 0.01$, $F_{1,43} = 0.10$, $P = 0.76$	$r^2 < 0.01$, $F_{1,43} = 0.03$, $P = 0.87$
Floral spp. richness	$r^2 = 0.07$, $F_{1,43} = 2.90$, $P = 0.10$	$\mathbf{r^2 = 0.11, F_{1,43} = 5.10, P = 0.03}$
Floral H′	$\mathbf{r^2 = 0.12, F_{1,43} = 5.64, P = 0.02}$	$\mathbf{r^2 = 0.21, F_{1,43} = 10.81, P < 0.01}$

5.4.4 Discussion

Butterflies can be considered as indicators of farmland biodiversity (Dover, 1999). Aside from hedgerows and reduced-spray headlands, many parts of the farm have received limited attention as potential resources for Lepidoptera. Many species are reported as being reliant on a landscape mosaic, with corridors and links between habitat patches (Sparks & Parish, 1995), thus even simple linear features may be of some importance in limiting isolation. In this simple study, only low species richness was found, even in hedgebanks, although the species seen corresponded with those from other reports (e.g. Sparks & Parish, 1995; Dover, 1999). Differences between beetle banks and hedgebanks undoubtedly related to abiotic factors such as shelter, sward structure, shading, and the abundance of key nectar-producing flowers, a major determinant of adult abundance (Feber, Smith & Macdonald, 1996). Because plant species richness increases with beetle bank age (Thomas, Goulson & Holland, 2000), they may increase in value for butterflies. Although there was no clear link between bank age and number of individuals or species of butterfly seen, there was a positive relationship with the species richness and diversity of plants present in all sites. Where selectively sprayed headlands are managed alongside beetle banks, as well as other field margins, there will be enhanced benefit to butterflies. Overall, beetle banks may contribute value as dispersal corridors in the farm landscape, even if they have a lesser role in providing breeding habitat because of their unsheltered location. Certainly they may be more useful to some species than others; for example, the Satyridae favour hedgebanks much more strongly, principally no doubt because of nectar source requirements (Feber *et al.*, 1996).

Concern about declining butterfly populations has stimulated research aimed at reassessing current agrochemical application techniques and field boundary management practices (Longley & Sotherton 1997). To date, much research has been concerned with enhancing butterfly populations in the margins of arable fields by reducing pesticide contamination. In a survey of 18 pairs of farms, Feber *et al.* (1997) recorded significantly more non-pest butterfly species on organic farmland than on conventionally farmed land. This approach may be effective but may also represent reduced yield for the farmer, and so is unacceptable to all but a minority. One compromise is to incorporate conservation headlands that act as a buffer strip between the main body of the crop and the hedgerow, and are selectively sprayed with narrow-spectrum pesticides to reduce drift into the boundary. Conservation headlands have been shown to be successful in enhancing butterflies populations (Rands & Sotherton 1986; Dover *et al.* 1990; Dover 1991). Increasing the width of field margins by creation of an additional uncultivated strip adjacent to the boundary performs a similar function to conservation headlands (Feber *et al.* 1994; Feber & Smith 1995) and also increases the area of habitat available to marginal species. De Snoo *et al.* (1998) found that unsprayed margins in winter wheat had over twice as many species as margins sprayed with herbicides or insecticides and that the number of individuals was increased by a factor of 4.6. Clearly, mid-field beetle banks are more vulnerable to more careless agrochemical applications, and managing conservation headlands adjacent to them might be advantageous.

In follow-on work from this pilot study, it would be fundamental to evaluate a number of factors influencing butterfly presence in the habitat strips. Their aspect, and physical characteristics such as shelter or exposure, and microclimate conditions are relevant. Botanical factors, such as the abundance of key nectar-providing flowers (easily recorded as the relative numbers of flowers open as a proportion of overall vegetational cover), the abundance of larvae host plants (measured in a similar way to the nectar plants), and vegetation height and width, would require measurement. It would be important to assess the impact of farming practice; for example, such as neighbouring crop type, distance from crop, antecedent spraying regime in the adjacent field, and overall farming system. All factors could be assessed using an appropriate analysis such as a stepwise multiple regression, to discover which was most responsible for capture results. Additionally, greater time allocated to the experiment could allow transect walking in the crop centre and crop headland, as well as within the habitats under study, so that results could be contrasted against the field or regional background.

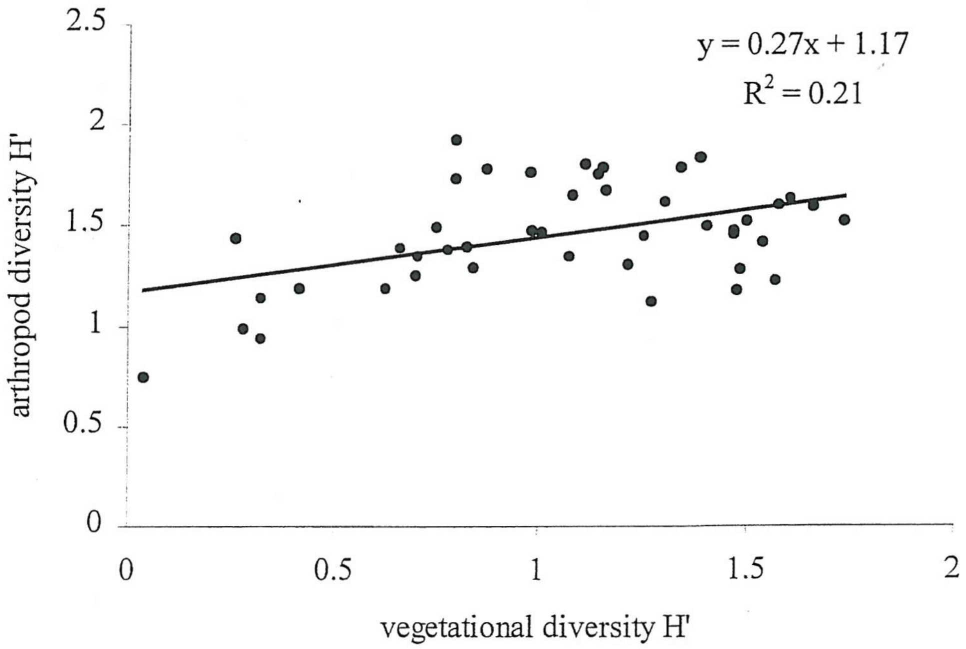
Future work could also distinguish between those species that were using such linear habitats as corridors to more resource rich sites, and those only making short range flight movements whilst mainly resident and breeding within the habitat. Such work might require techniques such as mark-recapture, and would be challenging to devise.

It would appear from both this and other work (e.g. by Feber *et al.*, 1996; Sparks & Parish, 1995; Dover, 1996 and others) that a heterogeneous farm landscape, comprising a range of field margins of different sward structure, composition and management, and including simple features such as mid-field beetle banks, are vital for continuing butterfly survival.

5.5 Overall arthropod diversity

Following examination of summer sweep net samples from all beetle banks and field margins sampled, the diversity of all arthropods captured was calculated using the Shannon-Wiener Diversity Index. A positive relationship between vegetational diversity was indicated ($F_{1,43} = 1.13$, $P = 0.002$) (Figure 5.7), and supports the assumption that successional changes in these habitats will impact on species composition within them. Similar results have been shown by Thomas & Marshall (1999), in field margin plots, where the number of invertebrate taxa was positively correlated with floral species number. Increased structural heterogeneity is probably the principal factor in increasing the diversity of arthropods found (Lawton, 1983; Dennis *et al.*, 1998). It would be interesting to examine this in more detail, as beetle banks provide an ideal tool for assessing community changes when a totally new habitat is established. Changes in proportions of 'pioneer' species against those normally found in long-established, undisturbed habitats, as well as species changes relating to vegetational height and density, would be relationships worth examining.

Figure 5.7 *Arthropod diversity against vegetation diversity within all beetle banks and field margins assessed over summer 1999*



6. Current use and perception of beetle banks by UK arable farmers

A version of this chapter was published as *'Progress on beetle banks in UK arable farming'*, S.R. Thomas (2000). *Pesticide Outlook*, **11** (2), 51-53.

This was in association with the article *'Increasing diversity in agro-ecosystems'*, S.R. Thomas (2000). *Pesticide Outlook*, **11** (2), 46-47.

6.1 Abstract

Beetle banks are now recommended by a number of advisory organisations, not just for potential biocontrol enhancement, but also to provide habitat for other wildlife, especially game birds. Many farmers in the UK are creating these features, and a cohort was questioned about their banks and their perception of them. There was much variation in current set up, with farmers adapting the design to fit in with their own ideas and requirements, but most farmers had positive opinions regarding the value of beetle banks on their farms, despite many as yet unquantified benefits.

6.2 Background and aim

Beetle banks are grass-sown ploughed ridges devised to provide perennial, herbaceous hedgerow bottom vegetation in a simple and inexpensive form (Sotherton, 1995). They were originally designed to be placed in the middle of large arable fields, where predator populations are most impoverished, to effectively 'shrink' the field size in terms of invertebrate densities and dispersal, though not with regard to farming management. Sotherton (1995) describes the original design for the creation of beetle banks. This study sought to compare current recommendations for the setting up of beetle banks, with what is actually taking place, through a survey of UK farmers' use of beetle banks and their opinions as to the value of these features on their farms.

6.3 Current recommendations

The Game Conservancy Trust's Farmland Ecology Unit provides advice to farmers about creating beetle banks, with a current leaflet, 'Beetle Banks – Helping Nature to Control Pests'. Beetle banks are also mentioned in their Factsheet 2 – Guidelines for the Management of Field Margins. Regional Farming and Wildlife Advisory Groups (FWAGs) may advise farmers about what to do based on this GCT guidance. The government-administered Countryside Stewardship Scheme (Anon., 1999b) and the experimental Arable Stewardship Scheme, (Anon., 1999a), also provide guidelines for the creation and maintenance of beetle banks, and gives information about payments available. They suggest that banks are as useful for game birds as much as for natural predators.

A 'Beetle Bank Mix', consisting of a 70% cock's-foot, 30% creeping red fescue, and 20% timothy grass mix, can be bought currently from grass seed suppliers (e.g. Cotswold Grass Seeds, Great Rissington, Gloucestershire). Yorkshire fog tends to drift towards the edges of banks, and is also less satisfactory than cock's-foot because of its more expensive seed (Collins, 1999). Wildflowers may be mixed into beetle banks, but they must be sown simultaneously with grass seed, if a mix is to be used, as they are unlikely to succeed in an existing sward (e.g. Hopkins *et al.*, 1999). 10-20% flower seed is usually used, depending on the kind of mix and cost of seed (Marshall & Moonen, 1998). The GCT Field Officer has suggested that plug-plants of flowering species such as knapweed may be planted into beetle banks after good establishment (P. Thompson, personal communication), although the success of this practice has yet to be reported. Umbelliferae and Asteraceae species are most useful, as beneficial bees, hoverflies and parasitoids may feed them on.

It is now recommended that beetle banks should not be cut more than once every two to three years, so that as a tussock structure develops, dead grass is accumulated which can provide camouflage for nesting birds (Vickery *et al.*, 1998) (Plate 1.2). There is no information about the effective life span of a bank, although Luff (1965) found that tussocks disintegrated after a decade. Re-seeding of patchy banks is one approach to maintain their structure.

Beetle banks are now present on farms in England and Scotland, and have recently been introduced to European countries such as France (N. Sotherton, personal communication).

6.4 Survey

Farming magazines featured a request for farmers who had constructed beetle banks to send their contact details forward. Questionnaires (see Appendix) were sent to these farmers, containing a range of questions about their beetle banks. As well as requiring factual information about dimensions, bank set-up, costs and so on, questions were also asked relating to views on the perceived usefulness of beetle banks on the farm, and other issues.

6.5 Results

Replies were received from farmers from Dorset, Wiltshire, Hampshire, Gloucestershire, Worcestershire, Hertfordshire, Oxfordshire, Kent, Norfolk and

Leicestershire. Sixteen farms gave a full and detailed response, with further information from other farmers or farm-related consultants being received informally in telephone conversations. Information relating to 52 separate beetle banks could be quantified; with a considerable number more adding to overall conclusions drawn.

6.5.1 Dimensions

The number of beetle banks that had been created on individual farms ranged from a single experimental bank on one farm, to nine on another. One estate describing having more than four miles of beetle bank present. Field size beside banks was highly variable, ranging from 7 to 29 hectares. One farmer commented that the ideal field size for inserting a beetle bank was 10 hectares, and another said that they were an ideal way of sub-dividing larger fields. The average dimension of a beetle bank was found to be 433.8m (± 32.4 SE) long and 3.4m (± 0.2) wide. The current average age of beetle bank was around 5.9 (± 0.5) years old, with further banks under construction or planned on a number of farms surveyed. One original bank that was created when the design was being developed by researchers at Southampton University, in collaboration with The Game Conservancy Trust, was still present on one site, and is now 14 years old (Plate 1.4).

6.5.2 Connectivity

Approximately 84% of beetle banks were constructed with gaps between the end of the bank and field margins, with 22% having a gap only at one end, to aid the movement of farm machinery. It was suggested in one questionnaire response that gaps at either end might lessen the attraction of foxes to the beetle bank. Conversely, connection to the entire field boundary/hedgerow network may assist the dispersal of animals such as carabids (Petit & Burel, 1998b; Tischendorf *et al.*, 1998) and small mammals (Zhang & Usher, 1991; Bennett, 1990).

In most cases, banks did not have the same crop grown on either side of them. The original design, in which a bank divides a large, single-crop field, was apparently no longer strictly followed. Many banks were now either used to create two separately cultivated fields and thus aid farm rotations, as a hedgerow might (Plate1.3), or were positioned at the edges of fields to create more potential wildlife refuges, blurring the distinction between sown grass field margins and beetle banks.

6.5.3 *Sowing and establishment*

95% of the banks had been established by sowing cock's-foot grass. One farmer commented that his experience indicated cock's-foot alone should be sown, for best results. However, 68% had some other seed incorporated into the sowing, many also containing Yorkshire fog and a number containing some other grass species alongside these recommended tussock-forming grasses, such as barren brome and red fescue. The recommended 'Beetle Bank Mix' has only been sown in a few cases. Some sites have used mixtures containing wild flowers, or allowed natural regeneration to complement grass sowing.

In 73% of cases, the banks were hand-seeded rather than tractor-drilled. According to establishment suggestions, 59% have had trimming or topping of the grass flowering heads, especially in the first few years since creation, possibly more frequently than was entirely necessary. Many farmers are understandably cautious when they perceive possible weed problems. Cutting is supposed to limit the spread of grass seeds into the crop, and encourage the grass cover to become densely established, lessening development of problem perennials such as thistles. Even where this had not been carried out, there was no reported weed invasion. Herbicide-treated sterile strips placed along the crop edge may be an important factor. Questionnaire replies indicated that 52% of beetle banks were supplemented by a conservation headland alongside them, which aid protection from spray drift (Longley *et al.*, 1997) and enhance natural enemy populations (Cardwell *et al.*, 1994; Sotherton, 1992). However, according to the GCT Field Officer (P. Thompson, personal communication) the strict definition (Sotherton, 1992) of what constitutes a conservation headland may not always be adhered to by farmers. No banks surveyed had received any kind of chemical control inputs. Although spot-treatments may be allowed, for instance against Barren brome infestation, agrochemical treatment are not recommended (Game Conservancy Trust - Factsheet 2) or even allowed within the Countryside Stewardship Scheme, but no farmer had found it necessary to resort to such means.

Many responses commented on the ease and flexibility of establishment of beetle banks, with one observation made about their low maintenance requirements.

6.5.4 *Costs*

The questionnaire asked farmers about the costs of setting up beetle banks on their farms, and responses were mixed. In most cases, negligible or no costs were given, or where stated, the cost of the seed only was quoted. This ranged from £20-50 for a single bank, with cultivation costs of £14 suggested by one farm. Labour and other costs were almost universally discounted, with only one farm suggesting £200-300 total costs for the creation of a beetle bank. One or two replies specifically added extra comments enthusing about the minimal bank establishment costs.

Sotherton (1995) suggested that a 400m bank in a 20ha field would cost less than £80, including seed, cultivation and loss of crop. There was, and currently still is, no IACS payment for the area taken up by a beetle bank, in fact the area of land it uses must be deducted from crop claims. Since 1998, the Countryside Stewardship Scheme (Anon., 1999b) offers a payment of £15 per 100m (£750/ha) per year for two-metre grass margins and beetle banks, which compensates for this area loss. Unfortunately, existing banks are not funded, and only those farms that are prepared to install a range of conservation measures, including beetle banks, may be considered for acceptance into the scheme. The similar Arable Stewardship Scheme (Anon., 1999a), currently being piloted in two areas of the UK, also offers this payment for beetle banks, and may been extended nationally.

6.5.5 Permanence

In 96% of cases surveyed, the beetle bank had become a permanent feature in the arable environment, and the two planned for removal had never actually been properly established. One farmer's comments stated that a bank could be realigned to suit cultivation requirements. Another suggested that banks were a good method of experimenting with the siting of a hedgerow, such that after concluding that the beetle bank was in a good position, it could be planted with shrubby species and be kept as a maintained, permanent field boundary. Other comments indicated that old fence or hedge lines, particularly where there was a slight ridge anyway, were obvious places to set up a beetle bank (Plate 1.1). After enthusiasm in previous decades for larger fields, for ease of cultivation by huge agricultural vehicles, the return to smaller field sizes by replacement of removed boundary habitat is now considered highly desirable, for a variety of reasons. These include aiding rotations, enhancing populations of pest control invertebrates, assisting declining farmland birds and providing increased habitat for profitable shooting activities, all commented upon in survey responses.

However, reports from agricultural advisors have anecdotal evidence that there are a few farmers who have put a beetle bank on their land but subsequently removed it, claiming that there was encroachment of weed species from the bank into the crop.

6.5.6 Potential biocontrol benefits

Mixed comments were received in relation to beetle banks acting as overwintering refuges for polyphagous predators. Either farmers had assumed that they were creating a habitat that would produce a reserve of such invertebrates, and that they would probably be useful, or they suggested that there was need for more concrete proof that biocontrol was actually occurring. One farmer stated that there was no evidence that beetle banks directly reduce the need to spray against crop pests, but presumed they were good for biodiversity anyway. Another said that at worse, it was 'no bother' to set up a bank, and at best, it might help reduce the need for insecticides. Others commented that they used insecticides very infrequently, with none in summer, and so any increase in biocontrol insect populations was just a bonus to their already successful farming regime.

6.5.7 Wildlife

There were many comments received about the potential or perceived benefits of beetle banks for wildlife. As well as remarks from several farmers that one of the reasons that they had set up the bank was in the hope of encouraging wildlife, there were many mentions of the use of banks specifically for game. Financial gains from increased game populations may easily compensate for small crop area losses. Provision of ground nesting cover was considered important, especially for grey partridges.

One farmer commented that his banks could provide habitat and food for barn owls known to live on the farm. Farmers have noted increased raptor presence over banks, where increased small mammal densities are providing more prey. There is an obvious conflict between the view that all small mammal species are 'vermin' and natural predator control is to be encouraged, and views that many species actually do little damage and should be conserved. Two of the farms interviewed are monitoring small mammal populations, with special interest in harvest mice, thought to be in decline. High densities have been found in beetle banks at one of these two sites (Bence *et al.*, 1999), and a third farm appeared to also have good populations, with a total of eight species recorded (author, unpublished data). Finally, banks in France are reportedly good habitat for wild boar (Sotherton, pers. comm.)!

6.5.8 Other comments received from farmers

The survey revealed other interesting information. That beetle banks caused minimal interference with farming operations was a positive comment in one case; and another farmer said that they were useful in helping draw up farm maps, particularly for IACS forms, presumably helping to demarcate field boundaries. The good advice received from an agronomist about beetle banks and their creation was said to add enjoyment to arable farming in one farmer's view! However, there were many responses requiring more information about where beetle banks should be established. Optimal field size, location within the field, numbers per farm, best seed mix, were questions that many farmers felt that they required greater help in answering. Quantification of claimed biocontrol benefits was another issue raised several times.

6.5.9 Public awareness and aesthetics

Many of the farmers interviewed gave views on the importance of features such as beetle banks for improving the aesthetic value of their farmland. Of those contacted nearly all had a range of other conservation-related features present on their land. They were aware that not only does such habitat have direct impact on farm incomes, (crop losses, biocontrol gains, game incomes, subsidies etc.), but that the impact on wildlife and conservation has public interest. Where farmers are seen to be concerned with the whole ecosystem, they receive greater co-operation and support from the public, and both farmers and non-farmers appreciated the aesthetic importance of a diverse habitat mosaic in the countryside.

Two farmers recommended specifically that public access should not be allowed onto beetle banks, or that footpaths should not lie alongside them. Damage to the tussock grass structure or flowers may occur by trampling, and insect populations may suffer. It has been suggested that the impact of human access, by walkers, riders and vehicles, on perennial margin strips, needs quantification (Marshall & Moonen, 1998).

6.6 Discussion

Unfortunately, concerns about weed encroachment into the crop have apparently caused some farmers to remove some beetle banks. This is despite recent work indicating that arable field margins are unlikely to affect weed levels in the crop, especially when sown with non-invasive perennial species (Smith, Firbank & Macdonald, 1999; Marshall, 1989;

Marshall & Moonen, 1997). These tend not to have sufficiently persistent seed banks, post-cultivation germination, and reproduction ability within the crop cycle, or herbicide resistance (Smith, Firbank & Macdonald, 1999). None of these farmers has offered viewpoints, and thus the present survey may be biased towards those farmers who feel that beetle banks offer a positive contribution to biological pest control and/or conservation on their farms, and were prepared to offer information about them. This is inevitable in this kind of survey.

Overall, in keeping with current scientific views, farmers and agricultural consultants agreed that the extensive research into habitat-enhanced biocontrol is still not conclusive. Polyphagous predators are known to limit pest species population growth, although only usually early on in the season (Holland & Thomas, 1997a). Beetle banks, and similar features, can provide ideal habitat where high numbers of such invertebrates can be recorded. However, evidence that fields with beetle banks, and improved predators densities, can lead directly to fewer pest outbreaks and insecticide reductions, is still elusive. Aphid densities have been found to increase at distance from a bank, though there was little evidence for good predator control where aphid populations were at outbreak level (Collins, 1999). Ultimately, impacts on yields are what a farmer may be most concerned about, and relationships between pests and predators are not always clear (Holland & Thomas, 1997b). The benefits of beetle banks will need further investigation.

Overall, the survey results suggested a positive view of beetle banks amongst farmers, and indicated that the small but increasing number of these features are contributing to an expansion in the area of non-cropped habitat available for the benefit of farmland biodiversity, including invertebrates, birds and mammals.

The interpretation of questionnaires such as this needs care, as opinions were taken only from a sample of farmers who had taken time to establish beetle banks. They tended also to have interests in game or wildlife conservation and had a range of other 'conservation' measures established on their farms, and perhaps were atypical farmers. It would have been valuable to talk to those who had made an active decision not to sow one, and to investigate their opinions and reasons also.

7. General discussion

7.1 Summary of thesis

Beetle banks supply overwintering refuge for invertebrates that feed on arable crop pests, and potentially providing habitat for other farm wildlife. They are simple and inexpensive to set up, and may require minimal management. Since their development over ten years ago, there has been considerable promotion of the design by farming advisory bodies, although more limited attention to their ecology. With a known time of establishment, they provide a useful means of investigating the effects of habitat creation on farmland wildlife, and whether simple prescriptions can fulfil equivalent functions of more complex non-cropped field margins. In this thesis, I found that beetle banks had lower plant species richness and H' diversity than conventional field margins including grassy hedge-banks and marginal grass strips, but these characteristics increase with age (Chapter 2). Although it might be predicted that such successional change would result in the habitat becoming less suitable as overwintering sites for polyphagous predators, evidence indicated that this was not the case within the age range of sites examined. Beetle banks contained more dense grass cover, especially that of tussock grass, and so remain of value as overwintering habitat for predatory invertebrates for well over a decade. Predator densities were very variable between sampling sites, but tended not to be different from those of conventional field margins overall, regardless of beetle bank age. Older beetle banks contained greater predators per m^2 and in particular, densities of Carabidae species known to overwinter in boundaries increased though time. Species richness of predatory beetles increased with age, and was little different from conventional boundaries (Chapter 3). Dense, tussocky grasses such as *Dactylis glomerata* have been shown to be important habitats for the winter survival of predatory invertebrates, and I confirmed their temperature buffering capabilities; but maturation and eventual degradation of tussocks could limit their shelter-providing characteristics. I did not find evidence for this, although it is possible that as the sites examined age further, such problems will emerge as successional change continues. A greater age and geographic range of beetle banks sampled, and more detailed analysis of the structural integrity of tussocks for example, might be more informative.

The novel 'Red-Blue spatial analysis by distance indices' technique was used to investigate within-field spatial patterns of Carabidae from winter through to summer in cereal fields, to consider potential impact and control of pest outbreaks (Chapter 4). Species of boundary-overwintering Carabidae were significantly clustered alongside beetle banks and the hedge in early spring, but became more homogeneously distributed across fields as the season progressed, supporting earlier evidence for a wave-like dispersal of key species over a short period. Beetle banks appear to be as valuable as conventional boundaries for aiding carabid dispersal into crops, and by inserting them across the centre of fields, they effectively increase 'quantity of source habitat' to 'field area' ratios. Field-inhabiting Carabidae species developed late in summer from within field centres, and so may be of lesser value for biocontrol. Some limited evidence was put forward for beetle banks acting as a reservoir of predators should within-field populations become depleted during the growing season, but much more research would be required to validate this idea.

The abundance of predatory Empididae was similar in a beetle bank and a conventional hedgerow, with a lower, homogeneous abundance through distances from these habitats across one field (Chapter 4), and resource provision for this little studied group may enhance its potential within the suite of natural enemies on farmland.

Severe declines have occurred in farmland bird populations, attributed to dwindling levels of invertebrates vital within chick diets in cereal fields, fewer adult feeding resources, and poor nesting and brood-rearing habitat provision. The abundance of game chick-food invertebrates in beetle banks, although lower than in conventional field margins, may be valuable in increasing availability within cereal fields. Adult game birds may find the high levels of dense, tussocky grass valuable as shelter and nesting cover, although vegetation permeability for chicks could be unsatisfactory (Chapter 5).

Beetle banks were found to contain less herbaceous cover and fewer melliferous plants compared with typical field margins, but floral diversity increases through time, and appears therefore to be of benefit to predatory beneficials and other species of conservation concern (Chapter 5). Banks certainly enrich fields with greater faunal diversity than would exist otherwise. Richness of Orthoptera was similar between banks and conventional margins, although there were compositional differences in capture, with Acrididae more frequently encountered in beetle banks and Tettigoniidae in field margins. Older beetle banks had a greater species richness of Orthoptera, which may be linked to structural botanical changes or slow colonisation. Lepidopteran abundance and richness certainly related to the floristic species richness and diversity of the habitats, with fewer butterflies recorded in beetle banks, as had been expected when in comparison with hedgerows and other margins with more diverse, resource-rich herbaceous bases. Further detailed study would be essential to measure the exact use made of beetle banks by grasshoppers, butterflies and other invertebrates, and whether vegetational change within them gives positive benefits. It would appear important to evaluate whether improving management practices, such as incorporating conservation headlands alongside beetle banks, would aid populations to make greater use of such simply created grass swards.

7.2 Implications of results to the farmer

Although initially simple grassy strips, the investigations described in this thesis have indicated that beetle banks can support a faunal diversity that approaches levels found in good quality permanently established field margins. In terms of broad farm diversity, farmers will benefit by creating more beetle banks in large arable fields, and leaving them undisturbed and protected from field-applied agrochemical damage and close ploughing. Weed cover was not significantly different between beetle banks and conventional margins, although was it very variable. Where economically threatening species are present farmers may feel uneasy, but crop encroachment may be minimal and control is relatively straightforward and can reportedly consist of direct treatment with a knapsack sprayer. At present, farmers may be too keen to top or trim beetle banks, when this may be rarely necessary (Chapter 6). Scrub development on beetle banks was evident, but local cutting and removal of unwanted woody plants may be an adequate and rapid solution. Organisms such as butterflies and grasshoppers are highly vulnerable to the impact of spray drift in such exposed mid-field features; thus beetle banks deserve as much care and protection as other margins. Beetle banks expand the mosaic of uncropped habitat on arable farmland, and so may assist in supporting or even increasing the abundance and diversity of beneficial invertebrates and other organisms, or facilitate their dispersal to more favourable habitats.

Dennis & Fry (1992) commented that placing grass strips into field centres was in effect creating ‘islands’. In fact, this was the original design intention of beetle banks, so as not to impact on agronomic activity within the field (Thomas *et al.*, 1991 & 1992a). Where field margins are linked, the activity of predatory arthropods along new habitats and into adjacent crops was found to be increased (Mader, 1988) and diversity could be enhanced

(Forman & Baudry, 1984). Certainly, the activity of the carabid *Nebria brevicollis* at the intersections of hedgerows has been recorded as greater than in mid-section strips (Joyce, 1999). The impact of gaps between field boundaries has also been evaluated, suggesting that they can be detrimental to arthropod dispersal (Mader *et al.*, 1990) but no movement inhibiting effects were found by Joyce *et al.* (1999). Although there has been considerable argument as to whether invertebrates really use such habitat as 'corridors', it seems reasonable that a network of linked linear non-cropped areas could be a means of ensuring that suitable habitat for both common and rare species is kept within dispersal range, to aid survival (Mader, 1990). As a consequence, although beetle banks were designed to be inserted into large fields so as not to disrupt them from being farmed as a single unit, it may be more desirable to encourage farmers to use them as a cheap means of dividing such fields into smaller units, connecting them to existing field boundaries where possible. Results from survey work indicate that at least some farmers have taken this approach (Chapter 6).

Weibull *et al.* (2000) advocated increasing small-scale heterogeneity in the agroecosystem to enhance butterfly diversity. They found that the structure of the farm landscape was more important than the farming system by which it was managed. Thus they suggested that simple measures could be used to increase heterogeneity, such as leaving small habitat islands or strips within fields, as well as increasing the overall quantity of field margins. Thus beetle banks unconnected to other field boundaries may still be important.

Marshall & Moonen (1998) suggested that although there had been considerable amounts of research and development towards understanding the ecology of field margins, there were many areas requiring further research. In particular, they perceived inadequate information on the use of margin habitats by different taxa including the Heteroptera, amphibia, reptiles and gastropods. Refuge, corridor or other functional roles are not at all well known for a number of different organisms. Clearly, because of their fairly recent development relative to other field margin designs, beetle banks may deserve further study.

It was also suggested that the arrangement of field margins in the agricultural landscape was an area little currently understood (Marshall & Moonen, 1998). The amount of semi-natural or uncropped habitat, the shape and orientation that is ideal for significant conservation impact or for maintaining declining taxa, is poorly understood. For example, there have now been a number of studies on the dispersal of beneficial invertebrates from beetle banks (Thomas *et al.*, 1991; Thomas *et al.*, 1997; Collins, 1999; Chapter 4), and their distribution and dispersal according to spatial scale (Jepson & Thacker, 1990; Duffield & Aebischer, 1994). Yet it is still not clear what the optimal field size is for efficient biological pest control, or ideal field size to edge ratio, including the number of beetle banks required for any field of a particular size. The Game Conservancy Trust recommends that one beetle bank is placed in a roughly square 20 ha field that already has established boundaries with tussocky grass cover, to achieve uniform cover of predatory invertebrates (Sotherton & Page, 1998). Suggesting that the field has dimensions of approximately 450 × 450 m, this means that the beetle bank will be more than 200 m from a parallel boundary. Where fields are long and narrow, obviously there is less need for overwintering habitat creation as no part of the field is at such a large distance from the edge. However, when analysing patterns of carabid distribution in the present study (Chapter 4), it was seen that at 150m into cereal fields, capture of many species was considerably lower than nearer to a beetle or hedge bank through much of the growing season of the crop (data for individual species not presented in this thesis). This suggests that in fields of this size, a single bank is not sufficient to provide efficient predator-mediated biocontrol.

The management of field margins was an area deemed to require further attention (Marshall & Moonen, 1998). The seed mixtures and cutting regimes of sown grass and flower strips especially need refining, particularly for their adaptation for different soils. Although the suitability of different grasses for sowing in beetle banks has been thoroughly investigated (Thomas, 1991; MacLeod, 1994; Collins, 1999), it is not explicit whether other plants can be successfully incorporated into the seed mix. Red clover has been sown within a *D. glomerata* stand by some farmers (personal observation) and is undoubtedly useful for nectivorous invertebrates. Collins (1999) suggested that a variety of wildflowers can be incorporated into beetle banks, and the GCT Field Officer has commented that flowering plug plants, such as knapweed, can be dug in to ensure they are not out-competed by grass growth (P. Thompson, personal communication). Certainly sowing grasses with creeping growth forms to fill in any bare gaps around tussocks has been found to be viable, and suggested as a means by which invading weeds can be kept out (Collins, 1999). This thesis found that the development of increasing floral diversity within the grass stand did not necessarily impair their major function as overwintering habitat for beetles and spiders, and yet could increase the availability of resources for other arthropods (Chapters 2 & 5). Whether this is sustained for many years is more doubtful, as scrub development and tussock decline are eventually inevitable. Long-term maintenance options, rather than just early establishment instructions, are needed to enable farmers to derive maximum returns from establishing these habitat strips within their fields. Notifiable and problematic species such as thistles and ragwort can easily be removed by localised spraying with selective herbicides, but a general decline in grass density may not be desirable, and may necessitate re-seeding.

This thesis has demonstrated that simple remedial measures, such as the creation of narrow grass banks across arable fields, can go a considerable way to address the need for greater biological diversity on farmland, through the expansion of the habitat mosaic present. They may give direct economic benefits, such as increased predator activity within the crop, and indirectly provide valuable resources for other less obviously beneficial organisms. Uncomplicated, inexpensive prescriptions that can easily and rapidly be put into practice by the farmer are essential in the current agricultural climate. Where there may be perceivable benefits, in terms of increased invertebrate abundance and other wildlife, this may give encouragement for farmers to then make extended efforts to increase the quality and quantity of non-cropped habitat on the farm. Such further measures might be daunting initially because of complex management and financial commitments. However, simple beetle bank creation may provide incentive for a farmer to then consider the re-establishment of lost hedgerows and the sowing of field boundaries of different mixtures, so that there is a more heterogeneous farmed landscape of maximum benefit to biodiversity.

7.3 Potential future research

Several of the experiments described in this thesis were carried out principally as pilot studies, and thus there are clear opportunities for them to be expanded into more detailed investigations. The examination of the value of sown grass strips for invertebrates such as the Orthoptera is an ideal example, with possible future study relating to exactly which botanical and structural variables are most important in determining species abundance and reproductive success in these habitats.

Other experiments would benefit by increasing sample sizes; for example, further evaluation of a greater age range of beetle banks for tussock deterioration, as well as for the densities and diversity of beneficial polyphagous predators, would give better evidence for their optimal lifespan before re-seeding or other management was necessary. As there are few very old banks in existence, the current study was limited, but whilst existing banks remain *in situ*, this topic may be worth returning to in the future.

The study relating to spatial and temporal distributions of carabids dispersing into cereal fields suffered time and weather constraints, and also limitations to where the experimental layout could be positioned. An improved design would possibly consist of replicated pairs of fields, with and without beetle banks present, to enable a direct comparison between spatial patterns in those fields. Collins (1999) used such a layout, with trends indicating a more uniform distribution of predators such as linyphiids in fields containing beetle banks; however, low capture rates, and different crops with heterogeneous vegetation structures confounded the results. She suggested that rather than just the two transects used in the experiment, a trap-grid design would allow more informative analysis using SADIE techniques. It would be important to assess prey densities simultaneously with predators, so that associations between the taxa, and through time, could be explored. If a paired field design is used, it would also be easier to contrast post-insecticide recovery patterns in fields with and without beetle bank refuges. Ideally, any such applications would be made during the peak dispersal of boundary-overwintering Carabidae, as had originally been planned for the present study.

Recently, Beck & Toft (2000) proposed that polyphagous predators may be more efficient predators in areas where there are regular outbreaks of cereal aphids, as their mean aphid tolerance is kept at a high level. Artificial selection experiments in the laboratory found that the spider *Lepthyphantes tenuis* had different genetic variation in tolerance to an aphid diet, leading to differences in survival, development and reproduction. They suggest that to keep predator efficiency high in areas of less frequent outbreaks, increasing the availability of non-pest aphids could create a selection pressure on polyphagous predators for greater tolerance. Allowing the presence of some weeds in the crop, and manipulating field margins, including creating new habitat, they suggest, may thus aid biological pest control (Beck & Toft, 2000). It would therefore be interesting to explore tolerance differences to prey species by predators in areas with and without such habitat improvements, to discover if selection was occurring to a measurable degree in the field.

Halley *et al.* (1996) suggested that populations of Linyphiidae could be greatly increased in cereal fields by including small areas of grassland in the arable landscape. Nyffeler (1982) had previously suggested that increasing the area of reservoir habitat where spiders were abundant would augment spider densities within fields. This is despite scarce information on just how much exchange occurs between edges and fields, and whether overwintering habitat truly is necessary for these invertebrates, as their high cold tolerance means that they are rarely inactive within cereal fields (Sunderland *et al.*, 1986). Certainly large numbers of linyphiids may be found in beetle banks and field margins, and such uncropped areas may be a valuable refuge during periods of disturbance such as pesticide application or ploughing (Halley *et al.*, 1996).

During the course of the fieldwork carried out for this thesis, considerable small mammal activity was observed within beetle banks. Eight species, including *Apodemus sylvaticus* (wood mouse), *Apodemus microps* (field mouse), *Micromys minutus* (harvest mouse), *Apodemus flavicollis* (yellow-necked mouse), *Clethrionomys glareolus* (bank vole), *Microtus agrestis* (field vole), *Sorex araneus* (common shrew), *Sorex minutus* (pygmy shrew) were recorded in banks. However, it was not clear whether these animals are breeding in the habitat, or merely using it for transitory purposes. Questions deserving attention relate to whether beetle banks have a diverse array of breeding populations of small mammals, especially in relation to the lack of fruits and berries that might normally be found in hedgerows; and whether any potential corridor function of these grass strips is impaired by lack of connection to other field margins. Colonisation of new sites may be rapid. Woods, Dunleavy & Key (1996) planted new blackthorn hedges, with differing treatments of sown grass understorey, finding that highly mobile small mammal populations rapidly moved into the new habitat. *M. agrestis* numbers were found to be significantly higher in areas sown with *Dactylis glomerata*, indicating the suitability of this plant for nest building. Bence *et al.* (1999) has described how *M. minutus* find dense cock's-foot stems a preferred nesting location in beetle banks, indicating their value for this threatened species, but it is not clear how the vegetational structure of banks is used by other species. Eight species of small mammal were found to be rapid colonisers of grassland plots of different successional ages (Churchfield *et al.*, 1997). In the most ruderal plots, *M. minutus* was most dominant, with *A. sylvaticus* more specialised to the mid-successional stage, with small shrubs and trees. Shrews and voles tended to be more generalist, with no distinct habitat preferences. Within one to two years of establishment of the plots, all of these species were being captured regularly. The mid-successional stages of grassland sustained the greatest number of small mammals overall. Beetle banks may be particularly valuable at providing dense vegetation when cover provided in the field has been harvested. Species such as wood mice suffer increased predation pressure at this time (Tew & Macdonald, 1993), and poorly managed hedge bottoms may not provide sufficient alternative protection, when herbaceous cover dies down after the summer.

Additionally, bumblebees rarely nest in newly disturbed land, but often occupy the disused nests of small mammals, or nest among tussocky grass in established vegetation, where moss is also available (Fussell & Corbet, 1992). Corbet (1995) describes how the provision of long-term undisturbed perennial habitat, such as in long-term set-aside, is much better than habitats managed over shorter periods. Unsown beetle bank swards may thus provide habitat for these invertebrates, vital for crop pollination and currently in decline (Williams, 1982).

In summary, the planting of grass strips of one or more species, with and without the incorporation or development of other flowering plants, has been found to be of substantial value for much farmland fauna. However, there is extensive scope to investigate many factors in greater detail; i.e. exactly which resources are of most importance to these species; whether there is any conflict of interest in managing the habitat for one group over another in the long-term; and what other organisms may also be found in these new habitats.

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9. Appendix

Summary of contents of questionnaire sent to farmers:

Questionnaire is **confidential**. Please fill in as much detail as you are able.
Leave blank any sections you are unable to answer.
If you have any other **useful information** about your use of beetle banks on your farm, please either fill in the final box, or use the other side of this sheet.
A simple **sketch of the layout** of the field(s) containing the beetle bank(s) would be of use, and can be drawn on the back of the sheet. If you have more than one bank, please fill in a questionnaire for each of them, on the extra sheets provided.

Name of farm owner/farm manager:
Name and address of farm:
No. of beetle banks present on farm:

1 Name of beetle bank (or field containing it):
2 Size of field containing bank:
3 Soil type of field:
4 Length of bank (approx.):
5 Width of bank (approx.):
6 Date of establishment:
7 What grass was it sown with?
8 Sowing rate:
9 Was it hand or tractor sown?
10 What was the approximate cost of setting up the bank?
11 Has the bank been cut/trimmed/mown since establishment? if so, when and how?
12 Has the beetle bank had any herbicide/insecticide applications since establishment? if so, what, when and how?
13 Is there a gap at each end of the bank to allow farm vehicles to pass around it, or does it join onto the other field margins?
14 Are the same crops always grown on either side of the bank?
15 What crops have been grown in the field containing the bank since its establishment? please list with date (if the two sides are different, please give details for both)
16 Are there 'conservation headlands' i.e. unsprayed 6m strips, along either side of the bank?
17 Why did you decide to set up this bank?
18 From where did you get the information about how/why to set it up? e.g. FWAG/GCT
19 Do you intend to remove the bank at any time, or do you consider it to be a permanent feature to the field? if you do want to remove it, please give reasons why.
20 Are you planning on setting up further beetle banks on your farm?
21 Are you establishing any new hedgerows on the farm?
22 What other 'conservation' measures do you have on your farm? e.g. conservation headlands; set-aside; game bird strips etc.
23 Do you have any ideas/comments about beetle banks in general?

Thank you very much for taking the time to fill in this questionnaire.
Your help is greatly appreciated.