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Botanical diversity of beetle banks Effects of age and comparison with conventional arable field margins in southern UK

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Abstract

Beetle banks are simple, grass-sown raised strips providing habitat for the invertebrate predators of arable crop pests and other farmland wildlife. To date, research has mainly focussed on such predators. Establishment guidelines for these features, which are considered as inexpensive substitutes for the considerable amount of hedgerows that have been lost in the UK, are available, as is some funding, but long-term management guidance is lacking. The botanical composition and diversity of a range of beetle banks was examined in southern UK over two summers and a winter, and compared with that of typical, adjacent field margins including grassy strips and hedgebanks, with a view to indicating potential management requirements.

Beetle banks had lower species richness and H' diversity than field margins, but these characteristics increased with age of the bank 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 tussock, but less herbaceous cover and fewer nectar-providing 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, although 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 are of value as refuge habitat for predatory invertebrates for over a decade. Increasing floral diversity may benefit beneficial invertebrates. As simple, inexpensive features, beetle banks provide a means of dividing fields and enhancing farmland biodiversity, while requiring minimal management.

Keywords: Beetle bank; Field margin; Arable weed; Succession; Farmland diversity; Non-crop habitat; Southern UK

1. Introduction

During the last 50 years, a very large number of hedgerows and field margins have been removed from farmland in the UK, and of those that remain, many are poorly maintained (Greaves and Marshall, 1987; Barr and Parr, 1994). This led to a loss of diversity, not just of floral species richness and corresponding faunal

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diversity, but also in the shape, structure and type of hedgerows (Muir and 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 and Krebs, 1989; Marshall et al., 1994; Kleijn et al., 1983). Many important functions of hedgerows and other field boundary habitats have been investigated in recent years. Field margins may provide overwintering sites for invertebrate predators of crop pests, corridors for vertebrate and invertebrate population dispersal, game bird shelter and reproduction sites, and temporary and permanent residential habitat for many organisms (Boatman and Wilson, 1988; Aebischer et al., 1994; Marshall and Moonen, 1998).

Predatory invertebrates, such as carabid and staphylinid beetles and spiders, can be valuable biological control agents in arable crops (Potts and Vickerman, 1974; Chambers et al., 1983; Chiverton, 1986; Sunderland et al., 1987). Many such species overwinter outside the field in marginal habitats, and dense, tussock grass has been found important in providing optimal microclimate conditions for shelter and survival (Luff, 1965; Asteraki et al., 1992, 1995). Inadequate management of many 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 are lost. Large field sizes associated with large vehicles and machinery have led to change in the ratio between crop area and 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 (Duffield and Aebischer, 1994).

Beetle banks are raised strips sown with *Dactylis glomerata* (cock's foot) or sometimes *Holcus lanatus* (Yorkshire fog); grasses with tussock-forming properties (Thomas et al., 1991; Sotherton, 1995). They were designed for placement in the middle of fields to provide more overwintering habitat for beneficial invertebrates (Thomas et al., 1991, 1992), and favour greater spring recolonisation of the field from shorter distances. Organisations such as The Game Conservancy Trust and Regional Farming and Wildlife Advisory Groups recommend the placing of beetle banks into large fields because they are inexpensive to set up and maintain, and need not interfere with usual farm management practices (Sotherton, 1995). Financial support is now available within certain UK farmland stewardship schemes (Anon., 1999a,b). 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 and monitored for a period (MacLeod, 1994; Collins et al., 1996); more recently, work was carried out to attempt to measure 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 and Burckhardt, 1992; Gardner et al., 1995; Thomas and Marshall, 1999).

D. glomerata tussocks were found to disintegrate after a period of 7–10 years (Luff, 1965), and so beetle banks may no longer represent ideal overwintering habitats. Farmers who set up banks have limited information regarding appropriate management of banks once established, such as how or whether to keep the grass stand dense and how to manage weed species that may become dominant within the banks. Additionally, it is likely that spray drift from the crop area will occur, causing damage to vegetation 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., 1991; Longley et al., 1997; Longley and Sotherton, 1997). Less competitive growth of a damaged grass stand could allow composition changes in the beetle bank, e.g. weed invasion. The associated invertebrate populations, including predators and other groups such as nectar- and pollen-feeding insects and pest species, may be altered.

Banks established for different periods of time were examined in terms of floral composition and its change with age. The floristic diversity of beetle banks was compared with other conventional field margins, such as grass edges and hedgerows, the incidence of potential weed species in particular being considered.

2. Materials and methods

In July 1998, the flora of nine beetle banks within arable fields on an estate in Hampshire, southern 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 management of the banks since. A 'sterile strip', i.e. a 0.5 m 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 300–900 m long, 2–5 m wide, on slightly flinty calcareous silty clay loams. Each site was also 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 200–900 m long, 2–6 m 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.

In each beetle bank or field margin, a 0.71 m × 0.71 m quadrat was placed on the ground at 10 m intervals and the vegetation was recorded by species as percentage cover. 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* spp. (sowthistles), *Cirsium* spp. (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.

2.1. Analysis

Species richness and plant cover were examined for each sampling site, with the Shannon-Wiener Diversity Index (H') being calculated to measure the diversity relating species number to relative abundance (Magurran, 1988). The index reflects species dominance as affected by changes in the abundance of rare species and is sensitive to sample size. For each beetle bank or field margin, a single mean value of species richness and diversity was calculated and used in subsequent analyses to avoid pseudo-replication. Regression analysis was used to relate species richness and H', tussock and weed cover, with beetle bank age. Paired *t*-test was used to compare logit-transformed means of beetle banks and field margins, after assessing homogeneity of variance.

3. Results

3.1. Summer vegetation

Total vegetation cover was significantly lower in beetle banks than in field margins in both summers (Table 1). A total of 82 plant species was recorded in beetle banks, compared with 89 in field margins. Field margins had a significantly higher mean species richness and vegetational diversity than beetle banks, in both sampling years (Table 1); the oldest banks having diversity indices above 1, almost equal to the average for field margins (1.35).

Cover of grasses tended to be higher in beetle banks compared with margins in the summer, the difference being significant in 1999 (Table 1). For tussock species the same pattern was found. Sown *D. glomerata* was highly variable; with a mean of only 34% cover overall, and higher values in banks than in field margins (Table 2). A decline in the amount of tussock with age of beetle bank occurred in 1998 ($r^2 = 0.65$, $F_{1,8} = 13.1$, $P < 0.01$), but not in 1999 ($r^2 = 0.03$, $F_{1,21} = 0.60$, $P = 0.45$).

Table 1
Number of species, diversity index and mean cover (% + S.E.) of different plant categories in beetle banks and field margins sampled in summer, with results of paired t-test for the differences[a]

Mean (+S.E.)	1998			1999		
	Beetle banks	Field margins		Beetle banks	Field margins	
No. of species	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' index	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 cover	78.8 (2.92)	90.5 (1.80)	$t = 2.12$, d.f. = 16, $P = 0.003$	80.7 (2.18)	87.7 (1.28)	$t = 2.04$, d.f. = 33, $P = 0.10$
% Tussock	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, $P = 0.04$
% Other grass	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, $P = 0.007$
% Woody plants	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 plants	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, $P = 0.001$
% 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, $P = 2.04$
% Broad-leaved 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	

[a] t-Test: where calculated value of t (mean difference between sample divided by standard error of the difference) is compared to the t-distribution at the appropriate degree of freedom.

Table 2
Mean cover (% + S.E.) per plant species in beetle banks and field margins, summer 1999, and % of sites with each species ($n = 22$)

Species	Mean % cover in beetle banks (+S.E.)	Percent of beetle banks with sp.	Mean % cover in field margins (+S.E.)	Percent of field margins with sp.
Grasses				
Agrostis gigantea	1.32 (0.97)	27.37	0.15 (0.14)	4.55
A. stolonifera	0.48 (0.47)	9.09	7.45 (2.55)	72.73
A. myosuroides	0.24 (0.23)	13.64	0.04 (0.04)	9.09
Arrhenatherum elatius[a]	3.82 (2.01)	59.09	17.98 (3.73)	95.45
B. mollis	0.05 (0.03)	27.27	0.05 (0.04)	22.73
B. sterilis	7.93 (5.21)	50.00	2.25 (1.13)	63.64
D. glomerata[a]	34.19 (5.66)	90.91	2.57 (0.67)	86.36
E. 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
H. lanatus[a]	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				
C. 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[b]	3.25 (0.97)	63.64	1.00 (0.31)	72.73
C. vulgare[b]	0.25 (0.12)	27.27	0.74 (0.55)	27.27
Convolvulus arvensis[b]	0.37 (0.21)	27.27	2.12 (0.65)	68.18
G. aparine[b]	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[b]	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[b]	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[b]	0.18 (0.10)	22.73	0	0
Stachys sylvatica	0	0	0.16 (0.07)	27.27
Taraxacum officinale[b]	0.13 (0.07)	18.18	0.15 (0.10)	18.18
T. japonica	0.25 (0.25)	4.55	6.30 (3.63)	54.55
U. dioica	0.19 (0.11)	13.64	7.87 (1.94)	77.27

[a] Only tussock-forming species; [b] Nectar-providing species present in >20% of beetle banks and/or field margins are shown.

More herb cover was found in field margins than in beetle banks in both sampling years during the summer, the difference being significant in 1999. The same pattern occurred for nectar providers (Table 1). Weed levels did not differ significantly between the two habitats, or with bank age and ranged from 3 up to 22%.

The number of species present was high in newly established beetle banks; it declined sharply in

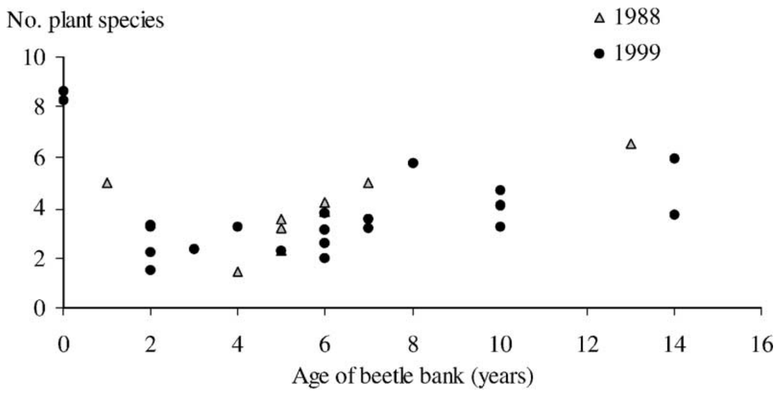

Fig. 1. Mean number of plant species in beetle banks in relation to bank age (summer 1998 and 1999).

2-year-old sites, increasing after 3 years (Fig. 1). A polynomial regression showed a highly significant relationship between species richness and age ($r^2 = 0.62$, $P < 0.001$; $y = -0.0162x^3 + 0.3925x^2 - 2.5 + 103x + 7.277$). Beetle bank diversity was high for newly established sites, dropped rapidly in the second year to steadily increase in older sites. 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 in one habitat exclusively. In addition to three wordy plant species, *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 (Table 2).

3.2. Life history strategy

In 1998, there was no clear trend in the number and proportion of annual, perennial or biennial herbaceous species in relation to age. In 1999, there was a trend for greater cover by annual species in young beetle banks, up to 2 years old, with more cover by perennials in following years; however, there was no obvious change in composition later (Fig. 2).

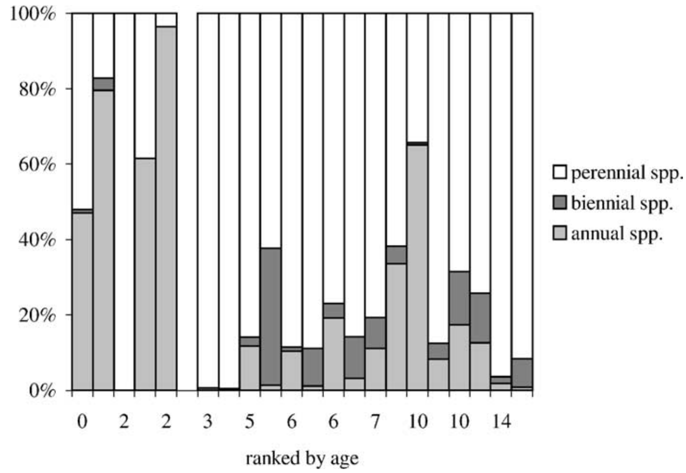

Fig. 2. Proportion of herbaceous species with different life history strategies in beetle banks of different age (summer 1999).

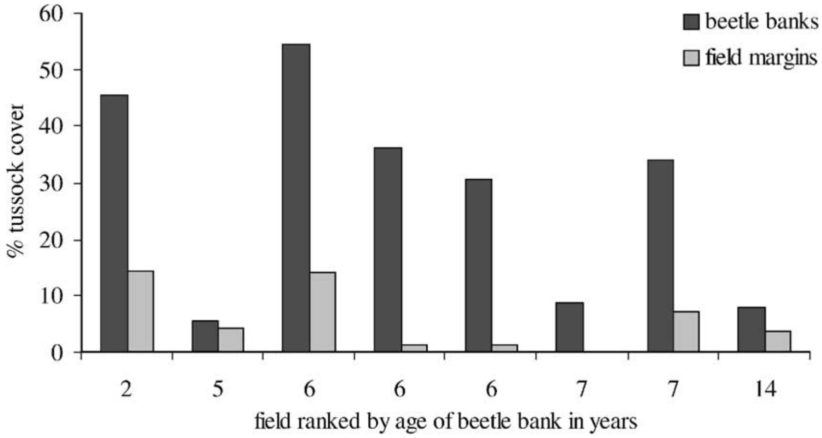

Fig. 3. Mean cover of tussock grass in beetle banks and field margins (winter 1998–1999).

3.3. Winter vegetation

Overall plant cover was high in all sites during winter, and there was no significant difference in cover between beetle banks and field margins ($t_{16} = 2.12$, $P = 0.18$). Significantly more grass tussock was present in beetle banks than field margins, although the overall amount was not always particularly high, and was variable between banks ($t_8 = 2.31$, $P = 0.03$; Fig. 3). Linear regression analysis found no relationship between bank age and tussock cover ($r^2 = 0.26$, $F_{1,8} = 2.49$, $P = 0.16$).

A total of 20 plant species was recorded in beetle banks and 33 in the field margins; the mean species richness of banks being significantly lower than that of field margins during the winter ($t_{16} = 2.12$, $P < 0.001$). More species were found exclusively in field margins in winter than in the summer. *Senecio jacobaea* (common ragwort) was found exclusively in beetle banks, though in low numbers.

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

4. Discussion

4.1. 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 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.

4.2. 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). A sterile strip between the field boundary or beetle bank and crop can be an extra barrier to potential invasion (Boatman and 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 and 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., 1999a,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 and 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 and Frost, 1997), and granular fertilisers permeating field edges also affect species composition (Tsiouris and Marshall, 1998), giving competitive advantages to nitrophilous plants such as *B. sterilis*. 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 and van der Poll, 1999). Three-quarters of the field margins assessed in the present study contained *U. dioica*, 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. Therefore, such habitat should be afforded levels of protection similar to field margins.

4.3. Deterioration as invertebrate refuges and its potential limitation by management

Tussocky grass is said to be the optimal vegetation for arthropod 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 found to be positively correlated with *D. glomerata* cover by Thomas et al. (1992). 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, research (S. Thomas, unpublished data) has 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. 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.

4.4. Value for other beneficial invertebrates

Interestingly, the 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.

4.5. Conclusions

In summary, beetle banks retain a vegetational structure that appears suitable as a refuge for predatory invertebrates for over a decade at least. After an initial reduction in diversity in the first 2 years, 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.

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