Title

Linear habitats across a range of farming intensities contribute differently to dipteran abundance and diversity

Running Title

Diptera and linear farmland habitats

Abstract

1. While the value of linear farm habitats for the protection and enhancement of farmland biodiversity in general is known, less is understood about their contribution to Diptera, especially those with different ecological requirements. In this study, we examined the impact of a range of linear farm habitats in agricultural grassland on Syrphidae and Sciomyzidae (Diptera) both of which are known indicators of wider aerial invertebrate taxa.

2. Species richness and abundance for each family were measured across five different linear habitat types (dense and open hedgerows with/without adjacent watercourses and watercourses only). While dense hedgerows with adjacent watercourses showed the greatest numbers of Syrphidae individuals and species, open hedgerows with adjacent watercourses had significantly more Sciomyzidae **individuals** and species than dense hedgerows without watercourses or open hedgerows only.

3. Syrphidae species richness was significantly correlated with the flowering plant species richness of linear habitats, while Sciomyzidae species richness was correlated with a habitat quality score for grasslands adjacent to the linear habitats.

4. Overall, Syrphidae and Sciomyzidae species richness and community composition are shown, for the first time, to reflect the "Ideal High Nature Value (HNV)" on-line tool used in this study to categorise the farms studied as extensive, intermediate or intensive with significantly greater species richness for both families on extensive farms.

5. The implications of the results of this study are discussed in the context of how we categorise farms for their value to biodiversity and how we assess the conservation value of linear farm habitats regarding current and future agri-environmental programmes.

Key words

Biodiversity, farmland habitats, hedgerows, watercourses, habitat quality, Syrphidae, Sciomyzidae, Bi-directional Malaise traps.

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Introduction

The global decline in biodiversity, due to anthropogenic activities, is now acknowledged (Brondizio et al., 2019), with approximately 60% of global ecosystems damaged or overexploited beyond their capacity to recover (Brickhill, 2015). Agricultural ecosystems, in particular, have been subject to significant increases in farming intensity, one of the primary causes of the rapid decline in farmland biodiversity over the past two decades (Benton et al., 2003; Larkin et al., 2019; Robinson & Sutherland, 2002). In Europe, agricultural area accounts for approximately 42% of total land (European Environment Agency, 2018) of which less than 40% is categorised as low intensity management (Eurostat, 2019). The intensification of agriculture has negatively affected not only farmland biodiversity but also associated ecosystem services, including those linked to food production such as pollination and biocontrol (Cole et al., 2020; Stoate et al., 2009).

Linear farm habitats (e.g. hedgerows, watercourses) have attracted considerable interest amongst conservationists in recent years due to their value as habitats for biodiversity (Brooks et al., 2012; Tattersall et al., 2002) and their role as wildlife corridors (Coulthard et al., 2016). Hedgerows in particular, provide valuable resources for wild bees (Ponisio et al., 2017; Stanley & Stout, 2014), butterflies (Cole et al., 2017) and dipteran families with high mobility such as hoverflies (Garratt et al., 2017; Haenke et al., 2014). Hedgerows are also considered as one of the most valuable semi-natural linear habitats on many farms, contributing significantly to the biodiversity of farmland (Baudry et al., 2000; Dover, 2019). On many intensive farming landscapes, they are the only remaining semi-natural habitat that can provide a valuable habitat for wildlife and deliver essential ecosystem services (Dover, 2019; Larkin et al., 2019). For this reason, hedgerows are given protection in several European countries including Ireland (Baudry et al. 2000) where hedgerows cover 4% of the total land area (Forest Service, 2018). Hedgerows can provide important food sources for pollinators and natural enemies during periods when crops are absent or not in flower (Cole et al., 2017; Dover, 2019). Moreover, hedgerows can provide additional resources including prey/hosts, shelter, breeding sites and protection from pesticides (Dover, 2019). Dense continuous hedgerows that are diverse in woody species and floral resources are generally considered to be good quality hedgerows and are recognised as important habitats for invertebrates with strong mobility such as bumblebees (Garratt et al., 2017; Volpato et al, 2019) and hoverflies (Garratt et al., 2017). However, little is known about the effect of dense hedgerows on flying insects with slow mobility (Burel et al., 2004) and studies on whether dense hedgerows can act as barriers to movement for weak flying insects (e.g. parasitoids) are lacking (Dover, 2019), particularly in agricultural lands with different levels of farming intensity.

Watercourses (e.g. streams, drainage ditches) on farmland can also provide valuable habitats as well as food sources to both aquatic and terrestrial invertebrates (including rare species), especially in dry and intensive farmlands where food sources are limited (Herzon & Helenius, 2008). In addition, they play an important role in habitat connectivity within wider landscapes and their function in regulating water flow and nutrient retention are likely to depend on the biological communities of watercourses (Herzon & Helenius, 2008). However, while good quality hedgerows (e.g. dense hedgerows) are known to support some invertebrate groups (Garratt et al., 2017; Graham et al., 2018), less is known about terrestrial invertebrates associated with watercourses (drains/streams) particularly the non-iconic insect groups (Kleijn & Van Langevelde, 2006). Moreover, studies evaluating the value of linear farm habitats for invertebrates often focus on individual habitats such as hedgerows or watercourses separately (Garratt et al., 2017; Kleijn & Van Langevelde, 2006; Wolton et al., 2014), whereas studies evaluating the combined effects of both habitats on farmland invertebrates are scarce (Speight, 2001).

While utilising invertebrates in the assessment of farm habitats for developing conservation strategies has been well investigated for some iconic insect groups such as bumblebees and butterflies (Carvell et al., 2007; Pywell et al., 2011), less is known about the use of other invertebrate groups such as Diptera in habitat assessments (Carey et al., 2017a). This is likely due to the greater abundance and diversity of Diptera, and the associated taxonomic challenges, in comparison with other taxa (Barnard, 2011). Including wider and less studied invertebrate groups such as Diptera in the assessment of conservation strategies could help in developing evidence-based measures with strong environmental effectiveness and cost-efficiency to protect and enhance biodiversity on farms. Moreover, Diptera are one of the most abundant animals in temperate habitats (Hughes et al., 2000) with almost 50% of all dipteran families containing flower-visiting flies or pollinators of at least 555 flowering plant species (Larson et al., 2001). Therefore, Diptera are one of the most important groups of pollinating organisms, second only to Hymenoptera, with both having a major contribution to plant diversity and agricultural production (Ssymank et al., 2008). In addition to pollination, Diptera have other important ecosystem services such as decomposition (Frouz & Šimek, 2009) and biological control of agricultural pests (Hynes et al., 2014b).

This study aims to fill current knowledge gaps by exploring the value of different types of linear farm habitats (individually or in combination) to insects, across a gradient of farming intensities, using adult Syrphidae and Sciomyzidae (Diptera), known indicators of wider invertebrate taxa in agricultural grassland (Carey et al., 2017a; Carey et al., 2017b). Both taxa co-exist within many of the same habitats; but have markedly different ecological requirements. Syrphidae are known as strong flyers (Dover, 2019; Speight, 2020), reflecting landscape scale effects, while Sciomyzidae appear to have limited movement (Williams et al., 2010), and reflect local scale differences. In addition, both fly families have important ecosystem services linked to food production in that adult Syrphidae are pollinators while the larval stages of many species act as predators of crop pests such as aphids (Speight, 2020). Other Syrphidae larval species contribute to dung breakdown and nutrient cycling (Speight, 2020). On the other hand, Sciomyzidae larvae feed primarily on molluscs, some of which act as intermediate hosts of liver fluke disease, and on pestiferous slug species (Hynes et al., 2014a,b & c; Knutson et al., 1965; Knutson & Vala, 2011). Adults of some Sciomyzidae species can also be minor pollinators (Stoffolano et al., 2015). In addition, adults of both fly families are characterized by their ease of collection, identification, and their ubiquity across a range of habitats (Speight, 1986).

With this in mind, the objectives of this study were to:

1. Evaluate different linear farm habitats (separately and in combination) in sustaining Syrphidae and Sciomyzidae, known indicators of dipteran diversity in agricultural grasslands.

2. Ascertain the role of habitat quality and other environmental variables in determining abundance, species richness and assemblages of each taxon.
3. Establish, for the first time, how these dipteran families reflect farm scale HNV farmland identification and address current thinking on the conservation value of farmland hedgerows.

Materials and methods

Site selection and classification

The study was conducted on farmland in the north-west of Ireland in County Sligo (Geographic Location: 54.1553° N, 8.6065° W; **Fig. S1**) as part of a larger project entitled "Farming and Natural Resources: Measures for Ecological Sustainability" or "FARM-ECOS". Mean annual temperature and precipitation in Sligo are 9.6°C and 1260.1 mm respectively (https://www.met.ie/, accessed 08/04/2020). Grassland (including rough grazing) accounts for approximately 99% of the farmed area of this study (www.cso.ie). Grass-based farms dominated by cattle and/or sheep grazing were classified according to land use intensity into extensive, intermediate, and intensive farms. Farm classification was based on the High Nature Value index (HNV) developed by Boyle, Hayes et al. (2015), which considers the area owned and farmed, the stocking rate, the proportion of improved grasslands and a visual assessment of the size of fields and linear habitats. The HNV score was calculated for each farm using the on-line tool "Is your farm HNV?" (http://www.high-nature-value-farmland.ie/is-your-farm-hnv/). The HNV scores obtained allowed us to classify the farms as: extensive (HNV index > 5; n=5); intermediate (HNV index between 3.5 and 5; n=5); and intensive farms (HNV index < 3.5; n=5).

In each of the three farming intensities, five categories of linear farm habitats were selected at field level for comparison as follows: a) Dense hedgerow with < 50% cover of gaps (DH); b) Open hedgerow with > 50% gap cover (OH); c) Dense Hedgerow with < 50% cover of gaps immediately adjacent to a watercourse (DH_W); d) Open hedgerow with > 50% cover of gaps immediately adjacent to a watercourse (OH_W); and e) Watercourse only (W) (Table S1 in Supplementary Information). For the purposes of this study, hedgerows were defined as woody components of a linear habitat (often associated with banks, walls, ditches or trees) with a maximum width of 4 m and with shrubs covering at least 25% of the length of a field (Foulkes et al., 2013). Gaps were defined as any area of hedgerow where woody species were absent in addition to spaces composed of brambles, walls, fences, non-structural hedgerow species e.g. climbers, and dead sections of hedgerow (Defra, 2007; Foulkes et al., 2013). Watercourses (ditches/streams) were defined as either channels created by humans (e.g. open drains) or watercourses resulting from natural processes (e.g. streams) (after Williams et al., 2004).

Sample collection and identification

Invertebrate sampling was conducted from May to September 2018 using Townes style bi-directional (or double headed) Malaise traps (Bastola et al., 2016; Macfadyen et al., 2015; Macfadyen & Muller, 2013; Samaranayake & Costamagna, 2018) protected from livestock by portable electric fences. In each of the five selected linear habitats across the three farming intensities, a pair of Malaise traps (as recommended by Speight et al. (2000)) were set up 2 m from the linear habitat (after Wolton et al. (2014)). Within a site, each pair of traps were placed 20 m apart (after Carey et al., 2017a), with trap pairs between sites at least 200 m apart after Gittings et al. (2006). This resulted in a total of 30 Malaise traps across farms, each with two collection bottles half filled with 70% ethanol, giving a total of 60 collection bottles. Each trap was positioned parallel to a linear habitat running in an east-west direction, with trap collection heads facing in an easterly direction thereby permitting catches from the linear habitats and open fields to be collected in separate collection heads (trap side - **Fig. S2**). Traps were activated on May 24th (2018) and insect samples were collected every two weeks until September 13th (2018) resulting in a total of 8 field visits and 480 samples. Vegetation immediately around the traps but inside the electric fences was cut periodically with a hand shears to maintain similar vegetation heights inside and outside the electric fences (Carey et al., 2017a).

All collected samples were stored in the laboratory for later identification. Samples were sieved through a fine mesh strainer (1 mm), and the remaining insects sorted to order and family level. Species of the families Syrphidae and Sciomyzidae, focal species for this study, were separated and subsequently identified to genus and species level using Ball and Morris (2015) and Stubbs and Falk (2002) for Syrphidae, and Rozkošný (1987) for Sciomyzidae. Sciomyzidae species were also compared with collected reference samples in the laboratory which were previously identified by taxonomic experts. A number of female syrphids were identified to genus only where identification to species level was not possible without male specimens (Table S2 & S3).

Environmental data

The quality of habitats was assessed using Rapid Assessment Cards (RACs) developed for each habitat type in both fields and linear habitats (Rotchés-Ribalta et al., 2020) and used to rate the ecosystem condition and provide a picture of the conservation status of habitats. Surveys of habitat quality in both grasslands and linear habitats involved the collection of several variables that were identified as indicators of environmental condition (e.g., vegetation structure, vegetation cover, height, shape of the hedgerow), habitat significance (e.g., number and cover of positive/negative indicators) and management pressure (e.g., visual assessment of the level of grazing or poaching pressure). Habitat quality surveys in grasslands were conducted while walking a "W" shaped route in fields, as recommended in the RBAPS assessment (Maher et al., 2018b). For linear habitats, the quality surveys were conducted along 30 m length; two surveys were conducted when a linear habitat was > 80 m long (Foulkes et al., 2013). From the RACs, a score of quality was obtained for each habitat, which was scaled between 0 and 1, with 0 being the lowest quality habitat and 1 the highest quality (see Rotchés-Ribalta et al., 2020). The number of flowering plant species (flowering plant species richness) in the linear features and in the grassland was recorded at each site. Soil samples were also collected within each trap location on November 6th (2018) using a standard soil auger (Eijkelkamp) and stored in a cold room (4°C) prior to processing. Soil organic matter, pH and soil moisture content were measured within five days of sampling following British Standards protocols (BSI, 1990).

Data analysis

A total of 420 samples from 7 collections were included for data analysis (excluding 60 samples from 21st of June due to trap damages by Storm Hector). Prior to performing statistical analysis, abundance and species richness data were combined for all the 7 sampling periods (separately for the linear and field side of the traps). Species area curves calculated for Syrphidae and Sciomyzidae showed adequate trapping effort for both species (Fig. S3).

Univariate analysis (IBM, SPSS Statistics v.24) was undertaken using Generalized Linear Mixed Models (GLMMs) with Poisson distribution and log link function to examine the effects of linear habitat type, farming intensity and trap side on species richness and abundance of Syrphidae and Sciomyzidae. To account for the nonindependence of trap side and trap numbers per site, trap side was nested within the random factor trap ID, and trap numbers nested within site ID in all the models. Post-hoc pairwise comparisons were conducted thereafter to determine the individual effects of linear habitat types and farming intensity on Syrphidae and Sciomyzidae (abundance and species richness). Model fitness were validated by analysing and verifying normality of residuals. We excluded the interaction terms between linear habitats and farming intensity in the models (after Volpato *et al.*, 2019) due to the low number of linear habitat types per farming intensity category (n = 1). Given that the environmental variables did not follow a normal distribution, we used nonparametric Kruskal-Wallis test followed by Bonferroni's pairwise comparison corrected for multiple ties to compare environmental variables measured across categories of farming intensities and farm linear habitats. In addition, Spearman’s rank correlation coefficient was used to determine the correlations between taxa abundance, richness and environmental variables. All univariate data were analysed at the $P < 0.05$ standard level of significance.

Prior to multivariate analysis, species data was log10(x +1) transformed to reduce the influence of very abundant species (Carey et al., 2017a; Schirmel et al., 2018). Moreover, an outlier analysis was performed in PC-ORD v.6 and no faunistic outliers with > 2.0 standard deviations were detected. Samples (traps) were also examined for extreme outliers with standard deviations > 3.0 using the Sørensen distance measure (after Carey et al., 2017a) and no potential outliers were detected among the samples in each site. Permutation-based Multivariate Analysis of Variance (PERMANOVA) was utilised to test the effects linear habitat type and farming intensity on the similarity within both taxa communities using PRIMER (v.7.0.13) with the PERMANOVA add-on (Anderson et al. 2008). Trap sides nested within the random factor trap ID, and trap ID within site ID in the analysis and we used Sørensen as a distance measure with 999 permutations. Non-metric multidimensional scaling (NMS) ordinations (McCune et al., 2002) of samples was undertaken to understand the community structure of both taxa at each farming intensity using the Sørensen distance in PC-ORD v.6 (McCune & Mefford, 2011). The number of significant axes was determined through 250 runs of real data to 250 runs with randomised data. An orthogonal principal axis output was selected for each NMS to illustrate maximum community variation along axis 1. Environmental data were utilised as a second explanatory matrix and variables with Pearson R^2 values > 0.2 overlain as a biplot (McCune and Mefford, 2011). Multi Response Permutation Procedures (MRPP), which are also non-parametric procedures for testing the hypothesis of no difference between two groups, were utilized to test for significant difference between habitat types based on the species composition of each assemblage (McCune and Mefford, 2011).

Results

General results

A total of 9,047 adult Syrphidae and Sciomyzidae insects were captured during the study (excluding June 21st samples), representing a total of 8,774 individuals of Syrphidae and 273 Sciomyzidae. Seventy-six species of Syrphidae representing 41.3% of all known Irish species and 17 species of Sciomyzidae representing 28.3% of all known Irish species (Chandler et al., 2008; Maher et al., 2018a) were captured. The dominant syrphid species were *Helophilus pendulus* (L.), 1758 (13%), *Platycheirus clypeatus* (Meigen), 1822 (12%), *Platycheirus granditarsus* (Forster), 1771 (11%) and *Eupeodes latifasciatus* (Macquart), 1829 (10%) comprising 46 % of the total syrphid catches. The dominant sciomyzid species were *Tetanocera arrogans* (Meigen), 1830 (21%), *Renocera pallida* (Fallén), 1820 (18%), *Tetanocera elata* (Fabricius), 1781 (15%), and *Tetanocera ferruginea* (Fallén), 1820 (13%) comprising 67% of total sciomyzid catches (Tables S2 & S3 in Supplementary Information).

Taxa response to linear habitats and farming intensity

Overall Sciomyzidae abundance and species richness across all farming intensities (Fig. 1; Tables 1/S4) were greatest in open hedgerows with adjacent water courses (OHw). While Sciomyzidae abundance and species richness were significantly greater in open hedgerows with adjacent watercourses (OHw) and watercourses only (W) than in either dense hedgerows (DH) or open hedgerows (OH), there were no significant differences between dense hedgerows with adjacent watercourses (DHw) and dense hedgerows (DH) / open hedgerows (OH) (see Table S4 for *P* values). In contrast, while Syrphidae abundance and species richness was greater in dense hedgerows with adjacent watercourses (DHw), no significant differences across categories of linear habitat types were detected (Fig. 1; Table 1).

A comparison of farming intensities (Tables 1/S5, Fig. 2) showed that Sciomyzidae and Syrphidae species richness were significantly greater in extensive than in either intermediate (P <0.01; P <0.001 respectively) or intensive farms ($P < 0.001$; $P < 0.001$ respectively). In addition, Syrphidae abundances, while following a similar pattern, were not significantly different across farming intensities but Sciomyzidae abundances (Tables 1/S5, Fig. 2) were significantly greater on extensive than on either intermediate ($P < 0.001$) or intensive ($P < 0.001$) farms.

Taxa response to environmental variables and habitat quality

The environmental variables measured throughout the study differed across categories of farming intensities. Mean percentage soil moisture was significantly greater in extensive farms in comparison to intermediate ($P = 0.03$) and intensive farms ($P = 0.04$; Tables 2 & S6). Moreover, mean percentage soil organic matter was also significantly greater in extensive than intensive farms ($P = 0.03$; Tables 2 & S6). Of all environmental variables, Syrphidae species richness was significantly correlated ($P = 0.04$) with linear habitat flowering plant species richness only (Table 3). Sciomyzidae, on the other hand, were correlated with adjacent grassland flowering plant species richness (P = 0.04 abundance) and the grassland habitat quality score (P < 0.01 abundance; P = 0.03 species richness). Structural elements contributing to the grassland habitat score which had significant positive correlations with Sciomyzidae (Table 3) included vegetation structure (abundance, P < 0.001; richness, P = 0.02), encroaching scrub (abundance, P < 0.01) and plant litter (abundance, P = 0.04). Sciomyzidae abundance and richness were also significantly correlated with percentage soil moisture (P < 0.001, P < 0.01 respectively) and soil organic matter (P < 0.01, P = 0.01 respectively).

Community Analysis

Permutation-based Multivariate Analysis of Variance (PERMANOVA) showed that farming intensity and linear habitat types had a significant effect on the similarity of both taxa communities (Table 4). NMS ordination biplots (Figs. 3a & b) show a two-dimensional solution for both taxa with stress values less than 11, where values of about 10 are known to indicate a good ordination with little chance of false inferences (McCune and Mefford, 2011). Environmental variables with Pearson R^2 values of > 0.2 are shown as biplots (Fig. 2). MRPP analysis showed significant differences in community structure for both taxa in relation to farming intensity. Farming intensity was a significant grouping variable in both the Syrphidae and Sciomyzidae species matrices (A = 0.08, P = 0.008; A = 0.07, P = 0.046 respectively). In addition, the community composition of Syrphidae was positively (R^2 > 0.02) correlated with the grassland habitat score, percentage soil moisture and percentage soil organic matter in extensive farms while the species composition of intermediate and intensive farms was similar with some degree of overlap (Fig. 3a). For Sciomyzidae communities, however, there was some overlap between all three farm types but with positive correlations ($R^2 > 0.02$) with grassland habitat score (Fig.3b).

Discussion

While the incorporation of linear habitats to counteract biodiversity decline on farmland has already been proposed (Brooks et al., 2012; Garratt et al., 2017; Schirmel et al., 2018; Tattersall et al., 2002), much remains unknown about its impact on specific insect species and communities, particularly on livestock-based grassland systems of different intensities. Moreover, the conservation of invertebrate diversity in agricultural lands requires that invertebrate indicators (particularly non-iconic groups which generally receive less attention) be incorporated in assessment methodologies at field and farm level to understand and predict biodiversity (Plantureux et al., 2005). This study was designed to examine the response of adult Syrphidae and Sciomyzidae, indicator species with different ecological requirements and ecosystem functions, to different linear farm habitats and to ascertain whether levels of farming intensity classified primarily on the basis of physical features and farming practices also reflect these insect indicator species.

Taxa response to linear habitats

The results of this study demonstrate that different types of linear habitats contribute differently to selected dipteran abundance and diversity in agricultural grassland. Both taxa demonstrated different responses to linear habitat types with mean Sciomyzidae species richness being significantly greater at open hedgerows with an adjacent watercourse than dense hedgerows or open hedgerows only. In contrast, there was no significant difference between dense hedgerows with an adjacent watercourse and dense / open hedgerows only. This finding is particularly important in the context of current advice on best practice for hedgerow maintenance, i.e. keeping the shrub layer dense ((Hedgelink leaflet (2013) - www.hedgelink.org.uk)) or in hedgerows being assessed as less favourable on the basis of increased gappiness (Foulkes et al., 2013). In the case of Sciomyzidae which are relatively sedentary (Williams et al., 2010), it is possible that dense hedgerows could inhibit their movements across habitats as has been suggested for other weak flying insects, particularly parasitoids (Dover, 2019) although this would need to be substantiated for Sciomyzidae using suitable mark-recapture methods (Williams *et al.*, 2010).

While Sciomyzidae (abundance and species richness) showed no significant correlations with linear habitat quality in this study, significant correlations were detected with overall grassland habitat quality and good vegetation structure in adjacent grassland fields (i.e. >50% of the field having a heterogeneous vegetation structure). This is supported by previous studies where Sciomyzidae (as well as other dipteran families of grassland – Ryder et al., 2005) have been shown to demonstrate positive correlations with vegetation structure, particularly taller vegetation (Maher et al., 2014; Ryder et al., 2005; Williams et al., 2009a; Williams et al., 2009b). In this study, heterogeneous vegetation structure is likely to be a result of the less intensively managed, wetter fields carrying lower stocking densities than the more improved fields with drier soils. In addition, the positive correlations with longer flooding periods of many Sciomyzidae species (Maher et al., 2014; Williams et al., 2009b) which feed on aquatic / semi-aquatic snails during the larval stage, further substantiates the need for wetter conditions (including adjacent watercourses) for many species of this family. The significant correlation of Sciomyzidae abundance with plant litter probably reflects the greater litter depths commonly found in wetter, seasonally flooded grasslands. In addition, the correlation of Sciomyzidae abundance with scrub encroachment likely reflects similar conditions to those of open hedgerows, i.e. providing some shelter but with gaps for ease of movement. Since dense hedgerows adjacent to watercourses in this study do not have significantly greater Sciomyzidae species richness/abundances than dense/open hedgerows while open hedgerows with adjacent watercourses/watercourses only do, further work is required to fine tune the advice currently given to landowners on the maintenance of hedgerows, particularly those adjacent to water bodies.

In contrast to Sciomyzidae, the abundance and species richness of Syrphidae captured were greater (although not significantly) in dense hedgerows adjacent to watercourses than in other linear habitat types. Dense continuous hedgerows, which are diverse in plant species and structure, have been shown to provide valuable resources to Syrphidae as for other strong flying insects such as bumblebees (Garratt et al., 2017). They are unlikely to inhibit Syrphidae movement across habitats since Syrphidae are capable of long-distance migrations (Dover, 2019). This may explain why Syrphidae abundance and species richness showed no significant differences between linear habitat types including dense hedgerows. However, it is noteworthy that dense hedgerows adjacent to watercourses are likely to provide multiple resources for Syrphidae, particularly standing water in addition to dead wood, litter, sap runs, host plants and damp holes important for larval development (e.g. saprophagous species) (Schirmel et al., 2018), explaining, at least in part, greater (albeit non-significant) Syrphidae abundance and species richness in dense hedgerows adjacent to watercourses. In addition, the proportion of Syrphidae captured on the linear habitat side on intensive farms (27% greater than on the field side) was comparatively larger than that on intermediate and extensive farms (< 15%), indicating the likely importance of linear habitats on intensive farms where less nectar resources would be available in the adjacent intensive grasslands. Linear habitats would also play an important role by providing shelter (Sutherland et al., 2001), overwintering sites

(Hondelmann & Poehling, 2007) and protection from agrochemical applications (Schirmel et al., 2018), particularly on intensive farms.

Taxa response to farming intensity

Species richness of both taxa showed a significant decline with increasing farming intensity; suggesting that farming intensification is a primary driver in reducing species richness of both families. Syrphidae are known to be positively influenced by pollen and nectar as food sources (Ricarte et al., 2011) and this is likely reflected by greater (albeit non-significant) flowering plant species richness in extensive farm grasslands. Sciomyzidae, on the other hand, are more likely to be influenced by the vegetation structure (i.e. taller plants) and wetter soils, found on the extensive farms (Maher et al., 2014; Ryder et al., 2005; Williams et al., 2009a; Williams et al., 2009b). A similar trend was observed in terms of the number of individuals captured for both families, but only Sciomyzidae abundance showed significant declines in abundance with increasing farming intensity. More than 70% of total Sciomyzidae species found in this study are hygrophilous in their larval stages, feeding on either on freshwater snails at or below water surface and/or semi-terrestrial snails, or on fingernail calms and pea mussels beneath the water surface (Knutson & Vala, 2011; McDonnell et al., 2010; Williams et al., 2007). This, coupled with the limited distances (up to 25 m) adult Sciomyzidae may travel (Williams et al., 2010), is likely to reflect their overall preferences, at a local scale, for grassland fields with good habitat quality (particularly good structural condition and low management pressure), wetter and more organic soils associated with the grasslands of more extensive farms. Many Syrphidae, on the other hand, are strong flyers (Dover, 2019; Speight, 2020) and polylectic as adults (Speight, 2020) visiting flowers in a wide range of habitats that can be far from their breeding sites (Ball & Morris, 2015; Speight, 2020). This may explain why Syrphidae abundance showed no significant response to farming intensity and associated environmental variables at a local scale.

Community analysis

In addition to abundance/species richness, farming intensity also showed a significant effect on the similarity of both fly family communities as explained by MRPP analysis. Moreover, NMS analysis shows that extensive farms are characterised by specific environmental conditions that are likely to play important roles in shaping the community composition of each family. NMS analysis indicates that grassland quality score, % soil moisture and % organic matter are important environmental variables playing a role in shaping Syrphidae species assemblages. This is in line with previous studies that showed intensively managed fields with poor-quality habitats are unlikely to provide valuable resources to sustain insect pollinators (Cole et al., 2020) including Syrphidae (Rotheray, 1993). In addition, other studies have also demonstrated that drainage along with high stocking rates and fertilizer inputs in intensive farms result in reduced soil moisture and organic matter (Plantureux et al., 2005) with intensive grazing causing habitat loss through the removal of ground vegetation and organic matter as well as soil compaction (Yadamsuren et al., 2015). Practices such as these coupled with greater levels of agrochemical inputs in intensive farms have also been shown to limit resource availability for many invertebrates (McMahon et al., 2012) and reduce plant and invertebrate species richness in general (Klimek et al., 2007; Zechmeister et al., 2003). On the other hand, Sciomyzidae communities were positively correlated with the grassland habitat score. Moreover, there were overlaps in Sciomyzidae species assemblages between all farm categories that can be explained by some extensive fields being located within a farm classified overall as intensive or intermediate. This demonstrates that the retention of extensive or wet grassland fields even within intensive farms can provide valuable habitats to sustain Sciomyzidae assemblages at small spatial scales. This agrees with the study by Carey et al., (2017a) who have demonstrated that Sciomyzidae communities in grassland habitats can vary at small scales of up to 20m.

Management implications

Overall, our results indicate that both taxa species richness reflect the broad scale HNV farm classification used in this study to categorise farms as extensive, intermediate, and intensive farms with greater species richness for both fly families on extensive farms. This reinforces the importance of HNV farms for biodiversity conservation in general and is particularly important for dipteran conservation on farmland. Nevertheless, since HNV farm classification considers not only farm management but also a visual assessment of the size of fields and linear habitats, careful considerations should also be taken at smaller scales since different linear habitats within fields/farms seem to contribute differently to dipteran abundance and diversity. While it is known that dense continuous hedgerows are generally considered as good quality hedgerows with valuable resources for insect pollinators (Garratt et al., 2017; Volpato, 2019), other, less mobile aerial invertebrates with important ecosystem functions, appear to have different requirements. Hence, hedgerows, irrespective of perceived quality, and particularly those deemed 'gappy' adjacent to watercourses, appear, in this study, to be of value to biodiversity. This is particularly important in the context of current agricultural Environmental Impact Assessment (EIA) regulations in Ireland which allow for up to 500m of boundary to be removed without assessment ((Environmental Impact Assessment) (Agriculture) Regulations 2011)). Under current regulations, therefore, hedgerows with significant value to biodiversity are likely to be lost if such regulations are not improved to protect these valuable habitats.

Discussions, based on the sound scientific evidence of multiple studies, regarding advice to farmers in Ireland under the current Agri-Environment Scheme (Green, Low-carbon Agri-Environment Scheme (GLAS)) to maintain dense hedgerows, will be required to infom future schemes under the new EU common agricultural policy (2021-2027) to facilitate those less mobile species (including those with conservation value) adversely affected through habitat loss and resource decline (Graham et al., 2018). It is likely that consideration to supporting a mixture of both open and dense hedgerows adjacent to watercourse is required (diversity within and between habitats), with particular attention given to spatial scales and management heterogeneity over both time and space (Graham et al., 2018).

Conclusions

Our results indicate that linear habitats irrespective of perceived quality, particularly those hedgerows deemed 'gappy' adjacent to watercourses, are of significant value to biodiversity. This could have important implications for future design and implementation of agri-environment schemes by considering the heterogeneity of linear habitats (i.e. not only dense hedgerows but also a diverse range of boundary types) across different farming intensities. In addition, our results show that farmland intensity as indicated by the HNV score is an important driver of overall pattern and community composition of both dipteran families investigated in this study. Nevertheless, enhancing habitat quality within and between farms appears to be a key message for conservation of dipteran diversity in farmland and in supporting their ecosystem functions. Thus, future agri-enviroment schemes should also incentivise low intensity farming since it is likely to generate favourable conditions to promote habitat quality and subsequently support invertebrate diversity in agricultural lands.

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Table 1: Overall effects of farming intensity, linear habitat type and trap side on the abundance and species richness of Syrphidae and Sciomyzidae. Bold numbers indicate significant differences (GLM and independent sample t test, P<0.05)[1].

	Farming intensity			**Linear habitat type**			**Trap side**		
	df	*Wald*	*P*	*df*	*Wald*	*P*	*df*	*f*	*P*
Abundance									
Syrphidae	2	4.127	0.127	4	3.984	0.408	1	1.309	0.236

Sciomyzidae	2	29.507	**<0.001**	4	8.312	0.081	1	0.049	0.652
Richness									
Syrphidae	2	14.136	**0.001**	4	8.404	0.078	1	0.923	0.476
Sciomyzidae	2	12.777	**0.002**	4	20.636	**<0.001**	1	0.334	0.573

[1]Due to the low number of linear habitat types per each farming intensity (n=1), it was not possible to include the interacting effects of farming intensity and linear habitat types in the model.

Table 2: Environmental variables (mean ± SD) measured throughout the study across categories of farming intensities and farm linear habitats. Linear habitat types are categorised as: Dense hedgerow (DH), Open hedgerow (OH), Dense hedgerow with adjacent watercourse (DH_W), Open hedgerow with adjacent watercourse (OH_W) and watercourse only (W). Different letters indicate significant differences (p<0.05) between each category using the Kruskal-Wallis test followed by Bonferroni's pairwise comparison corrected for multiple ties (see Table S7 for *P* values).

		Linear habitat score	**Grassland habitat score**	**Flowering plant species richness/linear habitat**	**Flowering plant species richness/grassland habitat**	**% Soil moisture**	**% Soil organic matter**	**pH**
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Farming intensity	Extensive (n=5)	0.34 ± 0.16	0.69 ± 0.07	15.20 ± 9.01	20.40 ± 8.91	**61.90 ± 12.09[a]**	**25.36 ± 13.15[a]**	5.7 ± 0.88
	Intermediate (n=5)	0.59 ± 0.12	0.40 ± 0.37	11.20 ± 3.42	14.20 ± 10.26	**36.32 ± 9.41[b]**	**12.58 ± 4.44[ab]**	6.3 ± 0.84
	Intensive (n=5)	0.48 ± 0.15	0.34 ± 0.27	10.00 ± 0.71	9.20 ± 5.72	**36.95 ± 9.41[b]**	**10.01 ± 3.04[b]**	6.2 ± 0.93
Linear habitat type	DH (n=3)	0.42 ± 0.07	0.22 ± 0.34	12.33 ± 2.88	15.67 ± 10.05	34.61 ± 7.94	12.35 ± 5.12	5.38 ± 0.46
	DH_W (n=3)	0.63 ± 0.07	0.48 ± 0.35	10.00 ± 0.89	8.67 ± 3.72	44.13 ± 10.82	14.17 ± 4.28	7.24 ± 0.82
	OH (n=3)	0.42 ± 0.06	0.42 ± 0.25	12.33 ± 1.37	10.33 ± 2.25	40.50 ± 21.25	9.50 ± 4.05	5.66 ± 0.39
	OH_W (n=3)	0.50 ± 0.15	0.37 ± 0.20	15.67 ± 11.91	16.67 ± 5.82	48.58 ± 12.88	19.35 ± 10.43	6.18 ± 0.62
	W (n=3)	0.39 ± 0.28	0.74 ± 0.16	10.33 ± 1.37	22.33 ± 14.38	57.43 ± 14.91	24.56 ± 15.99	5.82 ± 0.65

Table 3: Spearman's rank correlation coefficient between Syrphidae / Sciomyzidae abundance / species richness and environmental variables. Numbers in bold indicate significant correlations (P<0.05). Variables for the grassland habitat quality score subcategory (structural condition) are presented in italics.

	Syrphidae				Sciomyzidae			
	Abundance		Richness		Abundance		Richness	
	Corr. Coef.	*P*	*Corr. Coef.*	*P*	*Corr. Coef.*	*P*	*Corr. Coef.*	*P*
Flowering plant species richness/linear habitat	0.417	0.122	0.532	**0.041**	0.254	0.362	0.063	0.822
Flowering plant species richness/grassland habitat	0.014	0.959	0.060	0.830	0.537	**0.039**	0.380	0.162
Linear habitat score	0.068	0.810	0.039	0.889	-0.261	0.348	-0.140	0.619
Grassland habitat score	0.151	0.591	0.389	0.151	0.777	**0.001**	0.562	**0.029**
Vegetation structure	0.160	0.570	0.471	0.077	0.851	**<0.001**	0.060	**0.018**
Cover of ground flora	-0.253	0.364	-0.206	0.460	-0.262	-0.345	0.040	0.888
% Encroaching scrub	0.264	0.342	0.407	0.132	0.725	**0.002**	0.418	0.121
Plant litter	0.191	0.496	0.331	0.228	0.524	**0.045**	0.429	0.111
% Soil moisture	0.236	0.398	0.335	0.193	0.863	**<0.001**	0.698	**0.004**
% Soil Organic matter	0.225	0.420	0.390	0.164	0.739	**0.002**	0.714	**0.003**
Soil pH	0.261	0.348	0.264	0.342	-0.059	0.834	0.025	0.928

Table 4: PERMANOVA results testing the effects of farming intensity, linear habitat type and trap side with their interactions on the similarity of Syrphidae and Sciomyzidae communities. Numbers in bold indicate significant differences (P<0.05).

Source	*d.f.*	*SS*	*MS*	*F*	*P*
Syrphidae					
Farming intensity	2	0.89191	0.44595	3.5722	**0.0008**
Trap side	1	0.13401	0.13401	1.0734	0.3438
Interactions	2	0.12276	0.61382E-01	0.4917	0.9612
Residual	24	2.9962	0.12484		
Total	29	4.1449			
Linear habitat	4	0.52236	0.13059	0.80583	0.7466
Trap side	1	0.13401	0.13401	0.82691	0.5476
Interactions	4	0.24735	0.61838E-01	0.38158	1.0000
Residual	20	3.2412	0.16206		
Total	29	4.1449			
Sciomyzidae					
Farming intensity	2	1.7353	0.86766	2.6517	**0.0018**
Trap side	1	0.13E-01	0.13E-01	0.39E-01	0.9998
Interactions	2	0.22045	0.11022	0.33686	0.9976
Residual	24	7.8530	0.32721		
Total	29	9.8216			
Linear habitat	4	2.0696	0.51740	1.4484	0.0678
Trap side	1	0.13E-01	0.13E-01	0.36E-01	1.0000
Interactions	4	0.59475	0.14869	0.41623	0.9998
Residual	20	7.1444	0.35722		
Total	29	9.8216			

Table 5: Indicator Species Analysis showing significant (P<0.05) Syrphidae species response to farming intensity.

Farming intensity	***Maxgrp Value***	***IV***	***Mean***	***SD***	***P***
Eristalis arbustorum	Intermediate	66.7	28.6	12.16	**0.0352**
Leucozona lucorum	Intensive	55.6	34.3	10.63	**0.0456**

Figures

Fig. 1 Mean total abundance and species richness of Syrphidae and Sciomyzidae collected per site at each of the five categories of linear habitat type*: (a) Syrphidae abundance, (b) Syrphidae species richness, (c) Sciomyzidae abundance and (d) Sciomyzidae species richness. Columns annotated with the different letters are significantly different within each separate category (GLM followed by LSD pairwise comparisons, $P < 0.05$).

* DH=dense hedgerow, OH=open hedgerow, DH_W=dense hedgerow + watercourse, OH_W= open hedgerow + watercourse and W=Watercourse only.

Fig. 2 Mean total abundance and species richness of Syrphidae and Sciomyzidae collected per site at each of the three-farming intensities: (a) Syrphidae abundance, (b) Syrphidae species richness, (c) Sciomyzidae abundance and (d) Sciomyzidae species richness. Columns annotated with the different letters are significantly different within each separate category (GLM followed by LSD pairwise comparisons, $P < 0.05$; Table S5 & S6).

Fig. 3 Non-metric multi-dimensional scaling ordination of traps in (a) Syrphidae and (b) Sciomyzidae species-space. For Syrphidae: first two axes explain 94.2 % of the variation (75.4% axis 1 and 18.8% axis 2) with an orthogonality of 100%. Farming intensity is a significant grouping variable ($P = 7.5 \times 10^{-3}$) and explains approximately 8 % of the variation in the species matrix (MRPP chance-corrected within-group agreement A). For Sciomyzidae: first two axes explain 89.2% of the variation (49.6% axis 1 and 39.6% axis 2) with an orthogonality of 100%. Farming intensity is a significant grouping variable ($P = 4.6 \times 10^{-2}$) and explains approximately 6.7 % of the variation in the species matrix (MRPP chance-corrected within-group agreement A).

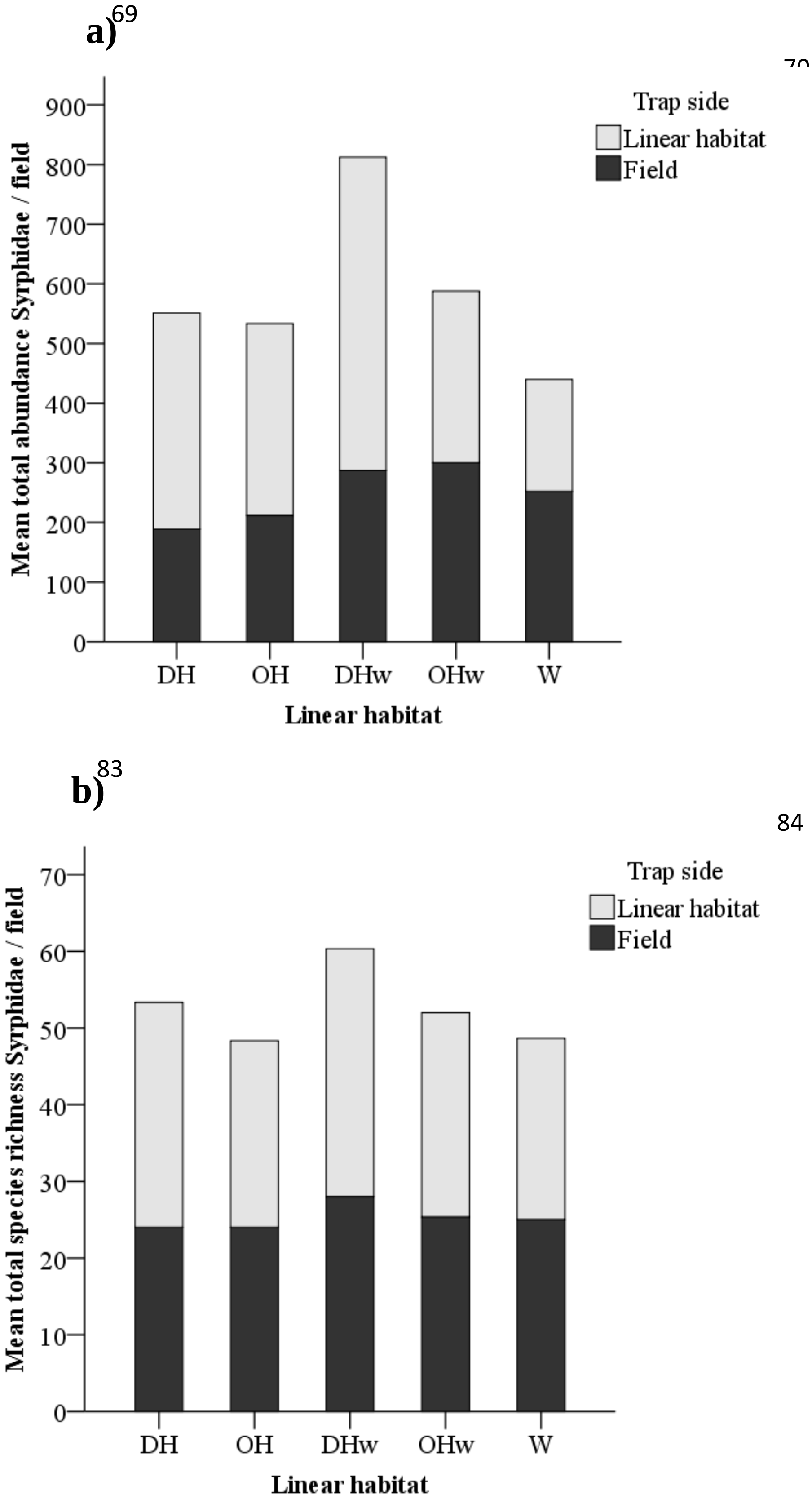

a)
Trap side
Linear habitat
Field
Mean total abundance Syrphidae / field
0
100
200
300
400
500
600
700
800
900
DH
OH
DHw
OHw
W
Linear habitat
b)
Trap side
Linear habitat
Field
Mean total species richness Syrphidae / field
0
10
20
30
40
50
60
70
DH
OH
DHw
OHw
W
Linear habitat

Fig. 1

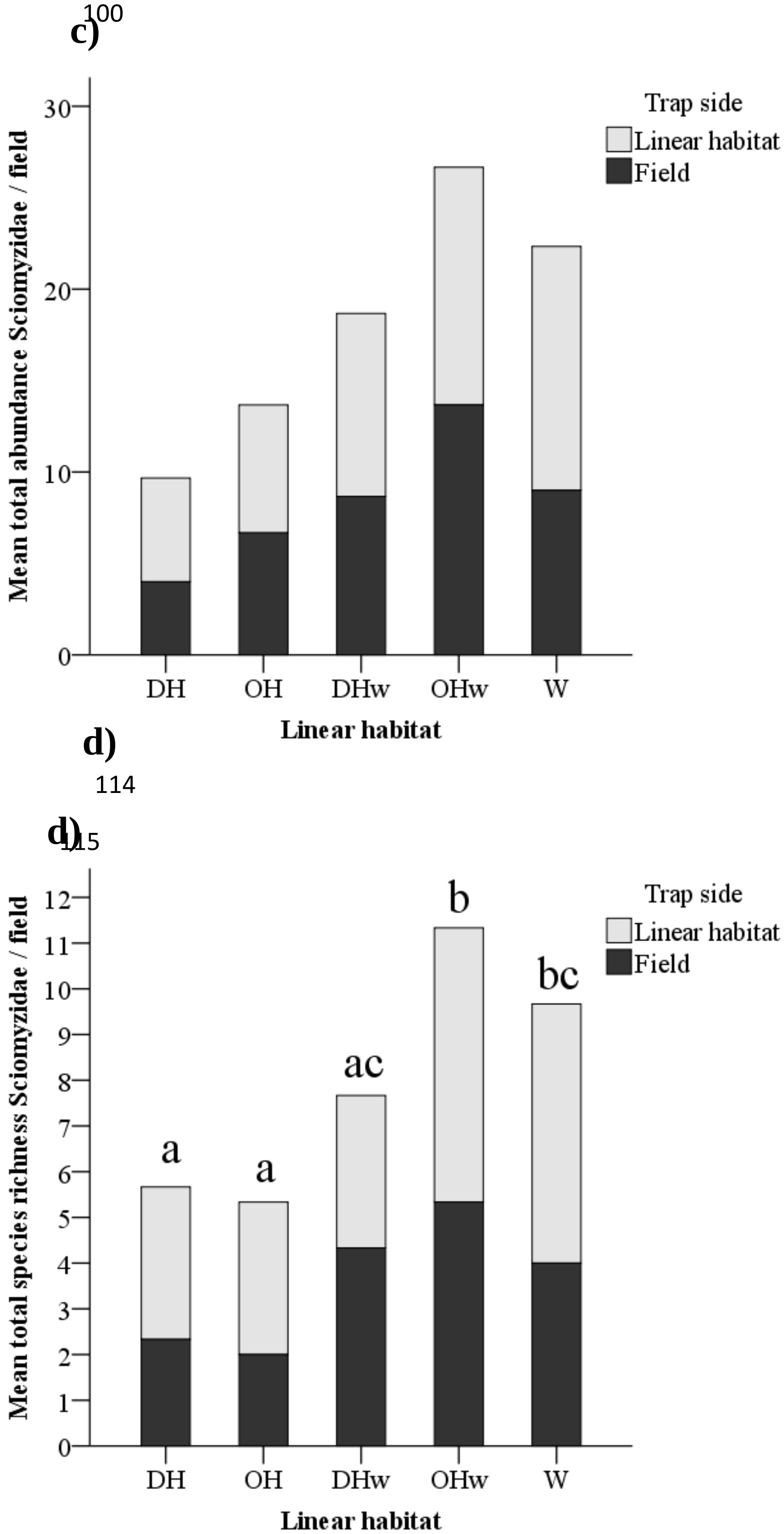

c)
Mean total abundance Sciomyzidae / field
0
10
20
30
Trap side
Linear habitat
Field
DH
OH
DHw
OHw
W
Linear habitat
d)
d)
Mean total species richness Sciomyzidae / field
0
1
2
3
4
5
6
7
8
9
10
11
12
a
a
ac
b
bc
Trap side
Linear habitat
Field
DH
OH
DHw
OHw
W
Linear habitat

Fig. 1

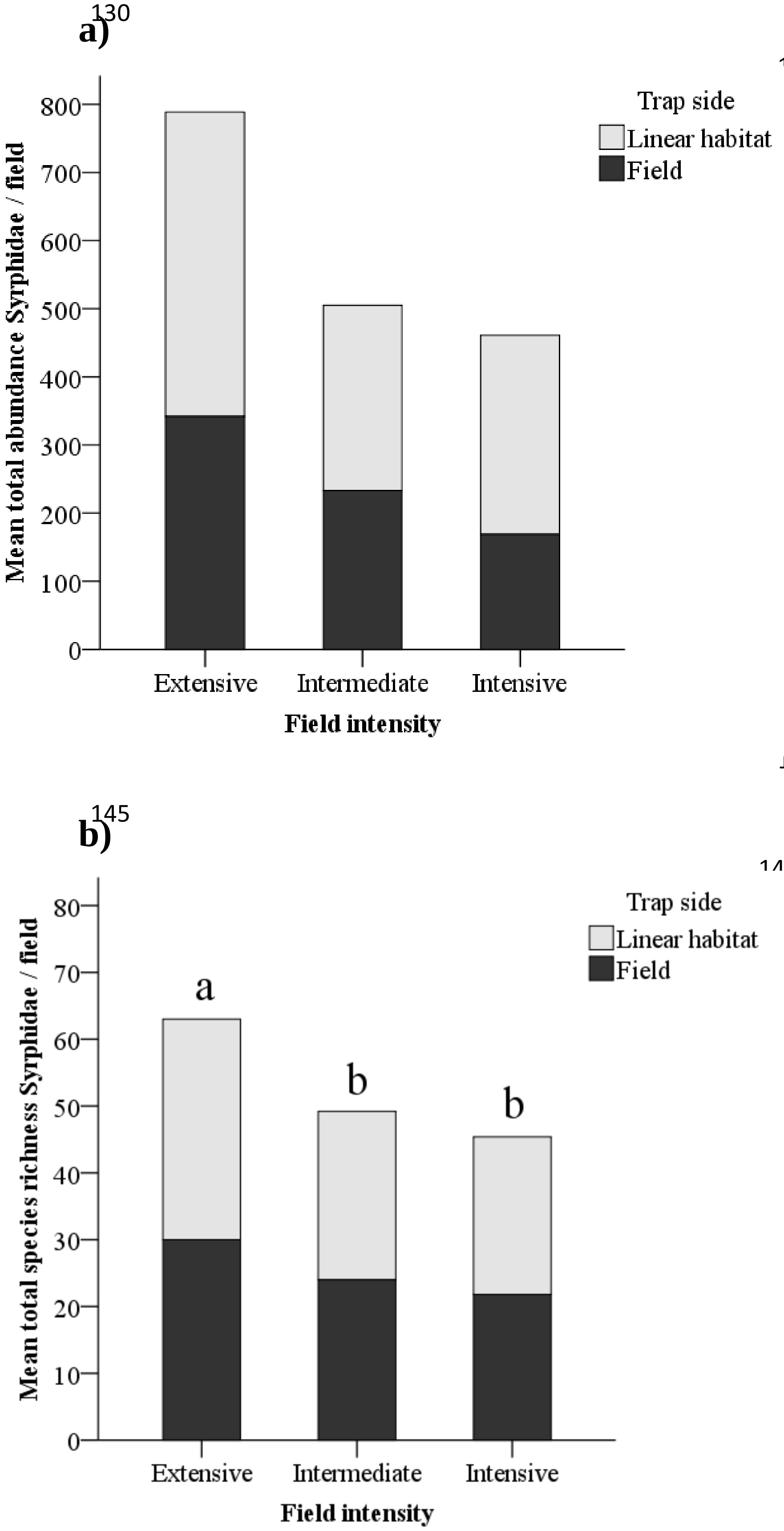
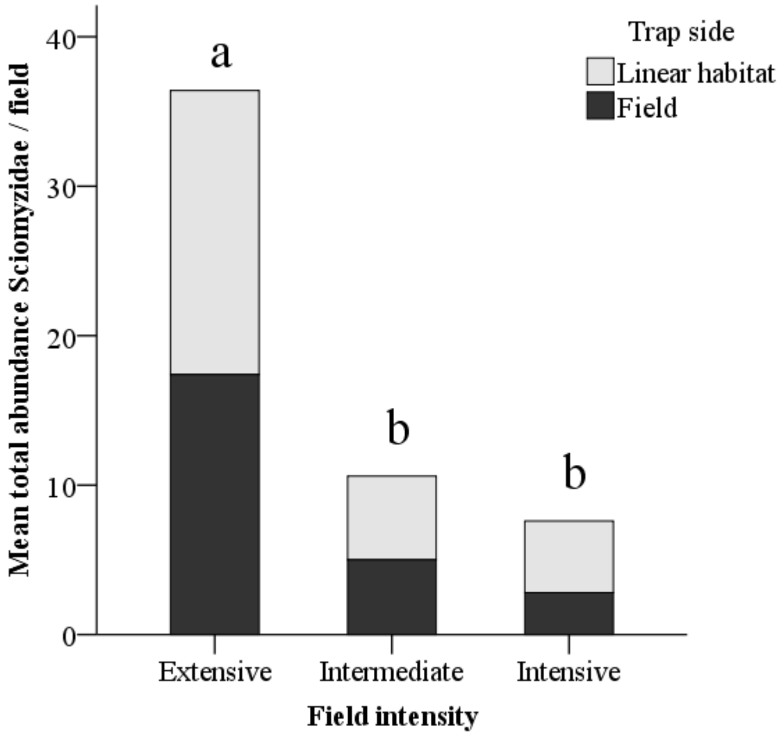

a)
Trap side
Linear habitat
Field
Mean total abundance Syrphidae / field
0
100
200
300
400
500
600
700
800
Extensive
Intermediate
Intensive
Field intensity
b)
Trap side
Linear habitat
Field
Mean total species richness Syrphidae / field
0
10
20
30
40
50
60
70
80
a
b
b
Extensive
Intermediate
Intensive
Field intensity

Fig. 2

c)


Trap side
Linear habitat
Field
Mean total abundance Sciomyzidae / field
40
30
20
10
0
a
b
b
Extensive
Intermediate
Intensive
Field intensity

d)

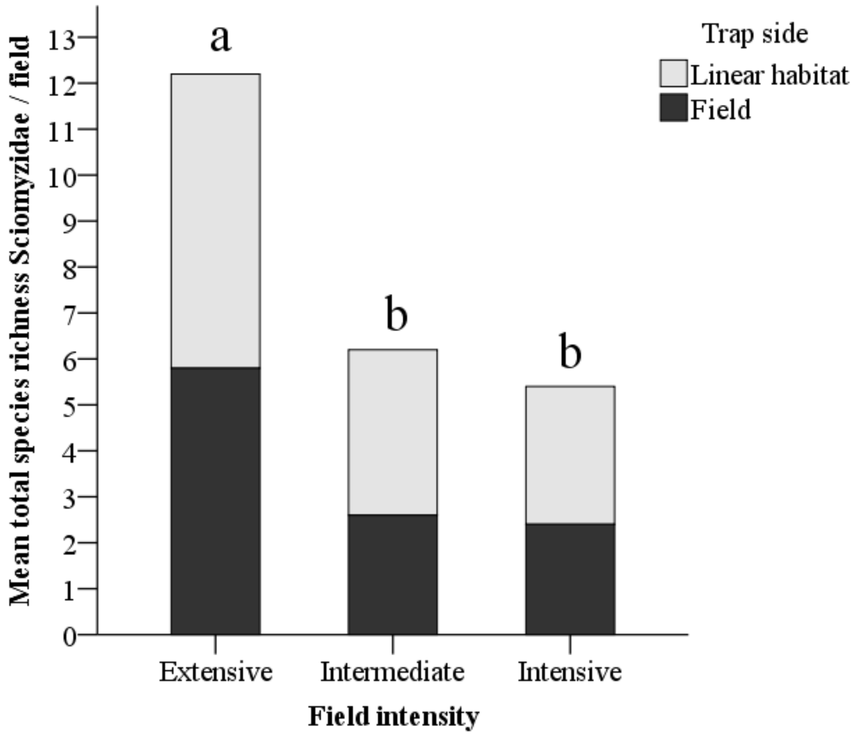

Trap side
Linear habitat
Field
Mean total species richness Sciomyzidae / field
13
12
11
10
9
8
7
6
5
4
3
2
1
0
a
b
b
Extensive
Intermediate
Intensive
Field intensity

Fig. 2

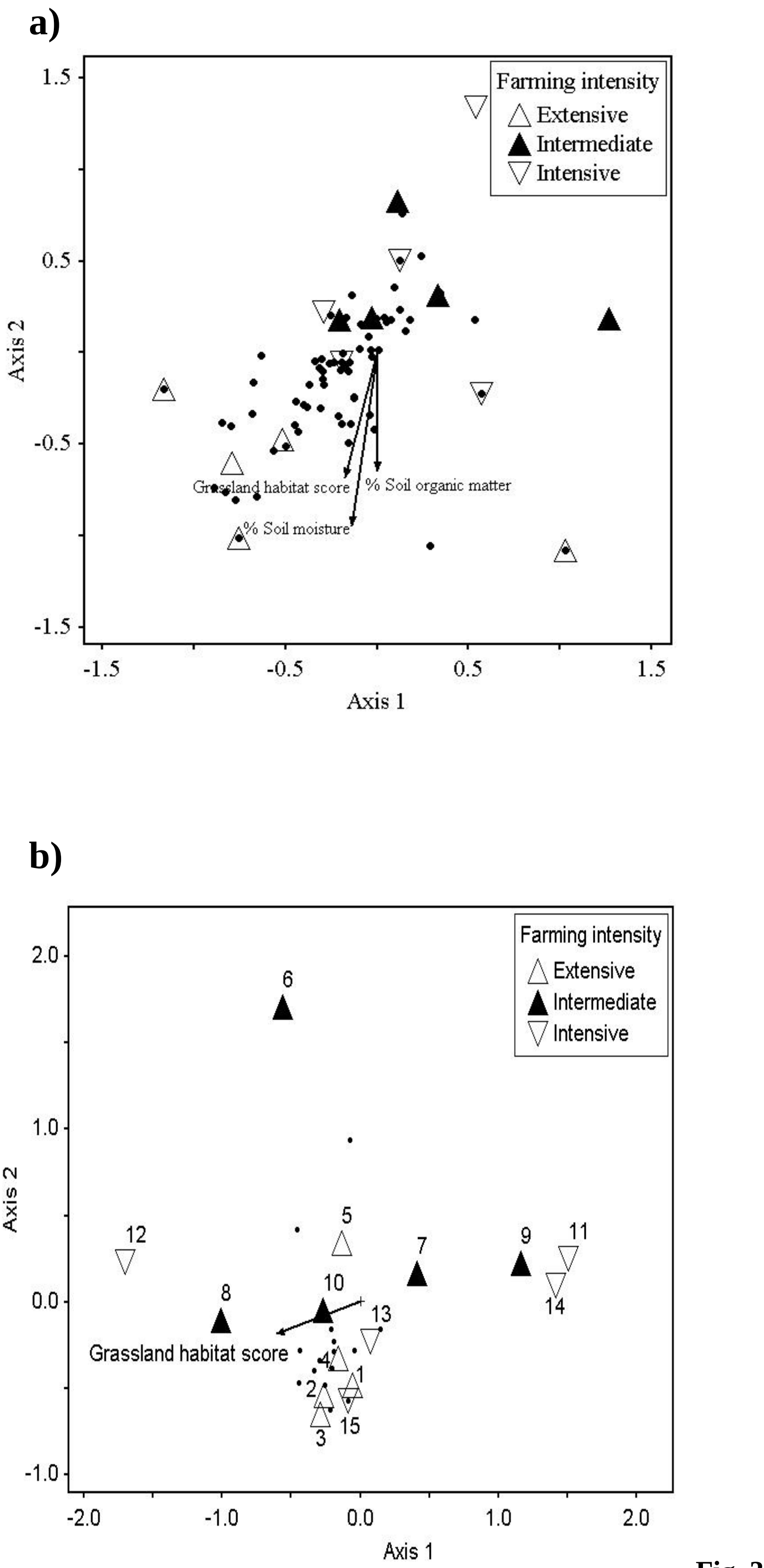

a)
Farming intensity
Extensive
Intermediate
Intensive
Grassland habitat score
% Soil organic matter
% Soil moisture
Axis 2
Axis 1
1.5
0.5
-0.5
-1.5
b)
Farming intensity
Extensive
Intermediate
Intensive
Grassland habitat score
Axis 2
Axis 1
2.0
1.0
0.0
-1.0
-2.0

Fig. 3

Supplementary Information

Table S1: Site description and classification based on farming intensity (extensive, intermediate, intensive) and linear habitat types[1]. The overall habitat quality scores (0-1) are calculated for both linear and adjacent grassland habitats based on several variables including physical structure (e.g. width, height), vegetation structure (profile, how many layers of vegetation, cover of trees, shrubs), management pressure (grazing pressure, poaching) and number and cover of plant species indicators.

Site no.	Parcel area (ha)	LU/ha	HNV	Linear habitat type	Linear habitat score	Grassland habitat score
Extensive						
1	18.30	0.59	6.90	DH	0.37	0.65
2	3.12	0.24	7.50	DH_W	0.55	0.80
3	3.91	0.24	7.50	OH	0.36	0.70
4	7.83	0.59	6.90	OH_W	0.32	0.60
5	45.05	0.36	8.20	W	0.11	0.70
Intermediate						

6	12.31	1.18	3.80	DH	0.51	0.00
7	7.73	0.78	4.10	DH_W	0.62	0.50
8	7.47	1.00	4.60	OH	0.43	0.40
9	1.95	1.18	3.80	OH_W	0.66	0.15
10	15.61	0.74	3.90	W	0.73	0.95
Intensive						
11	3.05	0.75	3.40	DH	0.39	0.00
12	10.40	0.75	3.40	DH_W	0.71	0.60
13	9.22	1.02	3.30	OH	0.48	0.15
14	5.38	1.11	3.30	OH_W	0.51	0.35
15	10.40	0.75	3.40	W	0.315	0.60

[1]Linear habitat types are categorised as: Dense hedgerow (DH); Open hedgerow (OH); Dense hedgerow with adjacent watercourse (DH_W); Open hedgerow with adjacent watercourse (OH_W); and watercourse only (W).

Table S2: Syrphidae species recorded on farms in Co. Sligo, Ireland

Species	Total Abundance	% Total Abundance
Anasimyia contracta Claussen & Torp, 1980	2	0.02
Anasimyia lineata (Fabricius, 1787)	8	0.09
Arctophila superbiens (Müller, 1776)	3	0.03
Baccha elongata (Fabricius, 1775)	29	0.33
Chalcosyrphus nemorum (Fabricius, 1805)	18	0.21
Cheilosia albipila Meigen, 1838	1	0.01
Cheilosia albitarsis (Meigen, 1822)	14	0.16
Cheilosia spp.	1	0.01
Chrysogaster cemiteriorum (Linnaeus, 1758)	3	0.03
Chrysotoxum bicinctum (Linnaeus, 1758)	28	0.32
Chrysotoxum festivum (Linnaeus, 1758)	1	0.01
Dasysyrphus albostriatus (Fallén, 1817)	1	0.01
Dasysyrphus venustus (Meigen, 1822)	4	0.05
Epistrope eligans (Harris, 1780)	50	0.57
Epistrophe nitidicollis (Meigen, 1822)	1	0.01
Episyrphus balteatus (De Geer, 1776)	183	2.09
Eristalis abusiva Collin, 1931	3	0.03
Eristalis arbustorum (Linnaeus, 1758)	6	0.07
Eristalis horticola (De Geer, 1776)	11	0.13
Eristalis intricaria (Linnaeus, 1758)	41	0.47
Eristalis nemorum (Linnaeus, 1758)	41	0.47
Eristalis pertinax (Scopoli, 1763)	94	1.07
Eristalis tenax (Linnaeus, 1758)	16	0.18
Eupeodes corollae (Fabricius, 1794)	342	3.90
Eupeodes latifasciatus (Macquart, 1829)	889	10.13
Eupeodes luniger (Meigen, 1822)	12	0.14
Helophilus hybridus Loew, 1846	41	0.47
Helophilus pendulus (Linnaeus, 1758)	1160	13.22
Lejogaster metallina (Fabricius, 1781)	83	0.95
Leucozona lucorum (Linnaeus, 1758)	9	0.10
Melangyna lasiopthalma (Zetterstedt, 1843)	6	0.07
Melangyna sp.	4	0.05
Melanogaster hirtella (Loew, 1843)	11	0.13
Melanostoma [melanic]	10	0.11
Melanostoma mellinum (Linnaeus, 1758)	679	7.74
*Melanostoma scalare (*Fabricius, 1794)	778	8.87
Meligramma sp.	1	0.01
Meliscaeva cinctella (Zetterstedt, 1843)	3	0.03
Meliscaeva auricollis (Meigen, 1822)	1	0.01
Myathropa florea (Linnaeus, 1758)	2	0.02
Neoascia obliqua Coe, 1940	3	0.03
Neoascia podagrica (Fabricius, 1775)	62	0.71
Neoascia tenur (Harris 1780)	15	0.17
Orthonevra nobilis (Fallén, 1817)	1	0.01
Parasyrphus punctulatus (Verrall, 1873)	2	0.02

Table S2 continued

Species name	Total abundance	% Total Abundance
Parhelophilus versicolor (Fabricius, 1794)	1	0.01
Pipiza sp.	1	0.01
Pipiza noctilucaa (Linnaeus, 1758)	3	0.03
Platycheirus [melanic]	2	0.02
Platycheirus albimanus (Fabricius, 1781)	421	4.80
Platycheirus angustatus (Zetterstedt, 1843)	238	2.71
Platycheirus clypteatus (Meigen, 1822)	1071	12.21
Platycheirus granditarsus (Forster, 1771)	939	10.70
Platycheirus manicatus (Meigen, 1822)	1	0.01
Platycheirus peltatus (Meigen, 1822)	13	0.15
Platycheirus rosarum (Fabricius, 1787)	94	1.07
Platycheirus scambus (Staeger, 1843)	1	0.01
Platycheirus scutatus (Meigen, 1822)	14	0.16
Rhinga campestris Meigen, 1822	698	7.96
Riponnensia splendens (Meigen, 1822)	21	0.24
Scaeva pyrastri (Linnaeus, 1758)	50	0.57
Sericomyia silentis (Harris, 1776)	212	2.42
Sphaerophoria interrupta (Fabricius, 1805)	38	0.43
Sphaerophoria scripta (Linnaeus, 1758)	5	0.06
Sphaerophoria philanthus (Meigen, 1822)	4	0.05
Syritta pipiens (Linnaeus, 1758)	3	0.03
Syrphus torvus Osten Sacken, 1875	1	0.01
Syrphus ribesii (Linnaeus, 1758)	48	0.55
Syrphus vitripennis Meigen, 1822	4	0.05
Trichopsomyia flavitarsis (Meigen, 1822)	20	0.23
Tropidia scita (Harris, 1780)	142	1.62
Volucella bombylans (Linnaeus, 1758)	17	0.19
Volucella pellucens (Linnaeus, 1758)	10	0.11
Xylota jakutorum Bagachanova, 1980	3	0.03
Xylota segnis (Linnaeus, 1758)	21	0.24
Xylota sylvarum (Linnaeus, 1758)	5	0.06

Table S3: Sciomyzidae species recorded on farms in Co. Sligo, Ireland

Species name	Total abundance	% Total abundance
Coremacera marginata (Fabricius, 1775)	11	4.0
Elgiva cucularia (Linnaeus, 1767)	1	0.4
Ilione albiseta (Scopoli, 1763)	4	1.5
Ilione lineata (Fallen, 1820)	19	7.0
Limnia paludicola Elberg, 1965	4	1.5
Limnia unguicornis (Scopoli, 1763)	2	0.7
Pherbina coryleti (Scopoli, 1763)	4	1.5
Renocera pallida (Fallén, 1820)	50	18.3
Renocera striata (Meigen, 1830)	2	0.7
Sepedon spinipes (Scopoli, 1763)	1	0.4
Tetanocera arrogans Meigen, 1830	57	20.9
Tetanocera elata (Fabricius, 1781)	40	14.7
Tetanocera ferruginea Fallén, 1820	35	12.8
Tetanocera fuscinervis (Zetterstedt, 1838)	13	4.8
Tetanocera hyalipennis Roser, 1840	11	4.0
Tetanocera robusta Loew, 1847	17	6.2
Trypetoptera punctulata (Scopoli, 1763)	2	0.7

Table S4: *P* values for the mean total species richness of Sciomyzidae collected for each linear habitat type[1]. Numbers in bold indicate significant *P* values (GLMM followed by LSD pairwise comparisons, $P < 0.05$).

Boundary type	Sciomyzidae abundance			*Sciomyzidae richness*		
	d.f	t	*P*	*d.f.*	*t*	*P*
DH × DH_W	1	1.81	0.08	1	1.40	0.17
DH × OH	1	1.03	0.31	1	0.04	0.97
DH × OH_W	1	2.83	**0.01**	1	2.56	**0.01**
DH ×W	1	3.22	**<0.001**	1	2.51	**0.02**
DH_W × OH	1	0.84	0.40	1	1.44	0.16
DH_W × OH_W	1	1.26	0.21	1	1.19	0.24
DH_W × W	1	1.72	0.09	1	1.14	0.26
OH × OH_W	1	2.02	**0.04**	1	2.60	**0.01**
OH × W	1	2.45	**0.02**	1	2.54	**0.01**
OH_W × W	1	0.49	0.63	1	0.06	0.95

[1]Linear habitat types are categorised as: Dense hedgerow (DH); Open hedgerow (OH); Dense hedgerow with adjacent watercourse (DH_W); Open hedgerow with adjacent watercourse (OH_W); and watercourse only (W).

Table S5: *P* values for the mean total abundance and species richness of Syrphidae and Sciomyzidae collected per site at each of the three-farming intensities. Numbers in bold indicate significant *P* values (GLMM followed by LSD pairwise comparisons, P < 0.05).

	Farming intensities				Linear habitat types			
Parameter	*n*	*t*	*d.f*	*P*	*n*	*t*	*d.f*	*P*
Flowering plant species richness/linear habitat	15.00	1.86	2.00	0.39	15.00	3.22	4.00	0.52
Flowering plant species richness/grassland habitat	15.00	3.29	2.00	0.19	15.00	2.73	4.00	0.60
Linear habitat quality score	15.00	5.47	2.00	0.07	15.00	3.97	4.00	0.41
Grassland habitat quality score	15.00	5.60	2.00	0.06	15.00	5.48	4.00	0.24
% Soil moisture	15.00	8.66	2.00	**0.01**	15.00	3.60	4.00	0.46
% Soil Organic matter	15.00	7.02	2.00	**0.03**	15.00	4.53	4.00	0.34
Soil pH	15.00	1.82	2.00	0.40	15.00	7.47	4.00	0.11

Table S6a: Results of Kruskall-Wallis test to determine differences between environmental variables across three farming intensities and linear habitat types. Numbers in bold indicate significance.

	Syrphidae					
Farming intensity	Abundance			Richness		
	d.f	*t*	*P*	*d.f*	*t*	*P*
Extensive × Intermediate	1	1.31	0.20	1	3.25	**<0.01**
Extensive × Intensive	1	1.81	0.08	1	4.19	**<0.001**
Intermediate × Intensive	1	0.53	0.60	1	0.67	0.51

	Sciomyzidae					
Farming intensity	Abundance			Richness		
	d.f	*t*	*P*	*d.f*	*t*	*P*
Extensive × Intermediate	1	4.66	**<0.001**	1	3.86	**<0.001**
Extensive × Intensive	1	5.26	**<0.001**	1	4.69	**<0.001**
Intermediate × Intensive	1	1.13	0.26	1	0.91	0.37

Table S6b: Pairwise comparisons for % soil moisture and soil organic matter between the three farming intensity categories using Bonferroni correction for multiple comparisons. Numbers in bold indicate significance (P<0.05).

Comparison	% Soil moisture		% Soil organic matter	
	t	*P*	*t*	*P*
Extensive × Intermediate	7.40	**0.03**	5.40	1.69
Extensive × Intensive	7.00	**0.04**	7.20	**0.03**
Intermediate × intensive	-0.04	1.00	1.80	1.00

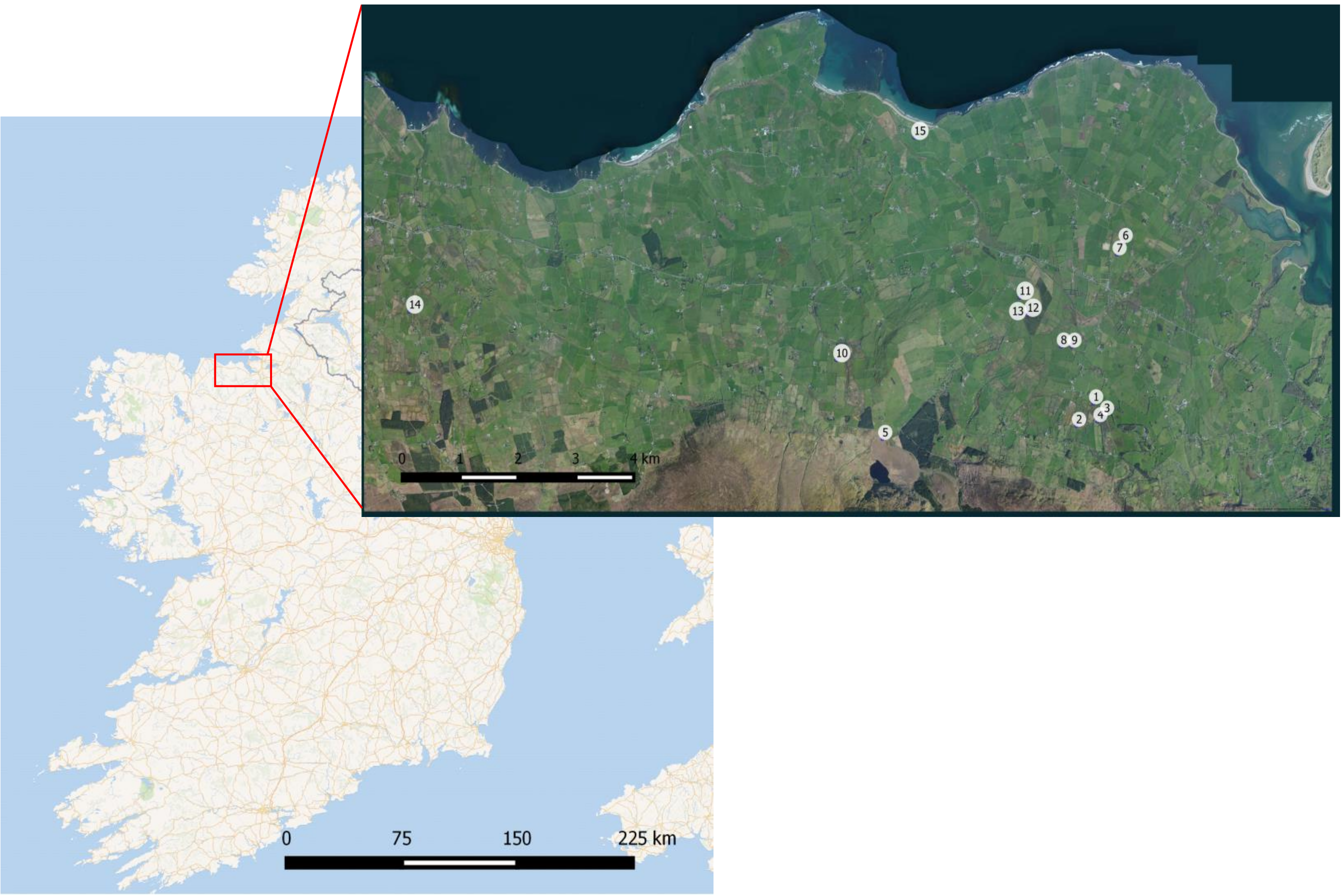
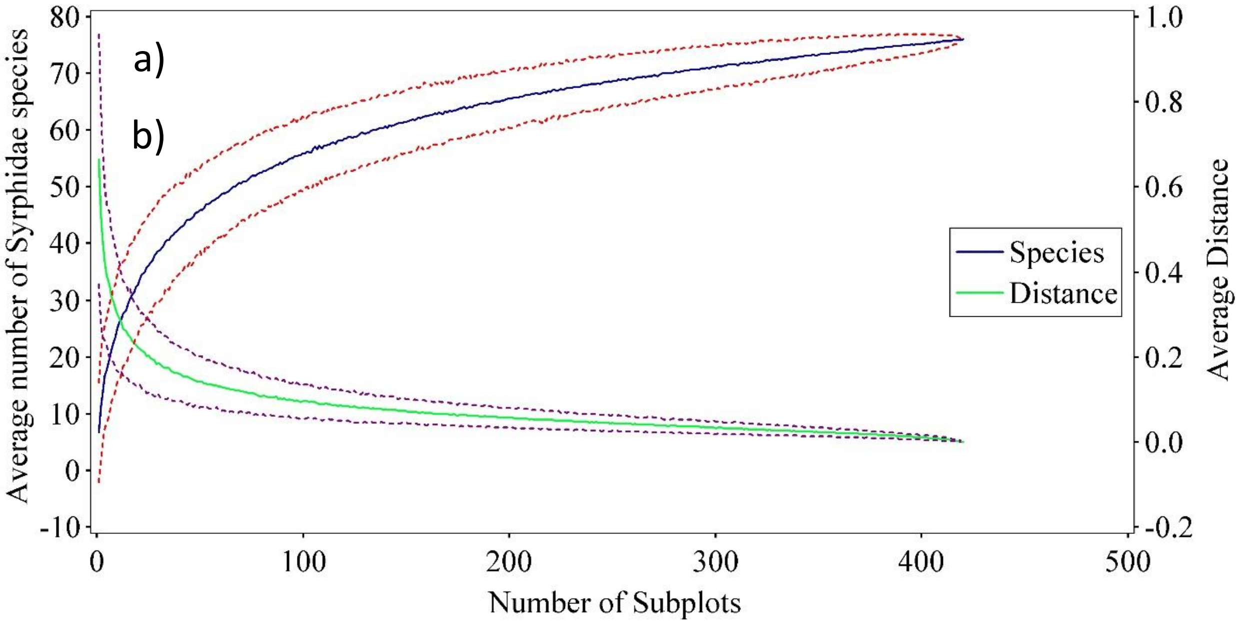


Fig. S1: A map showing location of the study sites in County Sligo, Northwest of Ireland (left). Farming intensity categories are denoted with different numbers (right). Extensive = 1-5; Intermediate = 6 -10; and Intensive = 11-15)

Figure S2: Bi-directional Malaise traps used throughout the study.



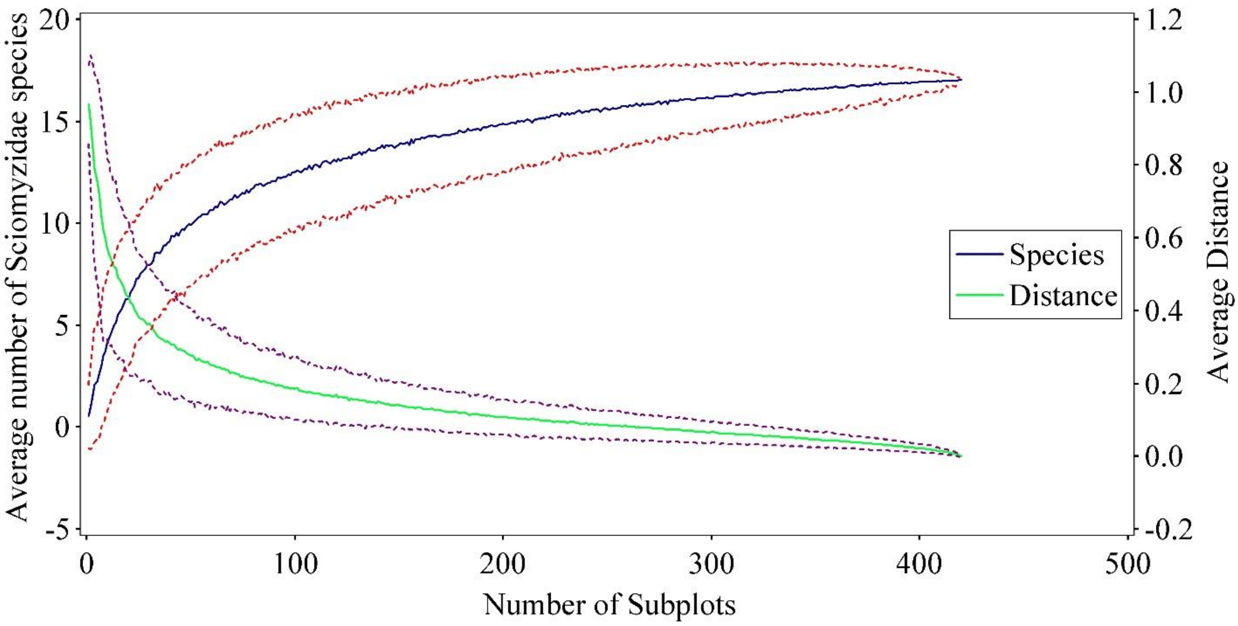


Figure S3: Species area curves for Syrphide (a) and Sciomyzidae (b). Dotted lines represent ±2SDs. First-order jackknife estimates of total species richness were 90.75 (Syrphidae) and 18.9 (Sciomyzidae).