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Agri-environment scheme enhances small mammal diversity and abundance at the farm-scale

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Abstract

The decline of farmland biodiversity over much of Europe has been largely attributed to agricultural intensification. Since the 1970s, governments have introduced agri-environment schemes (AES) aimed at mitigating this impact, but information on their success is limited. A five y, farm-scale experiment was conducted to test the efficacy of England's Environmental Stewardship AES in enhancing the species richness and abundance of small mammals (voles *Cricetidae*, mice *Muridae*, and shrews *Soricidae*) in an intensively-farmed arable landscape.

Small mammal communities were sampled in spring and autumn on grassy field margins installed under the Entry Level Scheme (ELS) tier of Environmental Stewardship, where 1% of cropped land was converted to wildlife habitats. Results were compared with those from field margins on a second, experimental treatment (ELS Extra: ELSX) in which 5% of cropped land was taken out of production, and also field margins on a conventionally-farmed control treatment ('cross compliance': CC). Species richness and abundance of small mammals showed a significant increase on all treatments in spring and autumn. Many increases were greater on ELS and ELSX field margins compared to the CC controls, but there was little evidence that ELSX was more beneficial than ELS, and there were species-specific differences. Voles were not detected on any treatment in the initial sampling period but bank voles *Myodes glareolus* rapidly became abundant thereafter, particularly on ELS and ELSX field margins, and field voles *Microtus agrestis* also colonised. Wood mice *Apodemus sylvaticus* were present on all treatments in all sampling periods, but spring abundance declined as vole abundance increased.

These results suggest that the Entry Level Scheme tier of the English agri-environment scheme is effective in enhancing small mammal communities on arable farmland, with potential benefits for higher trophic levels via their predators.

Keywords: AES, arable, field margins, voles, wood mouse

1. Introduction

The impoverishment of UK farmland biodiversity in the latter half of the 20th Century is well documented, with substantial declines observed in the abundance of birds (Newton, 2004), plants (Still and Byfield, 2007), and invertebrates (Benton et al., 2002). These changes have been largely attributed to agricultural intensification, particularly the removal of hedgerows and semi-natural habitats, and the increasing efficiency of pesticides and herbicides (Benton et al., 2002; Kleijn et al., 2011; Still and Byfield, 2007). Since the 1970s successive European governments, including the UK, have attempted to mitigate these detrimental impacts through policies aimed at restoring semi-natural habitats within agricultural landscapes (Kleijn et al., 2011). The resultant agri-environment schemes (AES) have been criticised as expensive and having limited success in enhancing biodiversity (Kleijn et al., 2006, 2011), leading to progressive refinement in the desire to achieve greater benefits and efficiency (Smallshire et al., 2004).

In order to qualify for farm subsidy payments under the Common Agricultural Policy, UK arable farmers must adopt basic 'cross compliance' (CC) environmental standards, including provision of 2-m-wide uncropped margins on fields larger than two ha. In 2005 a new optional AES, Environmental Stewardship, was introduced in England with an annual cost of £400 million and covering six million ha (66%) of agricultural land by 2009 (Natural England, 2009). Environmental Stewardship has two tiers, the Entry Level Scheme (ELS) and the Higher Level Scheme (HLS), and includes incentives for arable farmers to create and manage a range field margins and plots to benefit biodiversity, and to manage hedgerows to enhance food and shelter for wildlife.

Positive effects of Environmental Stewardship have been shown for the abundance and species richness of bumblebees *Bombus* spp. (Carvell et al., 2007; Pywell et al., 2006), wild plants (Walker et al., 2007), farmland birds (Baker et al., 2012; Hinsley et al., 2010), ground beetles *Carabidae* (Woodcock et al., 2010) and earthworms *Lumbricidae* (Hof and Bright, 2010). Prior to Environmental Stewardship, Shore et al. (2005) tested potential benefits of the incoming scheme for small mammals (voles *Cricetidae*, mice *Muridae*, and shrews *Soricidae*) and found that grassy field margins that approximated some later Environmental Stewardship options supported a greater biomass of small mammals, and higher abundance of bank voles *Myodes glareolus* and common shrews *Sorex araneus*, compared with conventional field edges. The small-mammal assemblage of arable farmland is of conservation importance, containing a UK Biodiversity Action Plan (BAP) priority species (harvest mouse *Micromys minutus*) and providing a key prey resource for depleted predators such as the polecat *Mustela putorius*, barn owl *Tyto alba* and common kestrel *Falco tinnunculus*. As such, enhancing small mammal communities has wider potential benefits for higher trophic levels, and may aid the recovery of such predators (Askew et al., 2007). Notwithstanding the results of Shore et al. (2005), information on the response of small mammals to AES implementation in the UK is scarce (reviewed in Macdonald et al., 2007). Tew et al. (1992) reported that wood mice *Apodemus sylvaticus* sought out 'conservation headlands' of reduced herbicide application in arable fields, where food was more abundant. At the farm scale, Tattersall et al. (1999) found that wood mice were more abundant on grassy field margins compared to the cropped area, and suggested that margins may be important habitat for field voles *Microtus agrestis*, harvest mice, common shrews and pygmy shrews *Sorex minutus*. Elsewhere in Europe, more intensively-farmed landscapes have been associated with less diverse mammal communities (Michel et al., 2006), and AES implementation has increased species richness and abundance (Fischer et al., 2011). However, there has been no large-scale assessment of the response of small mammal communities to AES provision over the typical period of an Environmental Stewardship agreement (five y), including the magnitude and persistence of any benefits.

In this paper, the efficacy of the Environmental Stewardship AES in enhancing small mammal communities on arable field margins was tested at the farm-scale, comparing two levels of intervention (1% and 5% of cropped land taken out of production for the creation of field margins and habitat plots) and a conventionally-farmed control. The hypothesis was that the species richness, abundance and over-winter persistence of small mammals would be greater on Environmental Stewardship field margins compared to the control, and greatest where the higher level of habitat was provided. A proportional increase of grassland species (notably field vole) exploiting the new field margin habitat was also predicted.

2. Materials and methods

The study was conducted in 2005-2011 on the 1000 ha Hillesden Estate, Buckinghamshire, central England (51°57'N, 1°00'W). The study area was characterised by lowland intensively-farmed arable fields of autumn-sown winter wheat, oil-seed rape or field beans, bordered by ditches and hedgerows dominated by hawthorn *Crataegus* spp. A randomised block experiment to investigate the efficacy of Environmental Stewardship options was established in 2005, with five replicates of three treatments (see Hinsley et al. 2010). Each treatment was established on 43-70 ha of farmland within each replicate block, and consisted of the following (see Supplementary Appendix A for plant species lists for patch and margin options listed):

1. Cross Compliance (CC): a control treatment of uncultivated field margins measuring two m in width from the centre of a bordering hedgerow, or one m from the top of a ditch. Hedgerows were cut annually after the summer harvest.
2. Entry Level Scheme (ELS): a treatment replicating typical ELS management for this region and farming system. One percent of cultivated land in each replicate block was converted to 6-m-wide field margins sown with a simple grass mix to provide semi-natural habitat for small mammals, invertebrates and birds (option EE3). A 0.25 ha field patch was also sown with a mix of four seed-providing crop species to provide food resources for granivorous birds (option EF2 b). Hedgerows were cut biennially.
3. Entry Level Scheme Extra (ELSX): a treatment providing a significantly larger area and more diverse range of wildlife habitats than ELS. Approximately 5% of cultivated land in

each replicate block was converted to 6-m-wide field margins sown with grasses and wildflowers to provide habitat for small mammals, invertebrates and birds (option EE3 (+)). Three 0.5 ha field patches were sown with wild bird seed-mixtures (options EF2 a-c), and three sown with or managed for perennial wildflowers (options EF1, EF4 and EF11). Hedgerows were cut biennially.

Margins on CC were roughly cut (flailed) annually to prevent shrub encroachment, and ELS/ELSX margins were mown in the first year after installation to suppress invasive weeds, but thence no more during the study to allow the grassy habitat to develop. The availability of hedgerows and their resources (such as berries) could influence small mammal populations (Poulton, 1994). However, despite different hedgerow-cutting regimes on CC and ELS/ELSX treatments, berry production did not differ between them at this site (Heard et al. 2012). Also, using a geographical information system, no difference was found in the length of hedgerow habitat within a 50 m buffer surrounding mammal sampling sites on each treatment (Kruskall-Wallis χ^2_2= 0.56, P = 0.756). As such, a treatment effect of these variables was not considered.

2.1. Survey methods

Small mammals were sampled in each replicate block by live trapping (Flowerdew et al., 2004) during autumn (November-December) in 2005, 2006, 2008 and 2010 (Y 0, 1, 3 and 5 respectively), and each following spring (May, also denoted as Y 0, 1, 3 and 5). Small mammal populations typically peak in autumn and are at a minimum in May (Flowerdew et al., 2004). Trapping was conducted on 6-m-wide grassy field margins within ELS and ELSX treatments (EE3 and EE3 (+), see supplementary Appendix A) and the one-two m field margins within CC control treatments. For each treatment replicate, trapping was undertaken on two 100-m-long trap lines between 95 and 667 m apart. Each trap line was situated one-two m from and parallel to the field boundary, and consisted of 11 Longworth traps (Chitty and Kempson, 1949) each spaced 10 m apart, giving 22 traps per treatment replicate.

Traps were ‘pre-baited’ with wheat for four nights (not set to catch), then baited with wheat, carrot and casters (*Calliphoridae* pupae) on the evening of the fifth day and set to catch for the following three nights, being checked morning and evening (five trapping sessions: 110 trapping opportunities per treatment replicate per season). All trapping was undertaken within a three week period each season. On first capture in autumn, animals were recorded to species along with mass (to 0.5 g), gender and breeding condition (Gurnell and Flowerdew, 2006). Wood mice, bank voles and field voles were implanted with a uniquely-coded 12 mm Passive Integrated Transponder (PIT) tag under the skin, enabling identification on recapture. This marking method is considered safe and reliable in small rodents (Harper and Batzli, 1996). Other species captured during autumn, and all species in spring, were marked using individually-identifiable fur clips which were moulted before the following season (Gurnell and Flowerdew, 2006).

2.2. Analytical methods

Spring and autumn trapping data were analysed separately to calculate seasonal species richness and abundance for each treatment. Data for both trap lines in a treatment replicate were combined, generating five values per treatment for analysis. Preliminary analysis showed that capture rates on a treatment replicate exceeded 70% of available traps on only 9% of trapping sessions in autumn and 7% in spring, and analyses proceeded assuming no significant bias of trap availability.

Species richness on treatment replicates in each spring or autumn was defined as the total number of species captured. Generalized linear models (GLM) were used to assess the effect of treatment and year (i.e. duration of study) on species richness, with Poisson error distributions and a log-link in R 2.10.0 (R Development Core Team, 2009). Piecewise (‘broken stick’) regression was used where initial plotting of the data indicated a discontinuous linear relationship between species richness and year (Crawley, 2007). Initial full models contained all parameters and interaction terms of treatment and year, with treatment as a three-level factor and year as a continuous variable. Step-wise model simplification was performed using analysis of deviance tests to identify and remove non-significant ($P \geq 0.05$) terms, with treatments being combined to create a two-level factor where appropriate, until a minimum adequate model was achieved (Crawley, 2007).

Total abundance of small mammals on treatment replicates in each spring or autumn was defined as the total number of individuals captured, of all species. The effect of treatment and year on abundance was analysed using a GLM approach as for species richness, although models were fitted with a quasi-Poisson adjustment due to overdispersion of the variance. Species-specific values of abundance were also derived. Similar models were constructed for the effect of treatment and year on the biomass of individual and combined species during spring and autumn. However, due to the very similar qualitative patterns between these results and those from analyses of abundance, results for biomass are not presented or discussed further.

Over-winter persistence of individuals of PIT tagged species was calculated from the number of animals marked in autumn that were re-captured the following spring, although formal estimates of survival were inappropriate due to small sample sizes.

3. Results

Ten mammal species were caught during the study, comprising 80-292 individuals in each spring and 99-423 in each autumn. Wood mouse, bank vole, field vole and common shrew accounted for 97% and 99% of spring and autumn captures respectively, and species-specific analyses of abundance were subsequently limited to this group. The data used to derive statistical models of species richness and abundance are given in the supplementary Appendices B and C.

3.1. Species richness

In autumn, wood mouse was the only species recorded in the baseline Y 0, but five species were recorded in the autumn of Y 1 (addition of bank vole, field vole, harvest mouse and common shrew), six in Y 3 (pygmy shrew), and seven in Y 5 (water shrew *Neomys fodiens*). Brown rat *Rattus norvegicus* and common weasel *Mustela nivalis* were captured only once, and were excluded from analyses. The minimum adequate model of autumn species richness (Figs. 1a-b) indicated a significant increase on all treatments over Y 0-1 (χ^2_1 = 13.26, $P < 0.001$), but no significant change thereafter (χ^2_1 = 3.08, $P = 0.079$). There was no difference in species richness between ELS and ELSX treatment margins (χ^2_1 = 0.43, P = 0.514), but this was 1.4 times greater than on the CC controls (χ^2_1 = 4.13, $P = 0.042$).

In spring, wood mouse, bank vole and harvest mouse were recorded in Y 0, doubling to six species in Y 2 (addition of field vole and common, water and pygmy shrews, but loss of harvest mouse), and seven by Y 5 (house mouse *Mus musculus*). The minimum adequate model of spring species richness (Fig. 1c) estimated a significant 2.4 fold increase between Y 0 and 5 (χ^2_1= 12.85, $P < 0.001$), but with no effect of treatment (χ^2_1 = 0.23, $P = 0.891$).

Details of model output for spring and autumn species richness are given in the supplementary Appendix D.

3.2. Abundance

3.2.1. Autumn

The minimum adequate model of the mean abundance of all (total) small mammals estimated an annual doubling of abundance on all treatments in Y 0-2 ($F_{1,57}$ = 34.39, $P <$ 0.001) but no significant change thereafter ($F_{1,57}$ = 0.01, $P = 0.905$) (Fig. 2a, Table 1). The model contained no significant interaction term nor individual effect of treatment (all P values ≥ 0.143).

Modelled abundance of wood mice (Fig. 2b) and bank voles (Figs. 2c-d) in autumn followed a similar trend, with significant annual increases in Y 0-2 (wood mouse: $F_{1,57} = 16.46$, $P < 0.001$; bank vole: $F_{1,56} = 60.39$, $P < 0.001$), before stabilising in Y 2-5 (wood mouse: $F_{1,57} = 1.82$, $P = 0.183$; bank vole: $F_{1,56} = 0.01$, $P = 0.929$; Table 1). Treatment had no significant effect on wood mouse abundance ($F_{1,55} = 0.24$, $P = 0.789$) unlike that of bank vole ($F_{1,56} = 7.47$, $P = 0.008$) and also field vole ($F_{1,57} = 8.70$, $P = 0.005$; Fig. 2e); for these species, mean abundance on the ELS and ELSX margins was 1.8 fold (bank vole) and 3.8 fold (field vole) greater than on the CC control margins. Field vole abundance increased consistently on all treatments from a very low baseline ($F_{1,57} = 25.00$, $P < 0.001$), but remained low in comparison to that of bank vole and wood mouse. The modelled abundance of common shrews in autumn was also relatively low (Fig. 2f), with a significant increase over time ($F_{1,58} = 14.57$, $P < 0.001$; Table 1) but no significant treatment effect ($F_{1,56} = 2.82$, $P = 0.068$). Overall, the greatest percentage increase in autumn abundance over Y 0-5 was modelled for bank vole, and the lowest for wood mouse (Table 1). Supplementary Appendix D details output from models of autumn abundance.

3.2.2. Spring

The minimum adequate model for mean abundance of total small mammals in spring indicated a significant interaction of treatment and year ($F_{1,54} = 16.87$, $P < 0.001$); abundance on ELS and ELSX treatments showed a significant increase over time from a comparatively low baseline in Y 0, and by Y 5 the abundance exceeded that on the CC control which showed little overall change during the study (Fig. 3a, Table 1).

The model estimating mean abundance of wood mice in spring (Fig. 3b) contained a significant treatment effect ($F_{51,55} = 57.30$, $P < 0.001$), with abundance on CC margins being 8.6 times higher than on ELS or ELSX, but with an overall decline across all treatments ($F_{1,55} = 13.78$, $P < 0.001$; Table 1). The modelled abundance of bank voles (Figs. 3c-d) depicted an increase on all treatments over Y 0-5 (Table 1), with a significant interaction between treatment and year ($F_{1,54}$ = 7.62, P = 0.008) indicating that abundance was greatest on ELSX margins by Y 5. The model for field vole (Fig. 3e) also indicated a significant increase over time ($F_{1,55}$ = 53.12, P < 0.001; Table 1) and an effect of treatment ($F_{1,55}$ = 7.53, P = 0.008), with abundance on CC field margins being only a quarter of that on ELS and ELSX margins throughout the study. The model for common shrew (Fig. 3f) included a significant treatment effect ($F_{1,55}$ = 4.45, P = 0.040) of greater abundance on ELS and ELSX margins compared to CC, but no significant effect of year to substantiate an increase over time ($F_{1,55}$ = 2.06, P = 0.153). Details of model output for spring abundance are given in the supplementary Appendix D.

3.3. Over-winter persistence

The number of animals that were PIT-tagged in autumn periods and recaptured in the following spring was only two, four, eight and 21 in Y 0, 1, 3 and 5 respectively (2% annually of the total number tagged in Y 0-3, and 5% in Y 5). Of the 35 PIT tagged animals recaptured in spring, the nine wood mice was 1% of those initially tagged, while the 23 bank voles and three field voles was respectively 7% and 6% of those tagged, although the small sample sizes prevented further interpretation or analysis. Only one animal, a male field vole, was detected moving between treatment replicates, dispersing 830 m from an ELSX to an ELS margin.

4. Discussion

4.1. Species richness and abundance

The results supported the hypothesis that provision of wildlife habitats under the ELS tier of Environmental Stewardship would significantly enhance the species richness and abundance of small mammal communities on arable farmland. This was consistent with the study by Shore et al. (2005) and the reported benefits of Environmental Stewardship options for other taxa (Hinsley et al., 2010; Pywell et al., 2006; Walker et al., 2007). In the current study, many of the enhancements associated with ELS implementation were rapid and sustained, or continued to accrue throughout the study. However, there was little support for the hypothesis that the enhanced ELSX treatment was more beneficial for small mammals than standard ELS at the scale examined.

The substantial increase in autumn species richness and abundance of total small mammals within the first two y after ELS and ELSX installation, followed by stabilisation at these higher levels, contrasted with the more gradual increases in spring. This may have been due to the mediating effects of winter mortality on small mammal communities, with individuals of less common species being more difficult to detect during the spring population minimum. The initial low values of total abundance in spring on ELS and ELSX margins probably resulted from limited ground cover in the first months after installation (cf. Tattersall et al., 2001), whereas crop cover adjoining the CC field margins in Y 0 and may have offered comparatively more shelter. Nevertheless, by spring of Y 5 the species richness and total abundance on ELS and ELSX margins had overtaken those on CC, indicating that ELS and ELSX field margins provided the greatest benefits once fully established.

As found in other studies of small mammal communities on arable farmland (Michel et al., 2006; Shore et al., 2005; Tattersall et al., 2002), the changes in total abundance on all treatments in autumn were driven largely by rapid increases in the numbers of bank voles and wood mice. In spring, however, overall trends in abundance on ELS and ELSX margins were driven by increasing numbers of bank voles and field voles, supporting the hypothesis that provision of grassy habitat strips on these treatments would favour such species.

Voles were only detected in the study area after establishment of the ELS and ELSX margins, generally being more abundant on these treatments compared to CC margins. Shore et al. (2005) also found a greater abundance of bank voles on Environmental Stewardship-type field margins in autumn but detected very few field voles, suggesting that the two-three y old margins had not developed sufficient cover for this species. Tattersall et al. (2000) reported that field voles took two y to colonise set-aside habitat in significant numbers, and results from the current study indicated that this species may take four-five y to show a substantial increase on newly-created Environmental Stewardship margins.

While Shore et al. (2005) detected no difference in abundance of wood mice between field edges with grassy margins up to six m in width, Tattersall et al. (2001) found that this species avoided 20-m-wide set-aside margins, possibly as a predator avoidance strategy. The results presented in this paper are consistent with some avoidance by wood mice of wide grassy margins, as more animals were detected on the narrow (one-two m) CC margins in spring compared to the wider (six m) ELS and ELSX margins. In contrast to wood mice, Bellamy et al. (2000) and Yletyinen and Norrdahl (2008) found that narrow habitat strips (four-five m) were poor habitat for field voles, and Shore et al. (2005) found a similar pattern for bank voles on three m habitat strips. In the present study, however, the wider six m grassy margins held significant numbers of voles, suggesting that margins of this width can provide sufficient habitat.

These differing responses to field margin width may be related to inter-specific competition, with wood mice possibly being less dependent on grassy habitat and so gaining a competitive advantage over voles in conventionally-farmed landscapes. However, the presented results indicate that voles largely replaced wood mice on the conventional CC margins in spring as their populations rose across the study area after installation of the ELS/ELSX margins nearby.

Abundance of common shrews was generally low in both seasons, with a significant increase on all field margins in autumn but no discernible treatment effect. Spring abundance of common shrews was greatest on ELS and ELSX margins, broadly in line with results from Shore et al. (2005), and this may be indicative of a greater abundance of over-wintering invertebrates when compared to conventional margins (Hof and Bright, 2010).

4.2. Over-winter persistence

Very few of the animals PIT-tagged in autumn were recaptured in the following spring. However, the sampling covered only a small area of the treatment margins in each replicate block, and 90% of final trapping sessions in autumn were still catching new individuals. As such, it was considered more likely that large numbers of over-wintering animals remained untagged, and that high overall mortality and diffusion of tagged animals away from the immediate vicinity of trap lines resulted in low recapture rates between autumn and spring.

4.3. Farm-scale effects

An important indication from the study was that of a farm-scale effect, with most measures of mammal abundance and diversity increasing not only on field margins on those areas managed under Environmental Stewardship prescriptions (ELS and ELSX), but also on nearby margins on farmland managed as conventional CC. Hinsley et al. (2010) found a similar response by birds at the same site, with provision of Environmental Stewardship margins and foraging plots resulting in farm-scale increases on areas of CC as well as ELS and ELSX. However, the data were limited in their ability to detect the mechanisms driving this effect, as there was no direct evidence of dispersal or ‘spill over’ of animals from ELS and ELSX margins onto CC margins. This lack of detection may, in part, have been a result of the distance between CC trap lines and the nearest ELS/ELSX trap lines (250-940 m). Furthermore, because autumn tagging occurred in November-December, when 98.5% of animals were in non-breeding condition (unpublished data), most natal dispersal may have already occurred. Therefore, any animals dispersing onto CC field margins from ELS and ELSX treatment margins, presumably via the network of hedgerows and field edges, may have done so in the months or weeks before tagging took place. As such, the results are not inconsistent with a farm-scale ‘spill over’ effect as a plausible explanation for the coincidental increases in abundance of small mammals, particularly voles, on CC margins after the installation of ELS and ELSX treatments.

4.4. Management implications

While increased abundance of small mammals in arable landscapes may be of conservation benefit to these species and their predators, conflict with farmers may occur where agri-environment field margins are perceived as habitat for agricultural pests, including increased numbers of rodents (Firbank et al., 1993; Heroldová et al., 2005). Although field and bank voles, which were the major beneficiaries of field margins in this study, appear to be insignificant crop pests in European arable systems, damage in other systems (e.g. forestry) and by other species (e.g. common vole *Microtus arvalis*) can be substantial (Jacob and Tkadlec, 2010). However, Yletyinen and Norrdahl (2008) found that wider (15 m) field margins reduced movements by field voles into cropped areas by providing sufficient resources within, and so provision of wide margins may provide the conservation benefits while minimising potential damage to crops.

While setting aside potentially-productive farmland to enhance biodiversity under agri-environment schemes necessarily affects agricultural output, this can be used as a useful tool to limit expensive surplus, as with the ‘set-aside’ scheme of the European Union’s Common Agricultural Policy in 1988-2008 (Macdonald et al. 2007).

5. Conclusions

The results of this study provide clear evidence that the Environmental Stewardship AES has the potential to enhance small mammal communities in intensively-farmed arable landscapes. Establishment of a variety of semi-natural wildlife habitats among arable fields, including grassy field margins and seed-bearing patches, coincided with a substantial and sustained increase in the abundance and species richness of small mammals in autumn and spring, with some benefits continuing to develop over five y. Furthermore, the apparent farm-scale ‘spill over’ effects, of enriched small mammal communities on neighbouring areas of conventional farmland not managed under the AES, suggest that the ELS tier of the English Environmental Stewardship scheme is an efficient mode of achieving biodiversity benefits at the landscape scale. These findings appear to fulfil the expectation of Askew et al. (2007) that adoption of Environmental Stewardship would significantly increase the diversity and abundance of rodent prey for predators such as the barn owl in intensive arable landscapes, and suggests that Environmental Stewardship field margins may provide benefits across multiple trophic levels.

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Table 1. Modelled percentage change in seasonal mean abundance of small mammals on field margins of two agri-environment scheme treatments (ELS: Entry Level Scheme, ELSX: Entry Level Scheme Extra) and a control (CC: Cross Compliance) over Y 0-5 of study. Values in parentheses indicate periods (Y) of statistically significant change ($P < 0.05$). NS denotes no period of significant change. Modelled estimates derived from five replicates per treatment, except spring values for CC and ELS in Y 5 where there were four replicates per treatment.

	Mean abundance	
	Autumn	Spring
Total animals:		
CC	298 (0-2)	-12 (NS)
ELS	298 (0-2)	140 (0-5)
ELSX	298 (0-2)	140 (0-5)
Wood mouse:		
CC	102 (0-2)	-76 (0-5)
ELS	102 (0-2)	-76 (0-5)
ELSX	102 (0-2)	-76 (0-5)
Bank vole:		
CC	5354 (0-2)	299 (0-5)
ELS	5354 (0-2)	299 (0-5)
ELSX	5354 (0-2)	6076 (0-5)
Field vole:		
CC	955 (0-5)	3606 (0-5)
ELS	955 (0-5)	3606 (0-5)
ELSX	955 (0-5)	3606 (0-5)
Common shrew:		
CC	1010 (0-5)	141 (NS)
ELS	1010 (0-5)	141 (NS)
ELSX	1010 (0-5)	141 (NS)

Figure Legends

Figure 1. Generalized linear models of species richness, as mean number of small mammal species captured (mid-lines, with 95% confidence interval as dashed lines), for autumn (a-b) and spring (c) on field margins provided under agri-environment scheme treatments (ELS: Entry Level Scheme; ELSX: Entry Level Scheme Extra; and a control, CC: Cross Compliance) and year since treatment installation (in Y 0). Modelled estimates derived from five replicates per treatment, except spring values for CC and ELS in Y 5 where there were four replicates per treatment. Full model details are given in the supplementary Appendix D.

Figure 2. Generalized linear models of small mammal abundance in autumn, as mean number of individuals detected on treatment field margins. For details see Figure 1.

Figure 3. Generalized linear models of small mammal abundance in spring, as mean number of individuals detected on treatment field margins. For details see Figure 1. For clarity, lower confidence limits for ELS & ELSX and upper limits for CC are not shown in (f).

Fig. 1

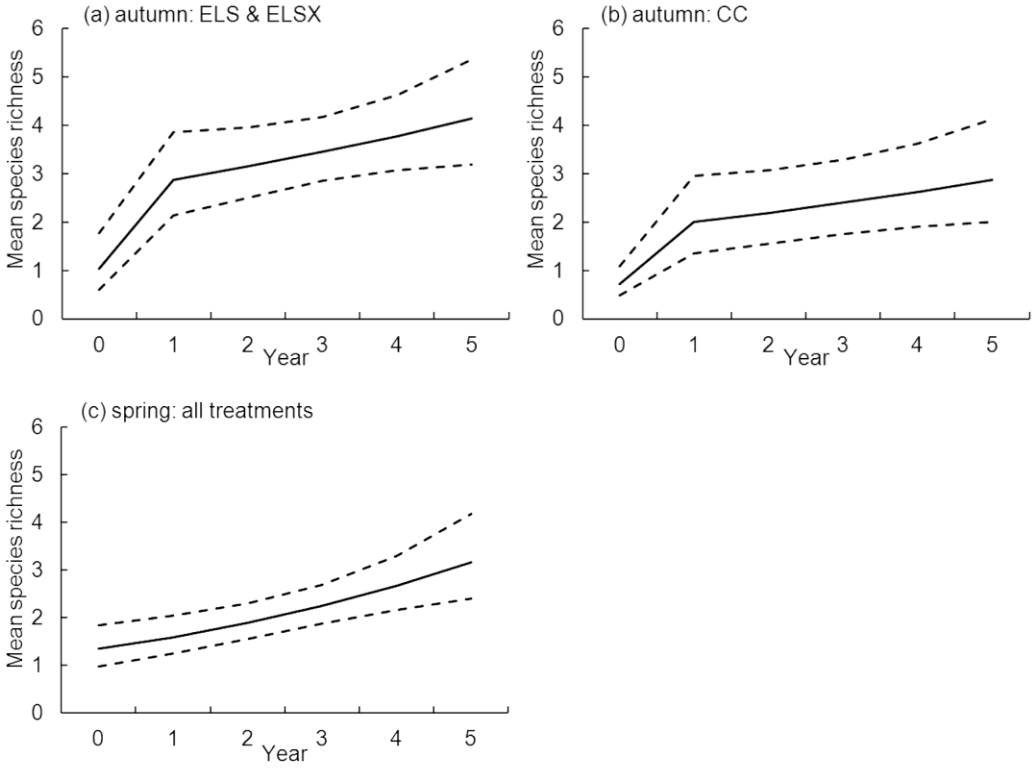

(a) autumn: ELS & ELSX
Mean species richness
0
1
2
3
4
5
6
Year
0
1
2
3
4
5
(b) autumn: CC
Mean species richness
0
1
2
3
4
5
6
Year
0
1
2
3
4
5
(c) spring: all treatments
Mean species richness
0
1
2
3
4
5
6
Year
0
1
2
3
4
5

Fig. 2

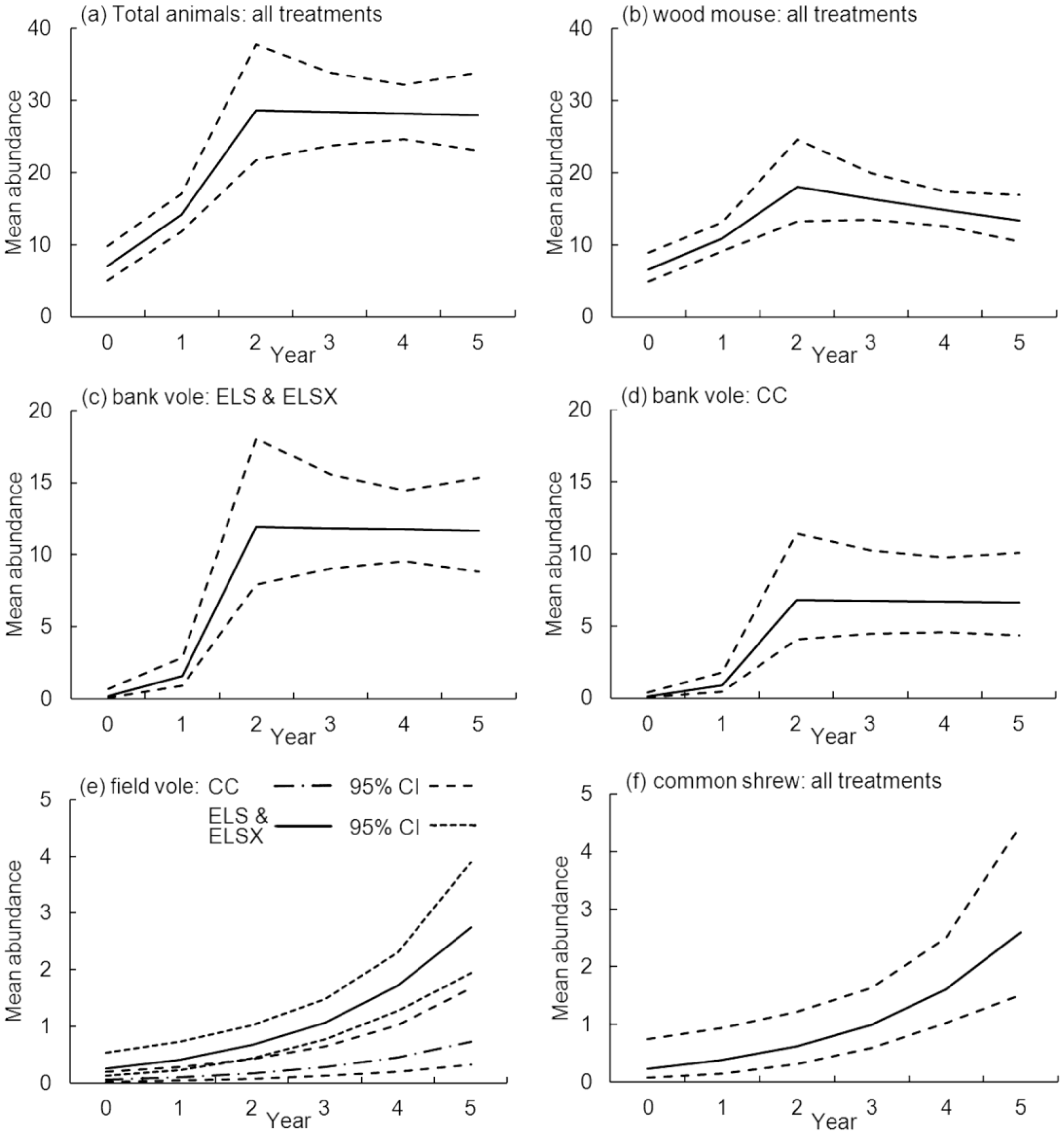
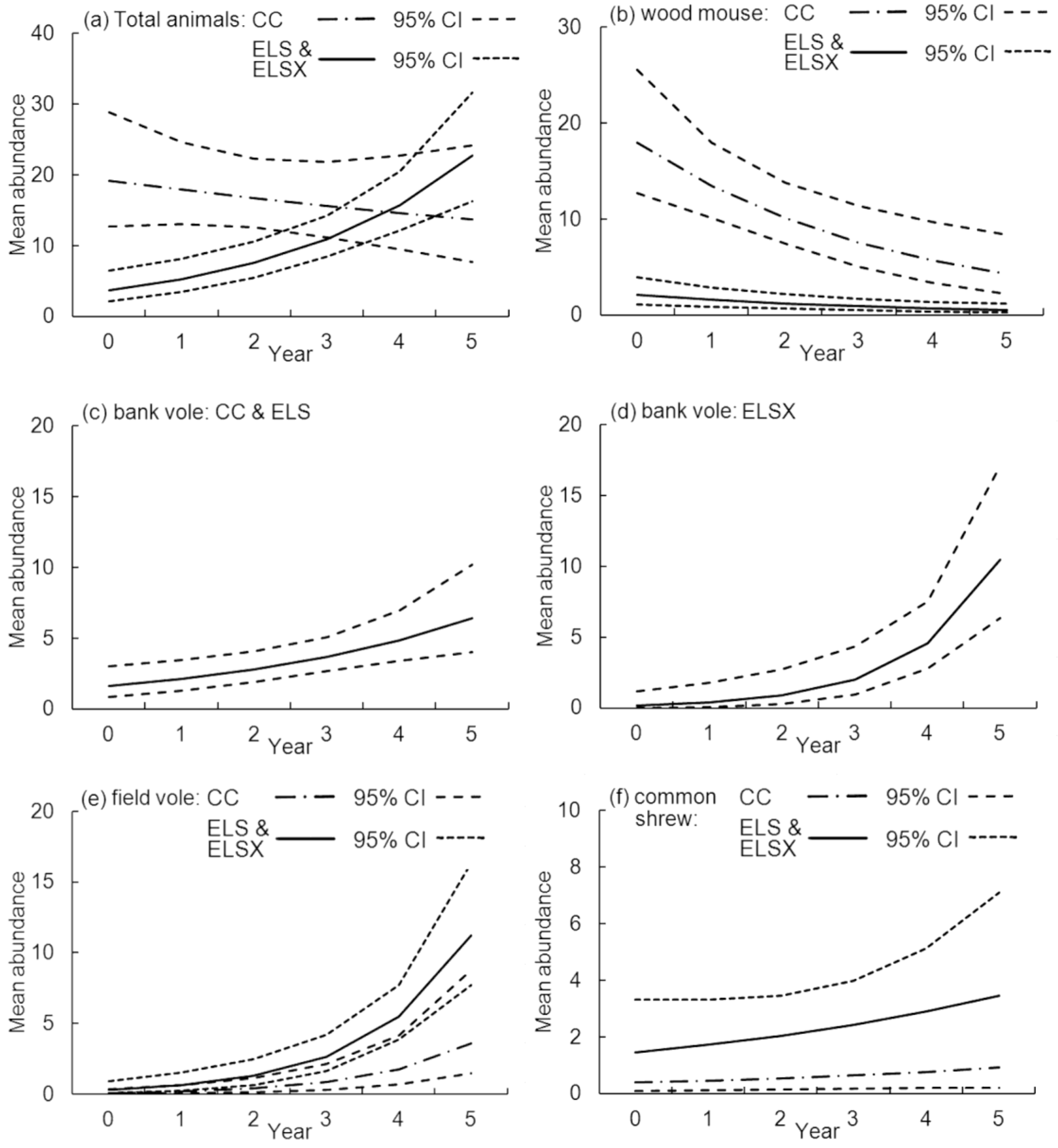

(a) Total animals: all treatments
(b) wood mouse: all treatments
(c) bank vole: ELS & ELSX
(d) bank vole: CC
(e) field vole: CC
95% CI
ELS & ELSX
95% CI
(f) common shrew: all treatments
Mean abundance
Year
0
1
2
3
4
5
10
15
20
30
40

Fig. 3


(a) Total animals: CC
95% CI
ELS & ELSX
95% CI
Mean abundance
0
10
20
30
40
Year
0
1
2
3
4
5
(b) wood mouse: CC
95% CI
ELS & ELSX
95% CI
Mean abundance
0
10
20
30
Year
(c) bank vole: CC & ELS
Mean abundance
0
5
10
15
20
Year
(d) bank vole: ELSX
Mean abundance
Year
(e) field vole: CC
95% CI
ELS & ELSX
95% CI
Mean abundance
Year
(f) common shrew: CC
95% CI
ELS & ELSX
95% CI
Mean abundance
0
2
4
6
8
10
Year

Supplementary Appendix A. Plant species composition of Environmental Stewardship options implemented under the agri-environment scheme treatments ELS (Entry Level Scheme) and ELSX (Entry Level Scheme Extra).

Treatment	Option	Description	Species
ELS	EE3	6-m grass margins sown with mix of 4 grasses of 20 kg ha^{-1}	*Dactylis glomerata* *Festuca arundinacea* *Festuca pratensis* *Festuca rubra*
ELS & ELSX	EF2 b	0.25 ha patch sown with biennial 'ELS tall' seed mix for wild birds	*Beta vulgaris* *Brassica oleracea* *Chenopodium quinoa* *Cichorium intybus* *x Triticosecale*
ELSX	EE3 (+)	6-m grass margins sown with five grasses & six forbs in a 95:5% mix of 20 kg ha^{-1} aimed at creating new habitat for small mammals invertebrates and birds and provide nectar and pollen resources	*Phleum pratense* *Vicia cracca* *Dactylis glomerata* *Festuca arundinacea* *Festuca pratensis* *Festuca rubra* *Achillea millefolium* *Centaurea nigra* *Dactylis glomerata* *Daucus carota* *Dipsacus fullonum*
ELSX	EF1	Field corners sown with four grasses & 25 forbs in a 90:10% mix of 20 kg ha^{-1}	*Achillea millefolium* *Centaurea nigra* *Clinopodium vulgare* *Daucus carota* *Filipendula ulmaria* *Galium mollugo* *Galium verum* *Knautia arvensis* *Leontodon hispidus* *Leucanthemum vulgare* *Lotus corniculatus* *Lychnis flos-cuculi* *Malva moschata* *Plantago media* *Primula veris* *Prunella vulgaris* *Ranunculus acris* *Rumex acetosa* *Sanguisorba minor*

			Silene dioica *Silene vulgaris* *Stachys officinalis* *Trifolium pratense* *Vicia cracca* *Agrostis capillaris* *Cynosurus cristatus* *Festuca rubra* *Festuca rubra*
ELSX	EF2 a EF2 c	One 0.5 ha patch each sown with seed mix for wild birds: a) annual ‘deluxe’ mix c) ‘Bumble-bird’ mix including species providing nectar resources for insect pollinators and seed resources for birds	EF2 a: *Chenopodium quinoa* *Echinochloa frumentacea* *Fagopyrum esculentum* *Raphanus sativus* *x Triticosecale* EF2 c: *Borago officinalis* *Chenopodium quinoa* *Echinochloa frumentacea* *Helianthus annuus* *Melilotus officinalis* *Raphanus sativus* *x Triticosecale*
ELSX	EF4	Nectar flower mix sown with four legumes @15kg ha^{-1} to provide food resources for nectar-feeding insects	*Lotus corniculatus* *Onobrychis viciifolia* *Trifolium hybridum* *Trifolium pratense*
ELSX	EF11	Annually cultivated strip (uncropped) to encourage rare plants and foraging sites for seed-eating birds	Natural colonisation

Supplementary Appendix B. Mean (s.d.) values of species richness (number of small mammal species captured) for autumn and spring trapping periods by agri-environment scheme treatment (CC: Cross Compliance [control treatment]; ELS: Entry Level Scheme; ELSX: Entry Level Scheme Extra) and year since treatment installation (in Year 0). Means derived from sample sizes of *n* = 5 (22 traps per replicate), except spring values for CC and ELS in Year 5 where *n* = 4

Season	Treatment	Year							
		0		1		3		5	
Autumn	CC	1.0	(0.0)	1.0	(0.0)	2.8	(1.1)	3.2	(1.5)
	ELS	0.8	(0.4)	4.0	(0.7)	3.4	(1.1)	4.0	(0.7)
	ELSX	1.0	(0.0)	2.6	(0.9)	3.4	(0.5)	3.8	(0.8)
Spring	CC	1.8	(0.4)	1.8	(0.4)	2.6	(1.1)	2.5	(0.6)
	ELS	0.6	(1.3)	2.6	(1.1)	2.0	(0.7)	3.0	(1.4)
	ELSX	0.0	(0.0)	2.8	(1.6)	1.4	(1.3)	3.8	(1.1)

Supplementary Appendix C. Mean (s.d.) values of abundance (number of animals detected) for total animals, wood mouse (WM), bank vole (BV), field vole (FV) and common shrew (CS) by agri-environment scheme treatment (CC: Cross Compliance [control treatment]; ELS: Entry Level Scheme; ELSX: Entry Level Scheme Extra) and year since treatment installation (in Year 0). Means derived from sample sizes of *n* = 5 (22 traps per replicate), except spring values for CC and ELS in Year 5 where *n* = 4

Autumn		Year							
Species	Treatment	0		1		3		5	
Total	CC	8.2	(1.8)	11.8	(7.2)	22.6	(10.0)	22.6	(10.8)
	ELS	5.6	(4.7)	18.8	(5.3)	33.6	(17.6)	28.0	(13.1)
	ELSX	6.0	(4.5)	14.4	(8.0)	27.0	(13.2)	33.8	(7.3)
WM	CC	8.2	(1.8)	11.8	(7.2)	13.0	(8.5)	13.4	(3.6)
	ELS	5.6	(4.7)	9.6	(7.0)	18.4	(9.6)	11.4	(5.0)
	ELSX	6.0	(4.5)	11.4	(7.4)	17.6	(6.5)	15.2	(7.8)
BV	CC	0.0	(0.0)	0.0	(0.0)	8.8	(2.6)	5.6	(4.8)
	ELS	0.0	(0.0)	4.4	(1.8)	10.8	(4.5)	11.2	(8.0)
	ELSX	0.0	(0.0)	0.8	(1.3)	10.0	(6.5)	13.4	(9.7)
FV	CC	0.0	(0.0)	0.0	(0.0)	0.4	(0.5)	0.8	(1.3)
	ELS	0.0	(0.0)	1.2	(1.6)	0.8	(1.1)	2.4	(2.1)
	ELSX	0.0	(0.0)	0.6	(0.9)	1.0	(0.7)	3.0	(2.8)
CS	CC	0.0	(0.0)	0.0	(0.0)	0.4	(0.5)	2.8	(4.1)
	ELS	0.0	(0.0)	1.6	(1.7)	2.4	(4.3)	3.0	(2.0)
	ELSX	0.0	(0.0)	0.2	(0.4)	0.6	(0.9)	1.6	(1.5)
Spring									
Total	CC	15.0	(4.1)	26.4	(4.8)	9.0	(6.5)	16.5	(3.4)
	ELS	1.2	(2.7)	12.6	(3.6)	9.0	(5.6)	23.3	(14.9)
	ELSX	0.0	(0.0)	10.0	(9.7)	4.2	(5.8)	25.0	(14.1)
WM	CC	12.6	(3.8)	24.0	(4.9)	2.0	(2.3)	4.8	(4.0)
	ELS	0.6	(1.3)	4.8	(3.4)	0.6	(1.3)	0.8	(1.5)
	ELSX	0.0	(0.0)	2.4	(3.2)	0.0	(0.0)	1.0	(1.0)
BV	CC	2.2	(2.7)	2.4	(2.5)	4.4	(3.7)	7.0	(7.4)
	ELS	0.2	(0.4)	3.4	(4.7)	1.8	(2.7)	6.3	(5.3)
	ELSX	0.0	(0.0)	1.2	(0.8)	0.8	(1.3)	11.0	(5.1)
FV	CC	0.0	(0.0)	0.0	(0.0)	0.8	(0.8)	4.0	(4.9)
	ELS	0.4	(0.9)	1.0	(1.7)	1.6	(1.1)	13.3	(13.5)
	ELSX	0.0	(0.0)	2.0	(3.1)	1.4	(1.7)	10.4	(8.2)
CS	CC	0.0	(0.0)	0.0	(0.0)	1.8	(2.7)	0.5	(1.0)
	ELS	0.0	(0.0)	3.0	(3.0)	5.0	(5.4)	2.8	(4.2)
	ELSX	0.0	(0.0)	3.4	(5.6)	1.8	(4.0)	2.0	(1.9)

Supplementary Appendix D. Minimum adequate models for small mammal species richness and abundance in autumn and spring on agri-environment scheme treatments (ELS: Entry Level Scheme; ELSX: Entry Level Scheme Extra; and a control CC: Cross Compliance), computed as GLM with Poisson errors in R version 2.10.0 (R Development Core Team 2009). WM = wood mouse, BV = bank vole, FV = field vole, CS = common shrew, Total = all species combined, and note that Years is a continuous variable with a piecewise ('broken stick') regression approach employed in some models (see Methods section 2.3. for details).

Model	Response Variable	Predictor Variable	Parameter Estimate	Standard Error	*z-value* t-value	*P*	Null deviance (df)	Residual deviance (df)
1	Species richness	(Intercept)	0.693	0.198	*3.501*	<0.001	51.49 (59)	18.35 (56)
	(autumn)	Years 0-1	1.018	0.304	*3.355*	<0.001		
		Years 1-5	0.091	0.052	*1.749*	0.080		
		Treatment(ELS & ELSX)	0.363	0.184	*1.977*	0.048		
2	Species richness	(Intercept)	0.296	0.162	*1.830*	0.067	71.06 (57)	58.21 (56)
	(spring)	Years 0-5	0.171	0.048	*3.581*	<0.001		

3	Total abundance	(Intercept)	3.353	0.141	23.756	<0.001	525.78 (59)	241.34 (57)
	(autumn)	Years 0-2	0.702	0.124	5.671	<0.001		
		Years 2-5	-0.008	0.065	-0.120	0.905		
4	WM abundance	(Intercept)	2.895	0.158	18.363	<0.001	249.11 (59)	181.00 (57)
	(autumn)	Years 0-2	0.504	0.126	3.992	<0.001		
		Years 2-5	-0.102	0.076	-1.339	0.186		
5	BV abundance	(Intercept)	1.916	0.265	7.225	<0.001	473.24 (59)	155.17 (56)
	(autumn)	Years 0-2	2.012	0.335	6.012	<0.001		
		Years 2-5	-0.008	0.092	-0.089	0.929		
		Treatment(ELS & ELSX)	0.564	0.216	2.604	0.012		
6	FV abundance	(Intercept)	-2.666	0.640	-4.168	<0.001	123.99 (59)	74.75 (57)
	(autumn)	Years 0-5	0.471	0.105	4.478	<0.001		
		Treatment(ELS & ELSX)	1.322	0.526	2.514	0.015		

7	CS abundance (autumn)	(Intercept)	-1.453	0.594	-2.445	0.018	160.78 (59)	114.11 (58)
		Years 0-5	0.481	0.141	3.405	0.001		
8	Total abundance (spring)	(Intercept)	2.952	0.210	14.087	<0.001	604.89 (57)	373.76 (54)
		Years 0-5	-0.068	0.081	-0.841	0.404		
		Treatment(ELS & ELSX)	-1.651	0.353	-4.677	<0.001		
		Years 0-5*Treatment (ELS & ELSX	0.431	0.109	3.978	<0.001		
9	WM abundance (spring)	(Intercept)	2.889	0.179	16.150	<0.001	547.93 (57)	229.53 (55)
		Years 0-5	-0.289	0.084	-3.427	0.001		
		Treatment(ELS & ELSX)	-2.148	0.331	-6.495	<0.001		
10	BV abundance (spring)	(Intercept)	0.471	0.321	1.466	0.149	327.33 (57)	194.13 (54)
		Years 0-5	0.277	0.089	3.113	0.003		

		Treatment(ELSX)	-2.248	1.032	-2.179	0.034		
		Years 0-5*Treatment (ELSX)	0.548	0.230	2.387	0.021		
11	FV abundance (spring)	(Intercept)	-2.338	0.697	-3.355	0.001	418.63 (57)	173.33 (55)
		Years 0-5	0.723	0.126	5.750	<0.001		
		Treatment(ELS & ELSX)	1.146	0.478	2.397	0.020		
12	CS abundance (spring)	(Intercept)	-0.972	0.779	-1.247	0.218	266.03 (57)	230.09 (55)
		Years 0-5	0.176	0.123	1.430	0.158		
		Treatment(ELS & ELSX)	1.334	0.746	1.789	0.079		