Biodiversity in arable systems: interactions at different spatial scales

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Abstract
Functional biodiversity is understood in terms of ecosystem processes provided by species richness, such as pollination, biocontrol or nutrient cycling. Biodiversity within agroecosystems can also be associated with the non-crop elements in the landscape. A recent EU project is described, assessing a range of taxa, including plants, arthropods and birds as affected by agri-environment schemes (AES). In the UK, the impacts of AES vary between taxa and also between different landscape structures. Introduced boundary habitat in arable fields can enhance the diversity of flora, bees and grasshoppers. Using data from 130 grasslands and 141 arable fields in six European countries, plant species richness was related to nitrogen (N) input as an indicator of land-use intensity. Plant species richness was significantly adversely related to N input on both field types, after effects of confounding environmental factors had been accounted for. Relationships were largely the result of the response of rare species (relative cover <1%). The results indicate that conservation benefits are disproportionally more costly in intensively farmed than in extensively farmed areas and may be better implemented in areas that still support high levels of biodiversity. We conclude a) existing non-crop habitat on farms should be retained, b) habitat (re-)creation in farmland can be appropriate, c) responses of fauna and flora are modified by structure at the landscape scale and d) land-use intensity has important non-linear effects on diversity in farmland.

Media summary

Biodiversity in agricultural systems can benefit production, crop protection and species conservation, but landscape structure and land-use intensity modify the effects.

Key Words

Biodiversity, landscape, weeds, flora, bees, birds, spiders, grasshoppers, nitrogen, fertiliser

Introduction

The term functional biodiversity is understood in terms of ecosystem processes provided by species richness, such as pollination, biocontrol or nutrient cycling. Biodiversity within agroecosystems is often associated with the non-crop elements in the landscape. Data on highest floral diversity in linear landscape elements is available from the UK Countryside Survey, which also show that plant species diversity is generally declining in the landscape (Haines-Young et al. 2000). At the same time, the proportions of nitrophilous species are increasing, which may indicate that terrestrial eutrophication is occurring. Non-crop habitats (ecological infrastructure) within agricultural landscapes can be remnants of many habitats, as well as refugia for their associated species. However, there are also many species that depend either entirely or partly on agricultural fields. Agriculture has co-evolved in Europe for 10000 years, so there are many farmland specialist species. Many of these, most notably birds, have shown dramatic declines in populations and/or ranges over the past 40 years, associated with major changes in agriculture. As noted by Kleijn et al. (In prep.) agricultural intensification has allowed mankind to feed the growing world population but is also one of the main drivers of world-wide biodiversity decline. Biodiversity is affected by land-use at the small spatial scale (e.g. by the use of agrochemicals, grazing intensity, crop rotation) but also at larger spatial scales (e.g. by habitat fragmentation, hydrological changes or atmospheric deposition).

Farming landscapes cover at least 50% of the EU and over 75% of the UK. Thus species and landscape conservation often needs to take place in farmland. Financial support for environmentally friendly farm management in Europe is provided in several ways, particularly under agri-environment schemes (AES). A recent EU project on efficacy of such schemes is described, covering a variety of individual management prescriptions and a range of taxa, including plants, arthropods and birds. Different taxa can provide ecosystem services that enhance crop production via pollination and pest control; similarly, weeds and crop pests may be enhanced by schemes. The impacts of AES were assessed in a project involving six European countries (Kleijn et al. 2006). Details of responses to a habitat creation prescription in the UK are described. Data on the relationship between plant species richness and land-use intensity in the form of nitrogen inputs were examined across six countries. The results provide insights into the responses of different taxa to management prescriptions, landscape structure and farming intensity.

Methods

As part of a large European project evaluating the biodiversity impacts of agri-environment support schemes, a paired-field design comparing fields with or without environmental prescriptions was established in The Netherlands, UK, Germany, Switzerland, Spain and Hungary (Kleijn et al. 2006). In the UK, the prescription evaluated was sown 6 m wide perennial vegetation strips at the edges of arable fields. The grass margins had been sown at least three years previously under Countryside Stewardship Scheme contracts (UK agri-environment scheme). A total of 42 arable field sites were evaluated, comprising 21 pairs of fields. Each field pair comprised one with a sown 6m margin (agri-environment scheme) and the other control non-scheme field, with no margin, was matched as far as possible for environmental factors. Both fields were located in similar landscapes, with a similar field boundary structure and arable crop on the same soil type. The 21 pairs were grouped *a priori* into three landscapes based on field size, each landscape represented by seven pairs of fields. The three landscapes were small fields (average = 4 ha) with much semi-natural habitat, intermediate field sizes (8-10 ha) and large fields (>10 ha) in open prairie-type landscapes. To evaluate if there were any consistent differences in land use and intensity of management between sites with and without 6 m margins and between landscapes, data was collected from farmer interviews, field visits and maps. Land use within a circle of radius 500 m, based on each field site, was ascribed to arable, grassland, woodland, water, hard-standing and nature reserve and calculated as a percentage. Data on applied pesticides and nitrogen fertiliser were taken from farmer interviews. The same design and sampling protocol was applied in the other five countries with different prescriptions.

Flora were assessed in 1 m by 5 m quadrats in the pre-existing boundary, usually beside hedges, in the crop edge and the crop centre (Marshall et al. 2006). Where 6 m margin strips had been established, these were also assessed. The plant communities present were assessed as percentage ground cover of higher plant species by eye between June and July 2003. Quadrats were located within the field boundary, where the natural vegetation persisted from before the introduction of a 6 m margin (where this was present) and in the crop centre at least 50 m from the field edge. In these locations, ten 5 m^2 quadrats were assessed. In addition, the flora was assessed in three quadrats in the centre of the 6m margin (where present) and three quadrats in the crop edge. The crop edge quadrats were located in the crop inside the outermost seed drill line and might be expected to contain both typical arable weed species and species that may originate from the field boundary (Marshall 1989).

Bird observations were made using a standard territory mapping approach to assess numbers of nesting birds. Bird occurrence and activity were recorded during four morning visits and territories were based on clusters of complementary observations of singing or displaying males or actual nest sites made during the four visits. The data were expressed as the total number of observations over the four visits and numbers of territories per species. The bee fauna (Apididae) were assessed on three occasions from June up to before crop harvest in mid-July. Flying bees were caught using a butterfly net in transects of 15 minutes total catching time along the field boundary and in the crop centre. Spiders (Aranaea), important crop pest predators, were collected in pitfall traps located within the field boundary and the crop centre. Traps were open for three two-week periods; the first two consecutive periods began in early June 2003, followed by a two-week break and the final trapping period in early July. Spiders were identified to species using standard keys. Carabidae were sorted, counted, weighed fresh, dried at 80^{o}C for 48 hours and re-weighed to give total dry weights. Grasshoppers (Orthoptera) were assessed in sweepnet catches from the 100m field boundary and crop transects taken shortly before harvest. Data were analysed formally using analysis of variance as a split-split plot design. Landscape type was taken as the main plot, with field pairs nested within landscapes. The effects of landscape type, treatment (with and without 6m margins) and, where necessary, location (boundary v. field centre) were analysed and interactions between these factors tested.

Using data from 130 grasslands and 141 arable fields in the six European countries, plant species richness was related to nitrogen (N) input as an indicator of land-use intensity. A number of biodiversity related environmental variables were included in the statistical models: latitude, altitude, precipitation, temperature for the months April-September) and landscape diversity. Landscape diversity was calculated as the Shannon index of diversity of six habitat types (grasslands; arable fields; buildings; aquatic habitats; and 'other habitats' located in a circular buffer of 500m around the centre of each field. The best model was selected on the basis of the Akaike Information Criterion (Kleijn et al. In prep.).

Results

Analysis of the species richness of the flora of field boundaries and crop centres indicated significantly greater biodiversity in the boundary of margins adjacent to sown 6 m margin strips (33.2 *v*. 27.7 species; s.e.d.=2.058; P=0.029), but no statistical difference between landscapes (Marshall, West & Kleijn, 2006).

Analysis of the number of bird territories in each 12.5 ha area showed that there were no significant impacts of the sown 6m margins. However, there was a significant trend in territory numbers across landscape types, with most in small (13.7) and intermediate fields (12.1) and least in large field landscapes (8.2; s.e.d.=2.038;df=18). Numbers of species nesting mirrored these results, with no margin effect, but more species nesting in small fields. Analyses of the total number of bird observations from the four visits also showed no impact of 6m margins, but significantly more birds seen in small and intermediate compared with open landscapes (118, 100, 59; s.e.d.=13.88;df=18).

More bees were caught in timed transects with a butterfly net, but catches were low, averaging only two bees per location per visit. Analyses of total bees caught showed a highly significant positive effect of 6m margins and boundary sampling location. More bees were found adjacent to sown 6m margins compared with controls (7.3 v. 4.6; P=0.01) and fewer in the centre of arable crop fields compared with the boundary (7.6 v. 4.4; P<0.001). Overall, bee numbers were lowest in field centres where 6m margins were absent. Species richness of bees followed the trends noted for bee numbers, with greater diversity in fields with 6m margins and in boundaries (mean=3.7 species) compared with field centres (mean = 1.1).

Analysis of total spider numbers per location from three trapping periods showed no overall effect of the 6m margin, but significant differences between the boundary and crop trap sites. Overall, more spiders were caught in field centres compared with the boundary (50 v. 36 per location). There were also significant interactions between margin treatment and landscape area and interactions between margin treatment and location. Highest numbers of spiders (67) were found in small landscapes with 6m margin strips; all other combinations were statistically similar, but with lower numbers (38). Analyses of the two groups of spiders, the Linyphiidae and the wolf spiders, indicated that after square root or log.e transformation there were significant differences between the field locations. As might be expected for highly dispersive Linyphiidae, more were caught in the crop (18 v. 42; P<0.001), whereas the more sedentary wolf spiders were more abundant in the field boundary (18 v. 8; P=0.006).

For numbers of wolf spiders, three were significant interactions between margin treatment and landscape type and also between margin treatment and location. The data indicate that non-Linyphiid spider numbers were highest in boundaries with 6m sown margins, with lower numbers in field centres and boundaries without 6m margins. This was particularly the case in small field landscapes. An examination of the spider densities of the two groups indicate some effects of landscape structure. Irrespective of field margin strips, numbers of Linyphiidae were highest in crop centres of small fields. Wolf spiders, in contrast were able to respond to the presence of 6m margin strips with increased numbers in field boundaries. However, the response only occurred in landscapes dominated by small fields. For Carabidae, there were no significant impact of the 6m margins or landscape types, but much higher numbers trapped within the arable crops, compared with the boundaries. Presence of the 6m sown margin strip had a highly significant (P<0.001) positive effect on the presence of Orthoptera. While Orthoptera were absent from the centre of arable crops, significantly higher numbers of individuals (5.2 v. 0.9; s.e.d.=1.021) and species (1.8 v. 0.6; s.e.d.=0.37) were found in the boundaries of sites with wide grass margins compared with controls. The Orthoptera were also significantly more abundant in small and intermediate landscapes, compared with open landscapes with large mean field size (3.3, 4.4, 1.4 respectively; P=0.011).

Analysis of the flora and nitrogen data from the six European countries showed that after correction for confounding environmental influences, there was still a significant impact of nitrogen on plant species richness. An exponential function provided best fit, with much of the relationship provide by rare species with low cover (<1%). Species richness declined with increasing nitrogen use, most particularly at low rates of nitrogen.

Conclusions

The results indicate that a prescription for a sown 6m grass strip has positive effects on the diversity of plants, bees (pollinators) and grasshoppers. Predatory spiders were more abundant in smaller scale landscapes and one sedentary group were particularly abundant where 6 m margins had been introduced in small fields. These data indicate that a case-by-case approach is needed for evaluating the influences of habitat manipulation on different farmland biota. The principle of targeted prescriptions as part of agri-environment schemes is confirmed as worthwhile for the maintenance and enhancement of farmland biodiversity. Nevertheless, agri-environment schemes need to address landscape structure, as well as habitat creation, as these results indicate that, in general, smaller-scale farmland landscapes may be more responsive to biodiversity initiatives. The negative relationship between plant species richness and nitrogen use also indicates that broad biodiversity initiatives are more likely to be successful in extensively managed farmland. The dependence of some species on different habitats within farmland for different parts of their life cycle indicates that the best approach to maintaining functional diversity may be to attempt the integration of biodiversity within agriculture. We conclude a) existing non-crop habitat on farms should be retained, b) habitat (re-)creation in farmland can be appropriate, c) responses of fauna and flora are modified by structure at the landscape scale and d) land-use intensity has important non-linear effects on diversity in farmland.

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