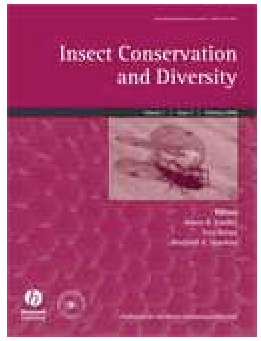

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The role of grassland sward islets in the distribution of arthropods in cattle pastures.

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Running title: Arthropods and sward islets

Abstract

1. It is well documented that cattle reduce their grazing activity in the vicinity of cattle dung, which gives rise to distinct patches, or islets as they have been termed, of longer sward. The influence of such islets on pasture utilisation and agronomic performance has been widely studied, but very little information is available concerning their influence on grassland biodiversity.

2. In this study the abundance and distribution of arthropods in relation to islets was assessed, using suction sampling, at 26 commercial farms and in a replicated pasture management experiment in the south and east of Ireland.

3. Islets were found to cover approximately 24% of pastures and to contain between 40 and 50% of arthropod individuals.

4. Islets consistently contained a higher density of arthropods, even when the difference in mean sward height between islets and more strongly grazed sward was accounted for. The relative concentration of arthropods in islets declined with increasing mean sward height, which may be related to a change in the recovery of well-grazed non-islet sward. Islets appear to act as refugia from sward removal.

5. The potential importance of islets in maintaining arthropod biodiversity within intensively grazed pastures and the wider landscape within intensive grass-based farming areas is discussed, particularly with reference to standard agronomic practices such as sward topping and chain harrowing, which aim to remove the sward heterogeneity created by grazing livestock.

Keywords. insects, spiders, biodiversity, agriculture, grazing, refugia, spatial heterogeneity

Introduction

It has been known for many years that grazing by cattle is reduced, although not completely avoided, in the immediate vicinity of cattle dung (Marsh & Campling, 1970; Norman & Green, 1958). A number of studies have investigated the possible reasons behind the behaviour, including the smell of the dung and the coarseness, sugar content and nutrient content of the grass, but there have be no definitive answers (Bosker *et al.*, 2002; MacDiarmid & Watkin, 1972; Marsh & Campling, 1970; Marten & Donker, 1964a, b; Plice, 1951). It may be that the dung causes an initial rejection in the proximal sward. With consequent differences in the chemical or physical characteristics the grazed and ungrazed vegetation maintaining the rejection by cattle (MacLusky, 1960; McNaughton, 1984; Norman & Green, 1958). Whatever the present reasons for such behaviour in grazing cattle, the underlying evolutionary explanation may lie in avoidance of infection by gastrointestinal parasite larvae, the distribution of which tends to remain highly concentrated in the vicinity of dung patches during the grazing season (Boom & Sheath, 2008).

The result of this behaviour by cattle in relatively intensive grasslands, is that distinct patches of longer sward are typically found around dung patches (Figure 1) (MacDiarmid & Watkin, 1972). These patches have been termed islets, due to the contrast between them and the more heavily grazed sward surrounding them, (Desender, 1982; Maelfait & De Keer, 1990). Although islets have taller vegetation, the botanical composition is initially little changed from the remaining sward (MacDiarmid & Watkin, 1971; Norman & Green, 1958; Parish & Turkington, 1990). However, some studies suggest that the spatial heterogeneity created by such patches, especially in soil nutrient status (Haynes & Williams, 1993; Lantinga *et al.*, 1987), is likely to influence relative plant population dynamics and the longer-term co-existence of sward species (Chesson, 2000; Schulte *et al.*, 2003; Schwinning & Parsons, 1996).

Islets have been estimated to cover between 10 and 47% of pasture area and to persist for between a few months to over a year, although both these characteristics vary with grazing intensity, rainfall and management such as cutting (Boswell, 1971; Castle & MacDaid, 1972; Gibb *et al.*, 1997; MacLusky, 1960; Marsh & Campling, 1970; Marten & Donker, 1964a; Norman & Green, 1958; Tayler & Large, 1955; Weeda, 1967). The extent and persistence of islets has often been considered to represent a reduction in productivity and consequently has stimulated many studies from an agronomic perspective (Bosker *et al.*, 2002; Castle & MacDaid, 1972; Greenhalgh & Reid, 1968; MacLusky, 1960; Marsh & Campling, 1970; Marten & Donker, 1964a; Tayler & Rudman, 1966). It is also a major reason for the practices of sward topping to reduce physical sward heterogeneity (and control weeds) and chain harrowing to re-distribute surface dung (Barry *et al.*, 2002; Boswell, 1971; MacLusky, 1960; Norman & Green, 1958; Weeda, 1967).

In contrast there has been little work done on the possible ecological effects of islets. Mikola (2009) recently reported a major study of the ecological effects of localised dung-deposition on plant and soil faunal communities in grazed pasture. Desender (1982), Desender *et al.* (1989) and D'Hulster and Desender (1982, 1984) found evidence that islets may be important overwintering sites for Carabidae and Staphylinidae, particularly as they are not trampled by cattle and cover a relatively large area. Some spiders (Araneae) are also thought to use islets for overwintering (De Keer *et al.*, 1986; Desender *et al.*, 1989; Maelfait & De Keer, 1990). De Keer *et al.* (1989) found that the contrast in microhabitat conditions between the vegetation within and outside islets resulted in differences in the growing season distribution, abundance and behaviour of different spider species. The present authors are not aware of any other studies specifically focused on the distribution of above-ground arthropods relative to islets, although their value in maintaining heterogeneity and botanical diversity in grassland is well recognised (Chesson, 2000; Rook & Tallowin, 2003; Wallis De Vries et al., 2007). Neither does there appear to have been any direct investigation in islets terms of above ground arthropod groups apart from Araneae, Carabidae and Staphylinidae.

There have been a number of studies of the arthropods found in more permanent tussock structures, including those in upland areas, in lowland field margins and in beetle banks. Unlike islets, these tussocks are associated with the growth form of specific grass or similar monocot plant species, such as the grasses *Dactylis glomerata* L. (Luff, 1965b), *Nardus stricta* L. (Dennis *et al.*, 1998) and *Holcus lanatus* L. (Bossenbroek *et al.*, 1977b). The importance of tussocks for arthropods, particularly in terms of overwintering, has long been recognised (Bayram & Luff, 1993; Luff, 1965a; Luff, 1966; Pearce, 1948). It has been suggested that their value to arthropods is particularly associated with their sheltered microclimate, including reduced temperature and humidity fluctuation (Bossenbroek *et al.*, 1977a, b; Luff, 1965b). At a larger habitat scale, the presence of tussocks helps to create heterogeneity within grasslands, which is considered a highly important factor in determining arthropod and other biodiversity (Benton *et al.*, 2003; Dennis *et al.*, 1998; Morris, 2000; Rook & Tallowin, 2003; Woodcock *et al.*, 2007). A reduction in structural diversity associated with intensified agricultural management has been an important factor in the decline in wildlife habitat quality of lowland grasslands during the latter part of the twentieth century (Vickery *et al.*, 2001). As grass-based agriculture accounts for a high proportion of land-use, particularly in countries such as Ireland (Anderson *et al.*, 2008) and the UK (Vickery *et al.*, 2001), the decline in the grassland biodiversity is likely to represent a major factor of the often noted more general decline in biodiversity within the wider countryside

(Krebs *et al.*, 1999). Conversely, any agricultural practices associated with a reversal of the trend to reduced grassland biodiversity, has the potential to have a very widespread positive effect. For this reason it is important to understand the major influences on biodiversity within lowland agricultural grasslands, and any factors that influence it. One such factor may be the heterogeneity in arthropod distribution that is introduced by the grazing behaviour of cattle.

The aim of the current study was to quantify the influence of grassland sward islets to arthropod population distribution in cattle pastures. It was hypothesised that islets contain a higher relative density of arthropods than non-islet areas of sward, and that the concentration of arthropods in islets varies in relation to the grazing cycle and sward characteristics, such as the mean sward height. These hypotheses were tested by measuring the abundance of five major arthropod groups (Araneae, Coleoptera, Diptera, Hemiptera and Hymenoptera) in islets and non-islet areas of sward within 27 grassland pastures in the south and east of Ireland. A further hypothesis, that the relative numbers of arthropods in islet and non-islet sward would differ between conventional pastures and those managed according to agri-environment practices, was investigated using a replicated field plot experiment at Teagasc Grange Research Centre.

Methods

Multi-farm survey

In the summer of 2005, grassland sward islet structure and arthropods populations were investigated in cattle grazed pastures on 26 randomly selected farms from the south and east Irish counties of Carlow, Cork, Kilkenny, Meath, Waterford, Wexford, and Wicklow (Appendix Figure 1). Further details of farm selection, the farms themselves and sampling dates can be found in Anderson *et al.* (2008), in which the farms utilised in the current study can be identified by site numbers: 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 16, 17, 18, 19, 22, 24, 26, 27, 28, 31, 33, 34, 36, 37, 39. The first farm (1) was sampled on 06 July 2005 and the last (39) on 03 August 2005. On each farm one pasture at approximately the mid-point of the grazing cycle (approximately days 10-14 since last grazing in a typical 21-28 day cycle) and representative of overall farm management, was selected.

In each of the selected pastures, 10 randomly placed suction samples, five from islets and five from non-islet areas of the sward, were taken with a Vortis Insect Suction Sampler (Burkard Manufacturing Co Ltd, Rickmansworth, Hertfordshire, UK) (Arnold, 1994; Brook *et al.*, 2008). Each of the 10 samples was pooled from six ten-second suctions, taken within the relevant sward type, at randomly selected points along a linear transect across the centre of the field. The total area of each sample was 0.12m^2, giving an overall coverage of 0.6m^2 for both islet and non-islet sward, per pasture. The arthropods collected were identified to order and counted. Only the five orders that dominate the macro-arthropod community of these agricultural grasslands (Araneae, Coleoptera, Diptera, Hemiptera and Hymenoptera) were counted.

For each pasture a number of other variables, later used as explanatory variables in statistical modelling (variable names in italics in parenthesis), were recorded; some related to the pasture itself and some to the farm where it was located. Date (*date*) was the number of days from the beginning of the year until the day of suction sampling. Farm type (*system*) was classified as either dairy or non-dairy cattle. Participation in the Irish agri-environment scheme, and nitrogen input level (kg ha^{-1}) of the farm, from both organic and inorganic sources) (*totalN*) were derived from the Irish National Farm Survey records. Latitude (*lat*) was obtained from the map location of the farms. Mean sward height (*sward ht*) was determined in each pasture by using a Filips Folding Plate Pasture Meter (www.jenquip.co.nz) to measure vegetation height at 50 randomly located points. At each sampling point the sward was visually categorized as either an islet or non-islet, and from this the proportion of the sward covered by islets (*prop*) was calculated. This could be done because, although islets are most clearly differentiated from the rest of the sward when recently grazed, the relative difference in vegetation height is retained throughout the grazing cycle (MacDiarmid & Watkin, 1972; Norman & Green, 1958). Total plant species richness (*plant*) was measured within each pasture by recording all plant species within 50 randomly located circular quadrats of 0.03 m^2 (total area sampled per pasture = 1.5 m^2). A habitat survey was carried out on each farm, following the Draft Habitat Survey Guidelines (The Heritage Council, 2005) using the classification of habitats followed (Fossitt, 2000). Further details of the habitat survey can be found in the Ag-Biota project report (Purvis *et al.*, 2009). As farm access was granted for individual farms and not neighbouring land, habitat surveys were conducted at the farm scale. The resulting data were combined with information from aerial photographs to calculate the area of different habitats. The areas were used with the Shannon diversity index to calculate the habitat diversity on each farm (*habitat div*), as well as to calculate the percentage of the farm area that was not used in agricultural production (*non-crop*).

Pasture management experiment

Use was made of a single-site field plot experiment located at Teagasc (The Irish Agriculture and Food Development Authority) Grange Research Centre, Co Meath in Ireland (longitude 6°40′4″, latitude 53°31′14″N, Irish grid reference N884530) to test the hypothesis that the distribution of arthropods relative to grassland sward islets would differ between pastures managed with conventional and agri-environment practices. The original experiment was established in 1997 to compare the agronomic performance of a conventional management system for suckler beef production with a system compatible with the Irish agri-environment scheme, the Rural Environment Protection System (REPS) (Emerson & Gillmor, 1999). Prior to setting up the experiment, the site had been managed intensively as grazed pasture. The experiment was set out with four blocks, each of which contained the two treatments, with three 0.28 ha paddocks in each treatment. The conventional suckler beef system had a stocking rate of 0.65 ha/cow unit, with 225 kg of inorganic nitrogen applied per hectare per year; REPS compatible system had 0.82 ha/cow unit and 88 kg N $ha^{-1}yr^{-1}$. The stocking rates were average values over time and across the experimental paddocks, as cattle were only found in four paddocks at any one time. The paddocks of each block-treatment combination were grazed by four separate, self-contained suckler herds. The experiment was grazed between April and November, in a fixed sequence with reference to treatment and block. As a result, individual paddocks were grazed approximately every 21-28 days, with each grazed for between 2 and 3 days on each occasion.

Sward and arthropod sampling within each grazing paddock was done on 27 June 2005 and 26 August 2005. Sward height was measured with the pasture meter at 50 randomly placed points within each paddock. Arthropod sampling was carried out with a Vortis suction sampler. One islet and one non-islet sample were taken, each randomly placed and each consisting of five, ten second suctions. The area sampled in both islet and non-islet sward was 0.1 m^2 per paddock. The arthropods collected were separated into their orders and numbers of Araneae, Coleoptera, Hemiptera, Hymenoptera were counted.

Statistical analysis

All statistical modelling was performed using R version 2.9.2 (R Development Core Team, 2009) , and in all cases significance was taken at the α=0.05 level.

Statistical analysis: multi-farm survey

The difference in mean sward height between islets and non-islet areas in the 27 sampled pastures was investigated using linear regression. Islet sward height was modelled as the response variable with non-islet sward height as the explanatory variable.

The density of the five major arthropod orders in islets and non-islets were compared with linear mixed models using the R function lme from the nlme package (Pinheiro *et al.*, 2009). Arthropod abundance was modelled as the response variable, with sub-habitat type (islet or non-islet) and sward height as explanatory variables with farm identity as a random (block) effect. Prior to modelling the response variables (arthropod group abundance) were log (ln) transformed and then tested for normality using the Shapiro-Wilk test. In all cases these data conformed to normality.

Generalised linear models using the glm function were used to investigate the relationship between various characteristics of the sites and the proportion of the catch of each arthropod group that were collected in islets compared with non-islet areas. The cbind function was used to combine the abundance data for the islets and non-islets into a new matrix response variable that quantified the proportional incidence in islets. This was modelled with quasibinomial (Araneae, Coleoptera, Diptera, Hemiptera) or binomial (Hymenoptera) error structure, defined using the family directive, and therefore with a logit link function.

The response variable was modelled with the following explanatory variables: *system*, *lat*, *totalN*, *non-crop*, *habitat div*, *plant*, *sward ht*, *prop*, and *date*. Initially models containing all the explanatory variables were used to test for significant interaction terms. Then a maximal model was created with all the explanatory variables and any interaction terms that showed significance. Subsequently, step-wise model simplification was carried out by the sequential removal of non-significant terms (Crawley, 2007), with tests of deletion, using the anova function to determine whether removal of terms was justified.

Statistical analysis: Pasture management experiment

The proportion of arthropods (Araneae, Coleoptera, Hemiptera (all individuals), Hemiptera (all individuals minus immature aphids) and Hymenoptera) found in islets and the relative abundance in islets was modelled with the lmer function. Two Hemiptera response variables were modelled, because immature aphids appeared to have a very large influence on the data. The response variable was a matrix generated using the cbind function to combine the numbers collected in islet and non-islet, and binomial error structure was defined using the family directive. The explanatory variables used were treatment and mean sward height, as well as their interaction. The nested experimental structure was accounted for by using three random effects: sample date, nested within paddock, nested within treatment (i.e. treatment/paddock/date).

Results

Multi-farm survey - proportion of islets and arthropods

The proportion of the multi-farm survey fields covered by islets and the proportion of the five arthropod group populations in islets, estimated from the numbers collected and the relative area of islets, were in all cases found to show distributions that were not significantly different from normality, when tested with the Shapiro-Wilk normality test. Islets covered a median proportion of 0.25 of cattle grazed fields with a range of between 0.10 and 0.52 (Figure 2). The proportion of invertebrate abundance in islets was in all cases higher than 0.25 with median proportions in islets as follows: Araneae 0.45; Coleoptera 0.43; Diptera 0.52; Hemiptera 0.46; Hymenoptera 0.45 (Figure 2).

Multi-farm survey - Relationship between islet and non-islet sward height

The linear regression model of islet sward height (response) against non-islet sward height (explanatory) from the 26 sites, was highly significant ($F_{1,24}$=30.69 P<0.001, r^2=0.54). The model estimated an intercept of 5.95 and slope of 0.96. The standard error for the slope estimate was 0.17 with 95% confidence intervals ±0.36. Therefore a slope of unity is very close to and well within the 95% confidence intervals for the estimated slope.

Multi-farm survey – relative arthropod abundance in islets and non-islets

Modelling of the number of arthropods in the 26 pastures gave very similar results for all five groups. All models indicated that there were significantly more individuals collected in islets than in non-islet areas, and that there was a significant negative interaction between sward height and sub-habitat type (Table 1). In all models the interaction indicated that while there was a significant positive sward height effect for non-islet areas, there was no sward effect with islets themselves.

Multi-farm survey – site variables

The generalised linear models of the proportion of individuals collected in islets showed some similarity between the arthropod orders (Table 2). They indicated that for Araneae, Coleoptera, Hemiptera and Hymenoptera there were significant negative relationships with mean sward height (Figure 3). There were significant positive relationships with the proportion of the sward covered by islets for the Araneae, Hemiptera and Hymenoptera (Table 2). There were significant positive relationships with farm habitat diversity for Coleoptera and Hymenoptera (Table 2). For the Hemiptera there was a system effect with a greater proportion of individuals in islets in non-dairy than dairy sites. Models for the Diptera showed little similarity with those for the other orders, with a significant negative relationship with date, such that the proportion of Diptera in islets declined during the sampling period (Table 2). The minimal adequate model for Hymenoptera was the most complex and revealed several additional significant parameters. These were the proportion of non-cropped habitats and an interaction of non-cropped area and sward height (Table 2). The non-crop-sward interaction indicated that although there was a significant negative sward height effect, the strength of this decreased as the proportion of non-crop habitats increased.

Using model parameter estimates, and mean observed values for non-sward height variables, estimates can be made of the average proportion of arthropods collected within islets at the two extremes of sward height sampled, 5 cm and 12 cm (Figure 3). Proportions at 5 cm were as follows: Araneae 0.81, Coleoptera, 0.83, Hemiptera, 0.80 and Hymenoptera 0.81. At 12 cm the figures had fallen to: Araneae 0.61, Coleoptera 0.55, Hemiptera, 0.56, and Hymenoptera 0.57.

Pasture management experiment

Models of the proportional incidence of arthropods within islets, indicated that for the Araneae, Coleoptera (REPS treatment only), Hemiptera and Hymenoptera there were significant negative effects with sward height (Table 3). The models for Coleoptera and Hemiptera indicated significant treatment-sward height interactions. For both groups there was a strongly significant negative sward height effect in the REPS treatment, and in the conventional treatment there was no sward height effect. When modelling was repeated with Hemiptera data from which aphid nymph abundance had been subtracted there were no significant interactions with only sward height indicating a decline in the proportion of individuals in islets as sward height increased. In addition to sward height, treatment itself was significant for Coleoptera and Hemiptera, and in both cases the proportion of individuals in islets was greater for the REPS treatment than in the conventional.

Discussion

Grassland sward islets, areas of longer sward resulting from reduced grazing activity by cattle, were found to cover a mean proportion of 0.24 of the area of the 26 cattle pastures surveyed. This is very much within the range of islet cover reported from other studies, which ranged between 0.10 and 0.47 (Castle & MacDaid, 1972; Gibb *et al.*, 1997; MacLusky, 1960; Marsh & Campling, 1970; Tayler & Large, 1955; Tayler & Rudman, 1966). Previous studies of islets have mainly concentrated on their agronomic effects and here we make little comment from that perspective. However the relationship between sward height within and outside of islets does give support to the suggestion of MacDiarmid and Watkin (1972) that once islets are established grazing occurs on islets and non-islet sward. The regression indicated that the difference in sward height between islets and surrounding sward was 5.95 cm, compared to the 4.06 cm (given as 1.6 inches) reported by MacDiarmid and Watkin (1972) , and that the slope was very close to 1, suggesting that the difference in sward height remains constant across a range of mean sward heights.

The main focus of this study was the arthropod populations associated with islets. Although islets covered a mean proportion of 0.24 of pastures, calculations from the numbers of arthropods collected and the relative area of islets indicated that the proportion of total arthropod populations found in islets varied between 0.45 and 0.54. Therefore it appears that approximately half the individual arthropods were concentrated in only a quarter of the area of the pastures. These figures were of course average findings from 26 fields in approximately the middle of the grazing cycle, and did not take into account the effect of changing sward height. However they do give an indication of the importance of islets in determining the distribution of arthropod populations within pastures. As such cattle, and similarly some other vertebrate herbivores, have an important role in terms of generating sward structural diversity and consequently enhancing arthropod and other forms of biodiversity (Davidson & Lightfoot, 2006; Knapp *et al.*, 1999).

The greater numbers of all arthropod groups within islets, relative to non-islets, even with sward height included as a covariate, indicated that the concentration within islets was due to more than the sampling of an increased volume of habitat related to sward height. The longer sward of the islets may enhance the abundance of invertebrates through niche availability and microclimate, as has been suggested for grassland vegetation height more generally (Andrzejewska, 1965; Baines *et al.*, 1998; Bell *et al.*, 2001; Cattin *et al.*, 2003; Curry, 1987b; Morris, 2000; Morris & Lakhani, 1979; Morris & Rispin, 1987).

The dung present at the centre of the islets may be directly attracting some species, particularly dung breeding species of Diptera and Coleoptera (Curry, 1987a; Skidmore, 1991). These in turn would attract their predators and parasites, including many staphylinid Coleoptera, some Araneae and many parasitoid Hymenoptera. The dung may provide an increase of nutrients such as nitrogen in the locality of the islet. This may be important in increasing the abundance of herbivores, particularly the sap-sucking Hemiptera, for which nitrogen is often limiting (Andrzejewska, 1976; Denno & Roderick, 1990; Olechowicz, 1976). Again, a greater abundance of herbivores will attract predators and parasites.

The longer sward may have an important effect on microclimate, buffering the effect of temperature variation and increasing humidity (Bossenbroek *et al.*, 1977a, b; D'Hulster & Desender, 1982; De Keer *et al.*, 1989; Luff, 1965b), which may be beneficial for a range of arthropods. The buffering of temperature may be particularly important in winter and islets may be a valuable overwintering site for some arthropods (D'Hulster & Desender, 1984; Dennis *et al.*, 1994; Desender, 1982). The humidity may be especially important for soil microarthropods, such as Collembola and Acari, and their many predators such as the staphylinid genus *Stenus* and Araneae of the family Linyphiidae (Curry, 1987a).

Spiders such as some of the Linyphiidae may also be dependent on the longer vegetation provided by islets for suitable sites for their webs (Bell *et al.*, 2001; Harwood *et al.*, 2003). The longer sward may provide additional feeding niches, for example flower and seed heads which are important for a range of Hemiptera and Coleoptera. There would also be a greater number of potential sites for leaf and stem mining species, which include many Diptera (Curry, 1987a). Of course islets may also provide a greater degree of shelter from vertebrate predators such as birds.

Although islets were found to hold higher densities of arthropods than non-islet areas of sward, generalised linear modelling indicated that the proportion collected in islets relative to non-islet sward was related to several factors. The most important of these appeared to be mean sward height, followed by the percentage of sward covered by islets, and there was also some evidence for differences related to farm habitat diversity, percentage of non-crop habitat and agri-environment sward management. In the Araneae, Hemiptera and Hymenoptera there was a positive relationship between the proportion of the sward covered by islets and the proportion of individuals collected in islets. This was not due to a sampling effect as the two sub-habitats were sampled equally. Perhaps with a greater density of islets arthropods have greater chance to encounter an islet, and therefore more of the arthropods are located within them. In the Coleoptera and Hymenoptera there was a positive relationship between farm habitat diversity and the proportion of individuals collected in islets which could arise if farmers who have a more diverse farm structure were more tolerant of well defined islet structure.

The higher concentration of individuals of Coleoptera and Hemiptera within islets in the REPS system may indicate that lower intensity grazing systems generate greater level of small-scale heterogeneity. It is widely considered that heterogeneity is very important for conserving biodiversity (Benton et al., 2003; Morris, 2000; Woodcock et al., 2009). Thus islets together with other factors, such as vegetation diversity, may contribute to the aims of agri-environment schemes to restore biodiversity within agricultural systems.

The proportion of Araneae, Coleoptera, Hemiptera and Hymenoptera collected from islets declined as the mean sward height increased. Estimates based on the generalised linear modelling indicated that at the extremes of sward height sampled, and given equal sampling in the two sub-habitats approximately 80% of arthropods would be found in islets when overall mean sward height was 5 cm but this would fall to about 59% in swards with a overall mean of 12 cm (equivalent to approximately 3% for each cm). Sward height data (Appendix Table 1) from eight of the paddocks at the Teagasc Grange field site, measured on 10 dates between May and September 2003, indicated that in only 8 out of 80 date-paddock combinations was the sward height greater than 12 cm. Therefore a high level of arthropod aggregation in islets is likely to remain through most if not all the grazing cycle. Nevertheless, the contrast of arthropod density between islets and non-islets was clearly reduced as the mean sward height increased between grazing events.

What might explain the change in the contrast in relative density? Once established, islets can remain as distinct structures for many months (MacDiarmid & Watkin, 1972; Norman & Green, 1958). Although some grazing of islets does occur (MacDiarmid & Watkin, 1972; Marten & Donker, 1964a) they are generally much less disturbed than non-islet areas and thus can represent a long-term refuge of suitable habitat for many invertebrates, This constancy of resource can explain the lack of a sward height effect with arthropod abundance in islets. In contrast, non-islet sward is grazed and therefore disturbed to a much great extent. When strongly grazed the very short grass, rather analogous to a domestic lawn, is likely to be a poor habitat, with reduced ecological niches, food resources and altered microclimate (Helden & Leather, 2004; Morris, 2000). As grazed sward recovers from grazing, the suitability of the habitat will increase again. Recovery after grazing may well explain the positive response of arthropod abundance to sward height in the non-islet sub-habitat. Thus the contrast in the relative abundance between islets and non-islets is likely to be related to a change in the contrast of habitat suitability.

The ecological constancy of islets means they have the potential to be refugia from grazing events. Humbert (2009) recently presented a very similar idea when proposing that un-cut patches should be left after mowing as a way of maintaining arthropod biodiversity in cut grasslands. Given this, the common and often, although not universally, recommended practice of topping (mowing) after grazing, to return a sward to a uniform height (Barry *et al.*, 2002; Boswell, 1971; Castle & MacDaid, 1972; MacLusky, 1960; Norman & Green, 1958), is likely to be detrimental to grassland arthropod biodiversity. Such topping is likely to lead to the death and/or migration of much of arthropod population (Humbert *et al.*, 2009).

The purpose of this work is not to comment on the agronomic value or otherwise of topping but rather to comment from an ecological perspective. Given this and the apparent importance of islets for grassland arthropods, could other ecological benefits be accrued from encouraging islet structure in cattle pastures? Arthropods fulfil many roles in ecological communities: herbivores, detritivores, predators, as well as being food for many consumers at higher levels in food webs. They are also important at providing many ecosystem services beneficial to humans, such as predation and parasitism of pests, pollination, nutrient cycling and decomposition processes (Altieri, 1999). Therefore any management that promotes islets and so arthropod populations may be expected to have benefits to ecological community structure and processes. One specific benefit would be for farmland birds, for which there has been considerable concern over recent years due to widespread population declines linked to intensive farming practices (Krebs *et al.*, 1999; Robinson & Sutherland, 2002; Vickery *et al.*, 2001). Larger arthropod populations would provide a greater food supply for insectivorous birds. In addition the heterogeneous sward structure itself may be beneficial for birds. Ground feeding birds find prey more accessible in short swards but more abundant in longer swards and therefore the interface of longer and shorter swards, such as around islets, may be valuable foraging areas (Douglas *et al.*, 2009).

Agricultural grasslands cover large areas of Ireland and other northern European countries (Anderson *et al*., 2008; Vickery *et al.*, 2001). As such they have a role in the maintenance of biodiversity within the wider countryside, both as habitats in themselves and as a forming much of the matrix in which many other more species rich habitats such as semi-natural habitat fragments, hedgerows and field margins are embedded (Donald & Evans, 2006). Therefore any enhancement of grassland biodiversity at the local scale has the potential to have wider landscape consequences. It is therefore important that islets and other factors that operate at the local scale are understood more and that related biodiversity positive management options are encouraged.

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Table 1. Summary of linear mixed model (lme) comparisons of the abundance of arthropods in islets and non-islets, from the 26 sites of the multi-farm survey. Parameter estimates are given in log(ln) values. Degrees of freedom for the estimates of the slope parameter estimates

were 23; so for a given slope parameter the equivalent numerator and denominator d.f. (e.g. sward height) would be 1 and 23 degrees of freedom. Significance is indicated as: *** p<0.001, ** p<0.01, * p<0.05.

Arthropod group	Parameter estimates			
	intercept (non-islets)	islets	sward height	islet:sward height interaction
Araneae	2.539***	2.739***	0.176*	-0.213**
Coleoptera	1.986***	3.092***	0.203***	-0.257***
Diptera	3.336***	2.844**	0.195*	-0.214*
Hemiptera	2.568***	2.037***	0.229**	-0.184**
Hymenoptera	2.645***	2.210***	0.160**	-0.176***

Table 2. Minimal adequate models from generalised linear modelling (glm) of the proportion of arthropods (abundance in islets/total abundance) collected in islets at the 26 multi-farm survey sites. Parameter estimates given in terms of logits. The logit estimates (x) can be

converted to proportions as follows: exp(x) / (1+(exp(x)). Degrees of freedom (d.f.) are given; for a given slope parameter (e.g. Araneae sward ht) the equivalent numerator and denominator d.f. would be 1 and 23 degrees of freedom. Significance is indicated as: *** p<0.001, ** p<0.01, * p<0.05.

Arthropod group	Model	Parameter estimates (intercept ± explanatory variables)	d.f.	Deviance explained (%)
Araneae	~ sward ht + prop	2.665*** – 0.291*** + 2.868**	23	50.3
Coleoptera	~ habitat div + sward ht	2.223*** + 0.376* – 0.195***	23	67.0
Diptera	~ date	9.969** - 0.043*	24	23.6
Hemiptera	~ system + sward ht + prop	2.845*** + 0.445* – 0.335*** + 2.925**	22	63.6
Hymenoptera	~ non-crop + habitat div + sward ht + prop + non-crop:sward ht	2.466***– 5.810* + 0.434** – 0.327*** + 1.915** + 0.933**	20	76.7

Table 3. Minimal adequate models from generalised linear mixed modelling (lmer) of the proportion of arthropods collected in islets from the pasture management experiment (Teagasc Grange). Proportion of arthropods in islets (abundance in islets/total abundance)

with parameter estimates given in terms of logits. The logit estimates (x) can be converted to proportions as follows: exp(x) / (1+(exp(x)). Model structure was such that it was equivalent to having numerator and denominator degrees of freedom for parameter estimates of 1 and 4. ((2 treatments) – 1 = 1 ; (3 plots/treatment) – 1 = 2 x 2 treatments).

Arthropod group	Model	Parameter estimates (intercept ± explanatory variables)	Deviance explained (%)
Araneae	sward ht	1.000** - 0.032*	1.9
Coleoptera	treatment + sward ht + treatment:sward ht	1.595*** + 1.177* - 0.056 - 0.116**	38.1
Hemiptera (all individuals)	treatment + sward ht + treatment:sward ht	1.091*** + 1.256*** - 0.037* - 0.083**	20.1
Hemiptera (minus aphid juveniles)	sward ht	1.706*** - 0.095***	56.0
Hymenoptera	sward ht	1.362*** - 0.056***	9.8

Figure legends

Figure 1. A well defined islet in a cattle-grazed pasture

Figure 2. Boxplots showing the median proportion of the total overall populations from the multi-farm survey pastures of Araneae (aran), Coleoptera (col), Diptera (dipt), Hemiptera (hem) and Hymenoptera (hym) estimated to be found in islets. Proportion data were estimated from the numbers collected and the relative area of islets. Also shown is the proportion of field area covered by islets (islets) from the same 26 sites. Boxplots show the median values as the dark horizontal lines and figures; 25^{th} and 75^{th} percentiles as the top and bottom of the boxes. The dashed lines show either 1.5 times the interquartile range together with outliers as small circles, or if there are no outliers, the maximum and minimum values.

Figure 3. Change with sward height, in the proportion of all individuals of Araneae, Coleoptera, Hemiptera and Hymenoptera collected in islets at the multi-farm survey sites. For the Hemiptera the dashed line indicates non-dairy and the solid line dairy sites.

Appendix Figure 1. Location of the 26 multi-farm survey sites (closed circles) and the pasture management experiment at Teagasc Grange (open triangle).

Figure 1.

Figure 2.

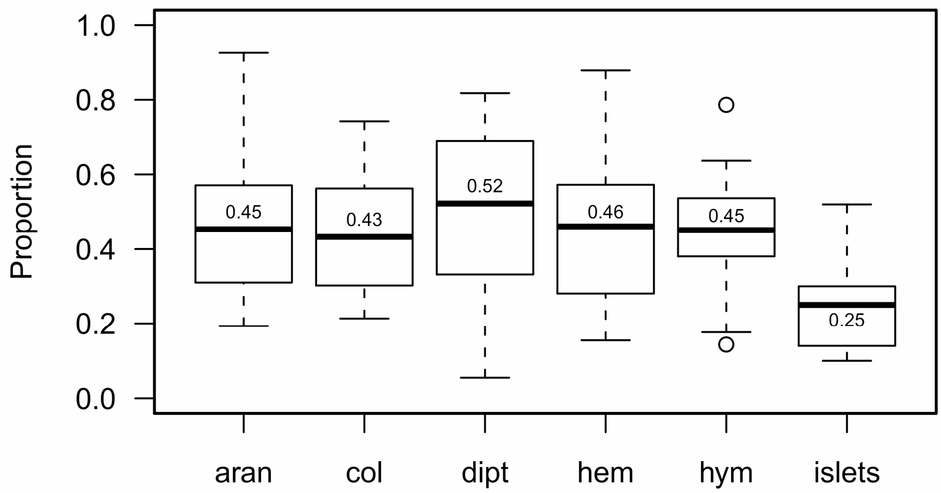
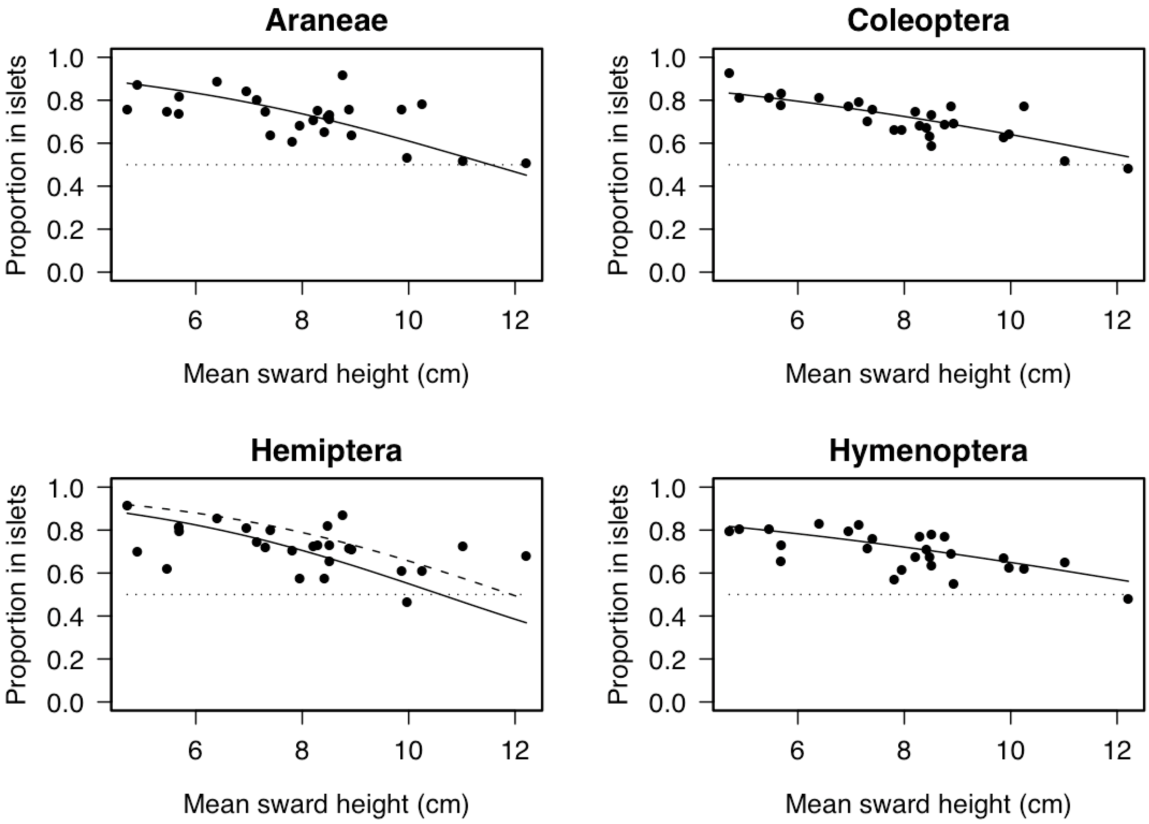

1.0
0.8
0.6
0.4
0.2
0.0
Proportion
0.45
0.43
0.52
0.46
0.45
0.25
aran
col
dipt
hem
hym
islets

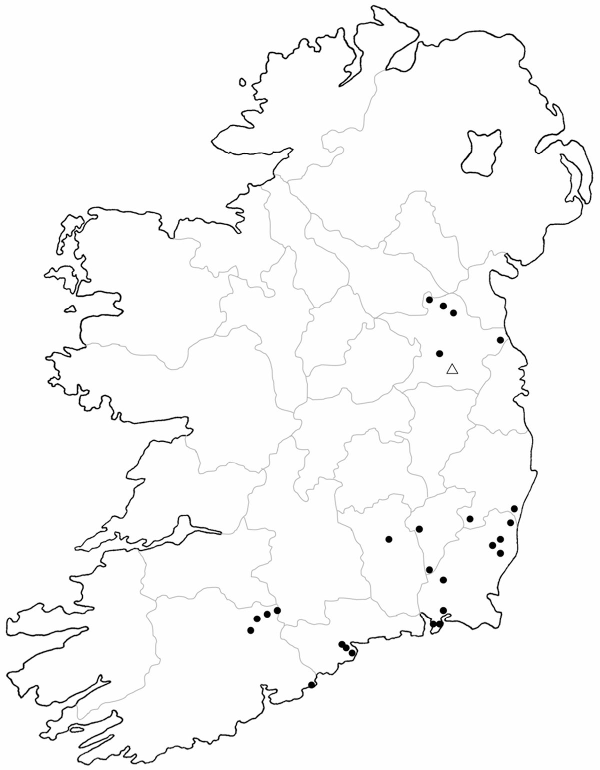
Figure 3,


Araneae
Coleoptera
Hemiptera
Hymenoptera
Proportion in islets
Mean sward height (cm)
1.0
0.8
0.6
0.4
0.2
0.0
6
8
10
12

Appendix Table 1. Mean sward height in eight of the Teagasc Grange paddocks on ten dates between May and September 2003. Values over 12 cm are shown in bold.

Paddock name	Date									
	7 May	27 May	11 June	17 June	3 July	15 July	30 July	14 Aug	26 Aug	9 Sept
Conventional M1	6.9	5.0	8.5	8.1	6.1	10.4	5.9	9.4	**14.0**	**14.7**
Conventional M2	7.2	4.9	9.0	10.5	7.5	8.7	5.6	10.0	**13.3**	**14.7**
REPS M1	8.6	4.2	9.0	9.0	7.4	7.3	**13.0**	6.3	9.9	11.2
REPS M2	7.2	6.1	8.1	10.2	6.9	11.0	**14.0**	7.3	10.3	11.2
Conventional F1	5.3	7.8	6.5	5.8	7.0	5.1	7.4	**12.7**	6.6	8.8
Conventional F2	5.2	6.0	5.4	3.7	5.7	9.3	6.4	**12.2**	6.6	7.0
REPS C1	5.4	6.7	4.9	5.0	8.7	9.8	5.1	8.9	5.0	6.7
REPS C2	5.9	6.8	6.4	5.9	6.7	9.2	5.5	9.2	5.6	5.4

Appendix Figure 1.



The role of grassland sward islets in the distribution of arthropods in cattle pastures.

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Running title: Arthropods and sward islets

Abstract

1. It is well documented that cattle reduce their grazing activity in the vicinity of cattle dung, which gives rise to distinct patches, or islets as they have been termed, of longer sward. The influence of such islets on pasture utilisation and agronomic performance has been widely studied, but very little information is available concerning their influence on grassland biodiversity.

2. In this study the abundance and distribution of arthropods in relation to islets was assessed, using suction sampling, at 26 commercial farms and in a replicated pasture management experiment in the south and east of Ireland.
3. Islets were found to cover approximately 24% of pastures and to contain between 40 and 50% of arthropod individuals.
4. Islets consistently contained a higher density of arthropods, even when the difference in mean sward height between islets and more strongly grazed sward was accounted for. The relative concentration of arthropods in islets declined with increasing mean sward height, which may be related to a change in the recovery of well-grazed non-islet sward. Islets appear to act as refugia from sward removal.

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5. The potential importance of islets in maintaining arthropod biodiversity within intensively grazed pastures and the wider landscape within intensive grass-based farming areas is discussed, particularly with reference to standard agronomic practices such as sward topping and chain harrowing, which aim to remove the sward heterogeneity created by grazing livestock.

Keywords. insects, spiders, biodiversity, agriculture, grazing, refugia, spatial heterogeneity

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Introduction

It has been known for many years that grazing by cattle is reduced, although not completely avoided, in the immediate vicinity of cattle dung (Marsh & Campling, 1970; Norman & Green, 1958). A number of studies have investigated the possible reasons behind the behaviour, including the smell of the dung and the coarseness, sugar content and nutrient content of the grass, but there have be no definitive answers (Bosker *et al.*, 2002; MacDiarmid & Watkin, 1972; Marsh & Campling, 1970; Marten & Donker, 1964a, b; Plice, 1951). It may be that the dung causes an initial rejection in the proximal sward. With consequent differences in the chemical or physical characteristics the grazed and ungrazed vegetation maintaining the rejection by cattle (MacLusky, 1960; McNaughton, 1984; Norman & Green, 1958). Whatever the present reasons for such behaviour in grazing cattle, the underlying evolutionary explanation may lie in avoidance of infection by gastrointestinal parasite larvae, the distribution of which tends to remain highly concentrated in the vicinity of dung patches during the grazing season (Boom & Sheath, 2008).

The result of this behaviour by cattle in relatively intensive grasslands, is that distinct patches of longer sward are typically found around dung patches (Figure 1) (MacDiarmid & Watkin, 1972). These patches have been termed islets, due to the contrast between them and the more heavily grazed sward surrounding them, (Desender, 1982; Maelfait & De Keer, 1990). Although islets have taller vegetation, the botanical composition is initially little changed from the remaining sward (MacDiarmid & Watkin, 1971; Norman & Green, 1958; Parish & Turkington, 1990). However, some studies suggest that the spatial heterogeneity created by such patches, especially in soil nutrient status (Haynes & Williams, 1993; Lantinga *et al.*, 1987), is likely to influence relative plant population dynamics and the

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longer-term co-existence of sward species (Chesson, 2000; Schulte *et al.*, 2003; Schwinning & Parsons, 1996).

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Islets have been estimated to cover between 10 and 47% of pasture area and to persist for between a few months to over a year, although both these characteristics vary with grazing intensity, rainfall and management such as cutting (Boswell, 1971; Castle & MacDaid, 1972; Gibb *et al.*, 1997; MacLusky, 1960; Marsh & Campling, 1970; Marten & Donker, 1964a; Norman & Green, 1958; Tayler & Large, 1955; Weeda, 1967). The extent and persistence of islets has often been considered to represent a reduction in productivity and consequently has stimulated many studies from an agronomic perspective (Bosker *et al.*, 2002; Castle & MacDaid, 1972; Greenhalgh & Reid, 1968; MacLusky, 1960; Marsh & Campling, 1970; Marten & Donker, 1964a; Tayler & Rudman, 1966). It is also a major reason for the practices of sward topping to reduce physical sward heterogeneity (and control weeds) and chain harrowing to re-distribute surface dung (Barry *et al.*, 2002; Boswell, 1971; MacLusky, 1960; Norman & Green, 1958; Weeda, 1967).

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In contrast there has been little work done on the possible ecological effects of islets. Mikola (2009) recently reported a major study of the ecological effects of localised dung-deposition on plant and soil faunal communities in grazed pasture. Desender (1982), Desender *et al.* (1989) and D'Hulster and Desender (1982, 1984) found evidence that islets may be important overwintering sites for Carabidae and Staphylinidae, particularly as they are not trampled by cattle and cover a relatively large area. Some spiders (Araneae) are also thought to use islets for overwintering (De Keer *et al.*, 1986; Desender *et al.*, 1989; Maelfait & De Keer, 1990). De Keer *et al.* (1989) found that the contrast in microhabitat conditions between the vegetation within and outside islets resulted in differences in the growing season distribution, abundance and behaviour of different spider species. The present authors are not

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aware of any other studies specifically focused on the distribution of above-ground arthropods relative to islets, although their value in maintaining heterogeneity and botanical diversity in grassland is well recognised (Chesson, 2000; Rook & Tallowin, 2003; Wallis De Vries et al., 2007). Neither does there appear to have been any direct investigation in islets terms of above ground arthropod groups apart from Araneae, Carabidae and Staphylinidae.

There have been a number of studies of the arthropods found in more permanent tussock structures, including those in upland areas, in lowland field margins and in beetle banks. Unlike islets, these tussocks are associated with the growth form of specific grass or similar monocot plant species, such as the grasses *Dactylis glomerata* L. (Luff, 1965b), *Nardus stricta* L. (Dennis *et al.*, 1998) and *Holcus lanatus* L. (Bossenbroek *et al.*, 1977b). The importance of tussocks for arthropods, particularly in terms of overwintering, has long been recognised (Bayram & Luff, 1993; Luff, 1965a; Luff, 1966; Pearce, 1948). It has been suggested that their value to arthropods is particularly associated with their sheltered microclimate, including reduced temperature and humidity fluctuation (Bossenbroek *et al.*, 1977a, b; Luff, 1965b). At a larger habitat scale, the presence of tussocks helps to create heterogeneity within grasslands, which is considered a highly important factor in determining arthropod and other biodiversity (Benton *et al.*, 2003; Dennis *et al.*, 1998; Morris, 2000; Rook & Tallowin, 2003; Woodcock *et al.*, 2007). A reduction in structural diversity associated with intensified agricultural management has been an important factor in the decline in wildlife habitat quality of lowland grasslands during the latter part of the twentieth century (Vickery *et al.*, 2001). As grass-based agriculture accounts for a high proportion of land-use, particularly in countries such as Ireland (Anderson *et al.*, 2008) and the UK (Vickery *et al.*, 2001), the decline in the grassland biodiversity is likely to represent a major factor of the often noted more general decline in biodiversity within the wider countryside

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(Krebs *et al.*, 1999). Conversely, any agricultural practices associated with a reversal of the trend to reduced grassland biodiversity, has the potential to have a very widespread positive effect. For this reason it is important to understand the major influences on biodiversity within lowland agricultural grasslands, and any factors that influence it. One such factor may be the heterogeneity in arthropod distribution that is introduced by the grazing behaviour of cattle.

The aim of the current study was to quantify the influence of grassland sward islets to arthropod population distribution in cattle pastures. It was hypothesised that islets contain a higher relative density of arthropods than non-islet areas of sward, and that the concentration of arthropods in islets varies in relation to the grazing cycle and sward characteristics, such as the mean sward height. These hypotheses were tested by measuring the abundance of five major arthropod groups (Araneae, Coleoptera, Diptera, Hemiptera and Hymenoptera) in islets and non-islet areas of sward within 27 grassland pastures in the south and east of Ireland. A further hypothesis, that the relative numbers of arthropods in islet and non-islet sward would differ between conventional pastures and those managed according to agri-environment practices, was investigated using a replicated field plot experiment at Teagasc Grange Research Centre.

Methods

Multi-farm survey

In the summer of 2005, grassland sward islet structure and arthropods populations were investigated in cattle grazed pastures on 26 randomly selected farms from the south and east Irish counties of Carlow, Cork, Kilkenny, Meath, Waterford, Wexford, and Wicklow (Appendix Figure 1). Further details of farm selection, the farms themselves and sampling dates can be found in Anderson *et al.* (2008), in which the farms utilised in the current study can be identified by site numbers: 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 16, 17, 18, 19, 22, 24, 26, 27, 28, 31, 33, 34, 36, 37, 39. The first farm (1) was sampled on 06 July 2005 and the last (39) on 03 August 2005. On each farm one pasture at approximately the mid-point of the grazing cycle (approximately days 10-14 since last grazing in a typical 21-28 day cycle) and representative of overall farm management, was selected.

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In each of the selected pastures, 10 randomly placed suction samples, five from islets and five from non-islet areas of the sward, were taken with a Vortis Insect Suction Sampler (Burkard Manufacturing Co Ltd, Rickmansworth, Hertfordshire, UK) (Arnold, 1994; Brook *et al.*, 2008). Each of the 10 samples was pooled from six ten-second suctions, taken within the relevant sward type, at randomly selected points along a linear transect across the centre of the field. The total area of each sample was $0.12m^2$, giving an overall coverage of $0.6m^2$ for both islet and non-islet sward, per pasture. The arthropods collected were identified to order and counted. Only the five orders that dominate the macro-arthropod community of these agricultural grasslands (Araneae, Coleoptera, Diptera, Hemiptera and Hymenoptera) were counted.

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For each pasture a number of other variables, later used as explanatory variables in statistical modelling (variable names in italics in parenthesis), were recorded; some related to the pasture itself and some to the farm where it was located. Date (*date*) was the number of days from the beginning of the year until the day of suction sampling. Farm type (*system*) was classified as either dairy or non-dairy cattle. Participation in the Irish agri-environment scheme, and nitrogen input level (kg ha^{-1}) of the farm, from both organic and inorganic sources) (*totalN*) were derived from the Irish National Farm Survey records. Latitude (*lat*) was obtained from the map location of the farms. Mean sward height (*sward ht*) was determined in each pasture by using a Filips Folding Plate Pasture Meter (www.jenquip.co.nz) to measure vegetation height at 50 randomly located points. At each sampling point the sward was visually categorized as either an islet or non-islet, and from this the proportion of the sward covered by islets (*prop*) was calculated. This could be done because, although islets are most clearly differentiated from the rest of the sward when recently grazed, the relative difference in vegetation height is retained throughout the grazing cycle (MacDiarmid & Watkin, 1972; Norman & Green, 1958). Total plant species richness (*plant*) was measured within each pasture by recording all plant species within 50 randomly located circular quadrats of 0.03 m^2 (total area sampled per pasture = 1.5 m^2). A habitat survey was carried out on each farm, following the Draft Habitat Survey Guidelines (The Heritage Council, 2005) using the classification of habitats followed (Fossitt, 2000). Further details of the habitat survey can be found in the Ag-Biota project report (Purvis *et al.*, 2009). As farm access was granted for individual farms and not neighbouring land, habitat surveys were conducted at the farm scale. The resulting data were combined with information from aerial photographs to calculate the area of different habitats. The areas were used with the Shannon diversity index to calculate the habitat diversity on each farm (*habitat div*), as well

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as to calculate the percentage of the farm area that was not used in agricultural production (*non-crop*).

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Pasture management experiment

Use was made of a single-site field plot experiment located at Teagasc (The Irish Agriculture and Food Development Authority) Grange Research Centre, Co Meath in Ireland (longitude 6°40′4″, latitude 53°31′14″N, Irish grid reference N884530) to test the hypothesis that the distribution of arthropods relative to grassland sward islets would differ between pastures managed with conventional and agri-environment practices. The original experiment was established in 1997 to compare the agronomic performance of a conventional management system for suckler beef production with a system compatible with the Irish agri-environment scheme, the Rural Environment Protection System (REPS) (Emerson & Gillmor, 1999). Prior to setting up the experiment, the site had been managed intensively as grazed pasture. The experiment was set out with four blocks, each of which contained the two treatments, with three 0.28 ha paddocks in each treatment. The conventional suckler beef system had a stocking rate of 0.65 ha/cow unit, with 225 kg of inorganic nitrogen applied per hectare per year; REPS compatible system had 0.82 ha/cow unit and 88 kg N $ha^{-1}yr^{-1}$. The stocking rates were average values over time and across the experimental paddocks, as cattle were only found in four paddocks at any one time. The paddocks of each block-treatment combination were grazed by four separate, self-contained suckler herds. The experiment was grazed between April and November, in a fixed sequence with reference to treatment and

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block. As a result, individual paddocks were grazed approximately every 21-28 days, with each grazed for between 2 and 3 days on each occasion.

Sward and arthropod sampling within each grazing paddock was done on 27 June 2005 and 26 August 2005. Sward height was measured with the pasture meter at 50 randomly placed points within each paddock. Arthropod sampling was carried out with a Vortis suction sampler. One islet and one non-islet sample were taken, each randomly placed and each consisting of five, ten second suctions. The area sampled in both islet and non-islet sward was 0.1 m^2 per paddock. The arthropods collected were separated into their orders and numbers of Araneae, Coleoptera, Hemiptera, Hymenoptera were counted.

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Statistical analysis

All statistical modelling was performed using R version 2.9.2 (R Development Core Team, 2009) , and in all cases significance was taken at the α=0.05 level.

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Statistical analysis: multi-farm survey

The difference in mean sward height between islets and non-islet areas in the 27 sampled pastures was investigated using linear regression. Islet sward height was modelled as the response variable with non-islet sward height as the explanatory variable.

The density of the five major arthropod orders in islets and non-islets were compared with linear mixed models using the R function lme from the nlme package (Pinheiro *et al.*, 2009). Arthropod abundance was modelled as the response variable, with sub-habitat type (islet or non-islet) and sward height as explanatory variables with farm identity as a random (block) effect. Prior to modelling the response variables (arthropod group abundance) were log (ln) transformed and then tested for normality using the Shapiro-Wilk test. In all cases these data conformed to normality.

Generalised linear models using the glm function were used to investigate the relationship between various characteristics of the sites and the proportion of the catch of each arthropod group that were collected in islets compared with non-islet areas. The cbind function was used to combine the abundance data for the islets and non-islets into a new matrix response variable that quantified the proportional incidence in islets. This was modelled with quasibinomial (Araneae, Coleoptera, Diptera, Hemiptera) or binomial (Hymenoptera) error structure, defined using the family directive, and therefore with a logit link function.

The response variable was modelled with the following explanatory variables: *system*, *lat*, *totalN*, *non-crop*, *habitat div*, *plant*, *sward ht*, *prop*, and *date*. Initially models containing all the explanatory variables were used to test for significant interaction terms. Then a maximal model was created with all the explanatory variables and any interaction terms that showed significance. Subsequently, step-wise model simplification was carried out by the sequential removal of non-significant terms (Crawley, 2007), with tests of deletion, using the anova function to determine whether removal of terms was justified.

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Statistical analysis: Pasture management experiment

The proportion of arthropods (Araneae, Coleoptera, Hemiptera (all individuals), Hemiptera (all individuals minus immature aphids) and Hymenoptera) found in islets and the relative abundance in islets was modelled with the lmer function. Two Hemiptera response variables were modelled, because immature aphids appeared to have a very large influence on the data. The response variable was a matrix generated using the cbind function to combine the numbers collected in islet and non-islet, and binomial error structure was defined using the family directive. The explanatory variables used were treatment and mean sward height, as well as their interaction. The nested experimental structure was accounted for by using three random effects: sample date, nested within paddock, nested within treatment (i.e. treatment/paddock/date).

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Results

Multi-farm survey - proportion of islets and arthropods

The proportion of the multi-farm survey fields covered by islets and the proportion of the five arthropod group populations in islets, estimated from the numbers collected and the relative area of islets, were in all cases found to show distributions that were not significantly different from normality, when tested with the Shapiro-Wilk normality test. Islets covered a median proportion of 0.25 of cattle grazed fields with a range of between 0.10 and 0.52 (Figure 2). The proportion of invertebrate abundance in islets was in all cases higher than 0.25 with median proportions in islets as follows: Araneae 0.45; Coleoptera 0.43; Diptera 0.52; Hemiptera 0.46; Hymenoptera 0.45 (Figure 2).

Multi-farm survey - Relationship between islet and non-islet sward height

The linear regression model of islet sward height (response) against non-islet sward height (explanatory) from the 26 sites, was highly significant ($F_{1,24}$=30.69 P<0.001, r^2=0.54). The model estimated an intercept of 5.95 and slope of 0.96. The standard error for the slope estimate was 0.17 with 95% confidence intervals ±0.36. Therefore a slope of unity is very close to and well within the 95% confidence intervals for the estimated slope.

Multi-farm survey – relative arthropod abundance in islets and non-islets

Modelling of the number of arthropods in the 26 pastures gave very similar results for all five groups. All models indicated that there were significantly more individuals collected in islets than in non-islet areas, and that there was a significant negative interaction between sward height and sub-habitat type (Table 1). In all models the interaction indicated that while there was a significant positive sward height effect for non-islet areas, there was no sward effect with islets themselves.

Multi-farm survey – site variables

The generalised linear models of the proportion of individuals collected in islets showed some similarity between the arthropod orders (Table 2). They indicated that for Araneae, Coleoptera, Hemiptera and Hymenoptera there were significant negative relationships with mean sward height (Figure 3). There were significant positive relationships with the proportion of the sward covered by islets for the Araneae, Hemiptera and Hymenoptera (Table 2). There were significant positive relationships with farm habitat diversity for Coleoptera and Hymenoptera (Table 2). For the Hemiptera there was a system effect with a greater proportion of individuals in islets in non-dairy than dairy sites. Models for the Diptera showed little similarity with those for the other orders, with a significant negative relationship with date, such that the proportion of Diptera in islets declined during the sampling period (Table 2). The minimal adequate model for Hymenoptera was the most complex and revealed several additional significant parameters. These were the proportion of non-cropped habitats and an interaction of non-cropped area and sward height (Table 2). The non-crop-sward interaction indicated that although there was a significant negative sward height effect, the strength of this decreased as the proportion of non-crop habitats increased.

Using model parameter estimates, and mean observed values for non-sward height variables, estimates can be made of the average proportion of arthropods collected within islets at the two extremes of sward height sampled, 5 cm and 12 cm (Figure 3). Proportions at 5 cm were as follows: Araneae 0.81, Coleoptera, 0.83, Hemiptera, 0.80 and Hymenoptera 0.81. At 12 cm the figures had fallen to: Araneae 0.61, Coleoptera 0.55, Hemiptera, 0.56, and Hymenoptera 0.57.

Pasture management experiment

Models of the proportional incidence of arthropods within islets, indicated that for the Araneae, Coleoptera (REPS treatment only), Hemiptera and Hymenoptera there were significant negative effects with sward height (Table 3). The models for Coleoptera and Hemiptera indicated significant treatment-sward height interactions. For both groups there was a strongly significant negative sward height effect in the REPS treatment, and in the conventional treatment there was no sward height effect. When modelling was repeated with Hemiptera data from which aphid nymph abundance had been subtracted there were no significant interactions with only sward height indicating a decline in the proportion of individuals in islets as sward height increased. In addition to sward height, treatment itself was significant for Coleoptera and Hemiptera, and in both cases the proportion of individuals in islets was greater for the REPS treatment than in the conventional.

Discussion

Grassland sward islets, areas of longer sward resulting from reduced grazing activity by cattle, were found to cover a mean proportion of 0.24 of the area of the 26 cattle pastures surveyed. This is very much within the range of islet cover reported from other studies, which ranged between 0.10 and 0.47 (Castle & MacDaid, 1972; Gibb *et al.*, 1997; MacLusky, 1960; Marsh & Campling, 1970; Tayler & Large, 1955; Tayler & Rudman, 1966). Previous studies of islets have mainly concentrated on their agronomic effects and here we make little comment from that perspective. However the relationship between sward height within and outside of islets does give support to the suggestion of MacDiarmid and Watkin (1972) that

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once islets are established grazing occurs on islets and non-islet sward. The regression indicated that the difference in sward height between islets and surrounding sward was 5.95 cm, compared to the 4.06 cm (given as 1.6 inches) reported by MacDiarmid and Watkin (1972) , and that the slope was very close to 1, suggesting that the difference in sward height remains constant across a range of mean sward heights.

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The main focus of this study was the arthropod populations associated with islets. Although islets covered a mean proportion of 0.24 of pastures, calculations from the numbers of arthropods collected and the relative area of islets indicated that the proportion of total arthropod populations found in islets varied between 0.45 and 0.54. Therefore it appears that approximately half the individual arthropods were concentrated in only a quarter of the area of the pastures. These figures were of course average findings from 26 fields in approximately the middle of the grazing cycle, and did not take into account the effect of changing sward height. However they do give an indication of the importance of islets in determining the distribution of arthropod populations within pastures. As such cattle, and similarly some other vertebrate herbivores, have an important role in terms of generating sward structural diversity and consequently enhancing arthropod and other forms of biodiversity (Davidson & Lightfoot, 2006; Knapp *et al.*, 1999).

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The greater numbers of all arthropod groups within islets, relative to non-islets, even with sward height included as a covariate, indicated that the concentration within islets was due to more than the sampling of an increased volume of habitat related to sward height. The longer sward of the islets may enhance the abundance of invertebrates through niche availability and microclimate, as has been suggested for grassland vegetation height more generally (Andrzejewska, 1965; Baines *et al.*, 1998; Bell *et al.*, 2001; Cattin *et al.*, 2003; Curry, 1987b; Morris, 2000; Morris & Lakhani, 1979; Morris & Rispin, 1987).

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The dung present at the centre of the islets may be directly attracting some species, particularly dung breeding species of Diptera and Coleoptera (Curry, 1987a; Skidmore, 1991). These in turn would attract their predators and parasites, including many staphylinid Coleoptera, some Araneae and many parasitoid Hymenoptera. The dung may provide an increase of nutrients such as nitrogen in the locality of the islet. This may be important in increasing the abundance of herbivores, particularly the sap-sucking Hemiptera, for which nitrogen is often limiting (Andrzejewska, 1976; Denno & Roderick, 1990; Olechowicz, 1976). Again, a greater abundance of herbivores will attract predators and parasites.

The longer sward may have an important effect on microclimate, buffering the effect of temperature variation and increasing humidity (Bossenbroek *et al.*, 1977a, b; D'Hulster & Desender, 1982; De Keer *et al.*, 1989; Luff, 1965b), which may be beneficial for a range of arthropods. The buffering of temperature may be particularly important in winter and islets may be a valuable overwintering site for some arthropods (D'Hulster & Desender, 1984; Dennis *et al.*, 1994; Desender, 1982). The humidity may be especially important for soil microarthropods, such as Collembola and Acari, and their many predators such as the staphylinid genus *Stenus* and Araneae of the family Linyphiidae (Curry, 1987a).

Spiders such as some of the Linyphiidae may also be dependent on the longer vegetation provided by islets for suitable sites for their webs (Bell *et al.*, 2001; Harwood *et al.*, 2003). The longer sward may provide additional feeding niches, for example flower and seed heads which are important for a range of Hemiptera and Coleoptera. There would also be a greater number of potential sites for leaf and stem mining species, which include many Diptera (Curry, 1987a). Of course islets may also provide a greater degree of shelter from vertebrate predators such as birds.

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Although islets were found to hold higher densities of arthropods than non-islet areas of sward, generalised linear modelling indicated that the proportion collected in islets relative to non-islet sward was related to several factors. The most important of these appeared to be mean sward height, followed by the percentage of sward covered by islets, and there was also some evidence for differences related to farm habitat diversity, percentage of non-crop habitat and agri-environment sward management. In the Araneae, Hemiptera and Hymenoptera there was a positive relationship between the proportion of the sward covered by islets and the proportion of individuals collected in islets. This was not due to a sampling effect as the two sub-habitats were sampled equally. Perhaps with a greater density of islets arthropods have greater chance to encounter an islet, and therefore more of the arthropods are located within them. In the Coleoptera and Hymenoptera there was a positive relationship between farm habitat diversity and the proportion of individuals collected in islets which could arise if farmers who have a more diverse farm structure were more tolerant of well defined islet structure.

The higher concentration of individuals of Coleoptera and Hemiptera within islets in the REPS system may indicate that lower intensity grazing systems generate greater level of small-scale heterogeneity. It is widely considered that heterogeneity is very important for conserving biodiversity (Benton et al., 2003; Morris, 2000; Woodcock et al., 2009). Thus islets together with other factors, such as vegetation diversity, may contribute to the aims of agri-environment schemes to restore biodiversity within agricultural systems.

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The proportion of Araneae, Coleoptera, Hemiptera and Hymenoptera collected from islets declined as the mean sward height increased. Estimates based on the generalised linear modelling indicated that at the extremes of sward height sampled, and given equal sampling in the two sub-habitats approximately 80% of arthropods would be found in islets when overall mean sward height was 5 cm but this would fall to about 59% in swards with a overall mean of 12 cm (equivalent to approximately 3% for each cm). Sward height data (Appendix Table 1) from eight of the paddocks at the Teagasc Grange field site, measured on 10 dates between May and September 2003, indicated that in only 8 out of 80 date-paddock combinations was the sward height greater than 12 cm. Therefore a high level of arthropod aggregation in islets is likely to remain through most if not all the grazing cycle. Nevertheless, the contrast of arthropod density between islets and non-islets was clearly reduced as the mean sward height increased between grazing events.

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What might explain the change in the contrast in relative density? Once established, islets can remain as distinct structures for many months (MacDiarmid & Watkin, 1972; Norman & Green, 1958). Although some grazing of islets does occur (MacDiarmid & Watkin, 1972; Marten & Donker, 1964a) they are generally much less disturbed than non-islet areas and thus can represent a long-term refuge of suitable habitat for many invertebrates, This constancy of resource can explain the lack of a sward height effect with arthropod abundance in islets. In contrast, non-islet sward is grazed and therefore disturbed to a much great extent. When strongly grazed the very short grass, rather analogous to a domestic lawn, is likely to be a poor habitat, with reduced ecological niches, food resources and altered microclimate (Helden & Leather, 2004; Morris, 2000). As grazed sward recovers from grazing, the suitability of the habitat will increase again. Recovery after grazing may well explain the positive response of arthropod abundance to sward height in the non-islet sub-habitat. Thus the contrast in the relative abundance between islets and non-islets is likely to be related to a change in the contrast of habitat suitability.

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The ecological constancy of islets means they have the potential to be refugia from grazing events. Humbert (2009) recently presented a very similar idea when proposing that

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un-cut patches should be left after mowing as a way of maintaining arthropod biodiversity in cut grasslands. Given this, the common and often, although not universally, recommended practice of topping (mowing) after grazing, to return a sward to a uniform height (Barry *et al.*, 2002; Boswell, 1971; Castle & MacDaid, 1972; MacLusky, 1960; Norman & Green, 1958), is likely to be detrimental to grassland arthropod biodiversity. Such topping is likely to lead to the death and/or migration of much of arthropod population (Humbert *et al.*, 2009).

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The purpose of this work is not to comment on the agronomic value or otherwise of topping but rather to comment from an ecological perspective. Given this and the apparent importance of islets for grassland arthropods, could other ecological benefits be accrued from encouraging islet structure in cattle pastures? Arthropods fulfil many roles in ecological communities: herbivores, detritivores, predators, as well as being food for many consumers at higher levels in food webs. They are also important at providing many ecosystem services beneficial to humans, such as predation and parasitism of pests, pollination, nutrient cycling and decomposition processes (Altieri, 1999). Therefore any management that promotes islets and so arthropod populations may be expected to have benefits to ecological community structure and processes. One specific benefit would be for farmland birds, for which there has been considerable concern over recent years due to widespread population declines linked to intensive farming practices (Krebs *et al.*, 1999; Robinson & Sutherland, 2002; Vickery *et al.*, 2001). Larger arthropod populations would provide a greater food supply for insectivorous birds. In addition the heterogeneous sward structure itself may be beneficial for birds. Ground feeding birds find prey more accessible in short swards but more abundant in longer swards and therefore the interface of longer and shorter swards, such as around islets, may be valuable foraging areas (Douglas *et al.*, 2009).

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Agricultural grasslands cover large areas of Ireland and other northern European countries (Anderson *et al*., 2008; Vickery *et al*., 2001). As such they have a role in the maintenance of biodiversity within the wider countryside, both as habitats in themselves and as a forming much of the matrix in which many other more species rich habitats such as semi-natural habitat fragments, hedgerows and field margins are embedded (Donald & Evans, 2006). Therefore any enhancement of grassland biodiversity at the local scale has the potential to have wider landscape consequences. It is therefore important that islets and other factors that operate at the local scale are understood more and that related biodiversity positive management options are encouraged.

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Table 1. Summary of linear mixed model (lme) comparisons of the abundance of arthropods in islets and non-islets, from the 26 sites of the multi-farm survey. Parameter estimates are given in log(ln) values. Degrees of freedom for the estimates of the slope parameter estimates

were 23; so for a given slope parameter the equivalent numerator and denominator d.f. (e.g. sward height) would be 1 and 23 degrees of freedom. Significance is indicated as: *** p<0.001, ** p<0.01, * p<0.05.

Arthropod group	Parameter estimates			
	intercept (non-islets)	islets	sward height	islet:sward height interaction
Araneae	2.539***	2.739***	0.176*	-0.213**
Coleoptera	1.986***	3.092***	0.203***	-0.257***
Diptera	3.336***	2.844**	0.195*	-0.214*
Hemiptera	2.568***	2.037***	0.229**	-0.184**
Hymenoptera	2.645***	2.210***	0.160**	-0.176***

Table 2. Minimal adequate models from generalised linear modelling (glm) of the proportion of arthropods (abundance in islets/total abundance) collected in islets at the 26 multi-farm survey sites. Parameter estimates given in terms of logits. The logit estimates (x) can be

converted to proportions as follows: exp(x) / (1+(exp(x)). Degrees of freedom (d.f.) are given; for a given slope parameter (e.g. Araneae sward ht) the equivalent numerator and denominator d.f. would be 1 and 23 degrees of freedom. Significance is indicated as: *** p<0.001, ** p<0.01, * p<0.05.

Arthropod group	Model	Parameter estimates (intercept ± explanatory variables)	d.f.	Deviance explained (%)
Araneae	~ sward ht + prop	2.665*** – 0.291*** + 2.868**	23	50.3
Coleoptera	~ habitat div + sward ht	2.223*** + 0.376* – 0.195***	23	67.0
Diptera	~ date	9.969** - 0.043*	24	23.6
Hemiptera	~ system + sward ht + prop	2.845*** + 0.445* – 0.335*** + 2.925**	22	63.6
Hymenoptera	~ non-crop + habitat div + sward ht + prop + non-crop:sward ht	2.466***– 5.810* + 0.434** – 0.327*** + 1.915** + 0.933**	20	76.7

Table 3. Minimal adequate models from generalised linear mixed modelling (lmer) of the proportion of arthropods collected in islets from the pasture management experiment (Teagasc Grange). Proportion of arthropods in islets (abundance in islets/total abundance)

with parameter estimates given in terms of logits. The logit estimates (x) can be converted to proportions as follows: exp(x) / (1+(exp(x)). Model structure was such that it was equivalent to having numerator and denominator degrees of freedom for parameter estimates of 1 and 4. ((2 treatments) – 1 = 1 ; (3 plots/treatment) – 1 = 2 x 2 treatments).

Arthropod group	Model	Parameter estimates (intercept ± explanatory variables)	Deviance explained (%)
Araneae	sward ht	1.000** - 0.032*	1.9
Coleoptera	treatment + sward ht + treatment:sward ht	1.595*** + 1.177* - 0.056 - 0.116**	38.1
Hemiptera (all individuals)	treatment + sward ht + treatment:sward ht	1.091*** + 1.256*** - 0.037* - 0.083**	20.1
Hemiptera (minus aphid juveniles)	sward ht	1.706*** - 0.095***	56.0
Hymenoptera	sward ht	1.362*** - 0.056***	9.8

Figure legends

Figure 1. A well defined islet in a cattle-grazed pasture

Figure 2. Boxplots showing the median proportion of the total overall populations from the multi-farm survey pastures of Araneae (aran), Coleoptera (col), Diptera (dipt), Hemiptera (hem) and Hymenoptera (hym) estimated to be found in islets. Proportion data were estimated from the numbers collected and the relative area of islets. Also shown is the proportion of field area covered by islets (islets) from the same 26 sites. Boxplots show the median values as the dark horizontal lines and figures; 25th and 75th percentiles as the top and bottom of the boxes. The dashed lines show either 1.5 times the interquartile range together with outliers as small circles, or if there are no outliers, the maximum and minimum values.

Deleted: ; and

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Figure 3. Change with sward height, in the proportion of all individuals of Araneae, Coleoptera, Hemiptera and Hymenoptera collected in islets at the multi-farm survey sites. For the Hemiptera the dashed line indicates non-dairy and the solid line dairy sites.

Appendix Figure 1. Location of the 26 multi-farm survey sites (closed circles) and the pasture management experiment at Teagasc Grange (open triangle).

Figure 1.

Figure 2.

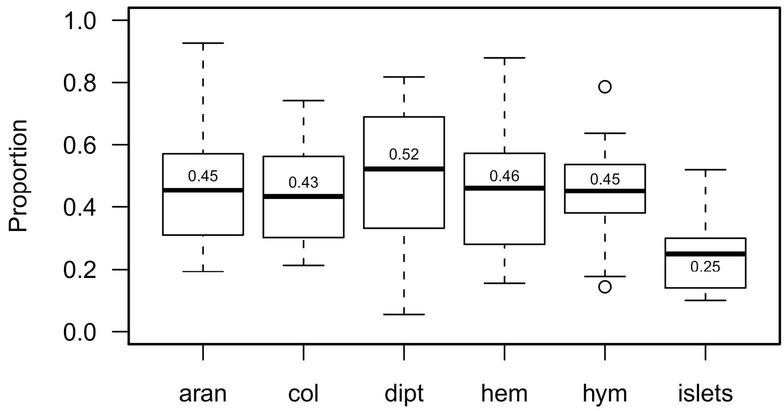
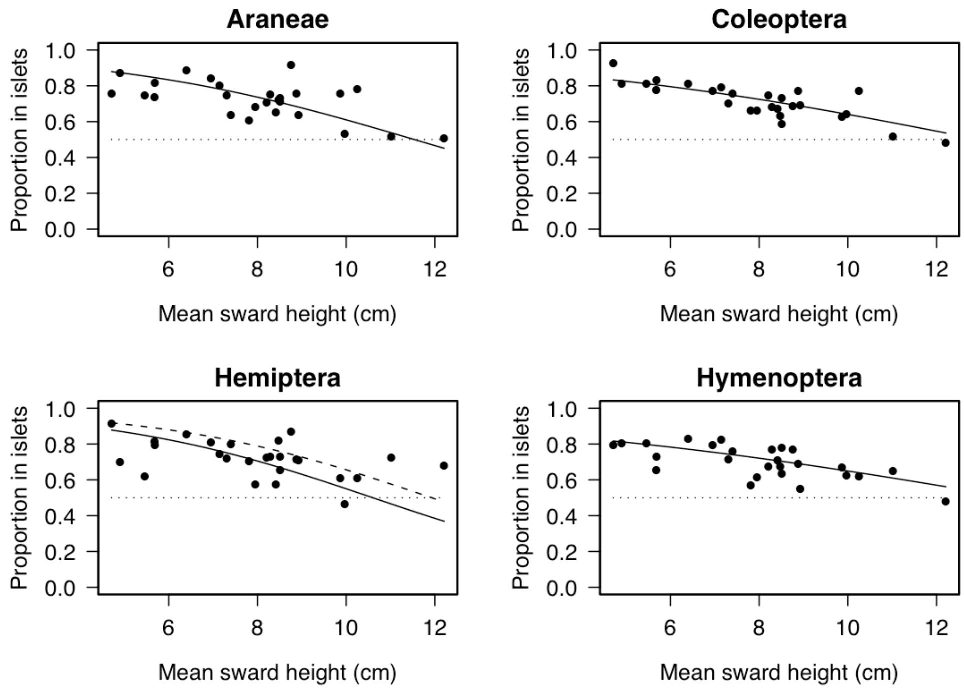

Proportion
1.0
0.8
0.6
0.4
0.2
0.0
0.45
0.43
0.52
0.46
0.45
0.25
aran
col
dipt
hem
hym
islets

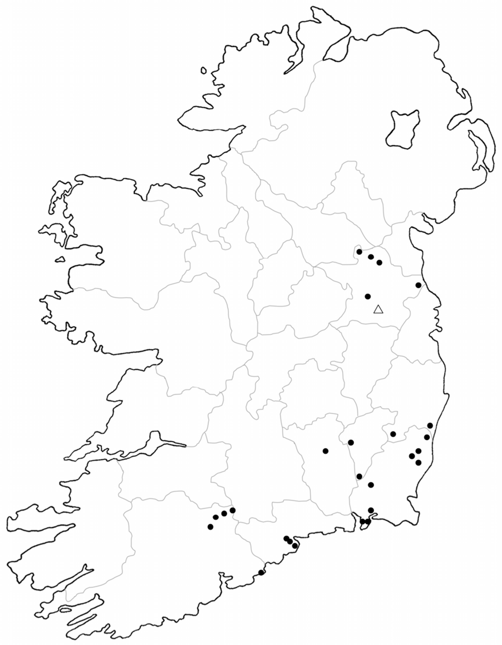
Figure 3,


Araneae
Coleoptera
Hemiptera
Hymenoptera
Proportion in islets
Mean sward height (cm)
0.0
0.2
0.4
0.6
0.8
1.0
6
8
10
12

Appendix Table 1. Mean sward height in eight of the Teagasc Grange paddocks on ten dates between May and September 2003. Values over 12 cm are shown in bold.

Paddock name	Date									
	7 May	27 May	11 June	17 June	3 July	15 July	30 July	14 Aug	26 Aug	9 Sept
Conventional M1	6.9	5.0	8.5	8.1	6.1	10.4	5.9	9.4	**14.0**	**14.7**
Conventional M2	7.2	4.9	9.0	10.5	7.5	8.7	5.6	10.0	**13.3**	**14.7**
REPS M1	8.6	4.2	9.0	9.0	7.4	7.3	**13.0**	6.3	9.9	11.2
REPS M2	7.2	6.1	8.1	10.2	6.9	11.0	**14.0**	7.3	10.3	11.2
Conventional F1	5.3	7.8	6.5	5.8	7.0	5.1	7.4	**12.7**	6.6	8.8
Conventional F2	5.2	6.0	5.4	3.7	5.7	9.3	6.4	**12.2**	6.6	7.0
REPS C1	5.4	6.7	4.9	5.0	8.7	9.8	5.1	8.9	5.0	6.7
REPS C2	5.9	6.8	6.4	5.9	6.7	9.2	5.5	9.2	5.6	5.4

Appendix Figure 1.



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