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Using Malaise traps to assess aculeate Hymenoptera associated with farmland linear habitats across a range of farming intensities

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Article

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Title

Using Malaise traps to assess aculeate Hymenoptera associated with farmland linear habitats across a range of farming intensities

Running Title

Malaise trap to assess habitats quality

Abstract

1. The intensification of farming practices, along with the loss and fragmentation of semi-natural habitats within agricultural areas, has contributed significantly to insect decline worldwide including flower-visiting aculeate Hymenoptera.
2. In this study aculeate Hymenoptera were collected using bi-directional Malaise traps placed along farmland linear habitats across a range of farming intensities. The aim was to further our understanding of the value of farmland linear habitats to this insect group and in particular the Vespinae, an understudied family.
3. Overall, significantly greater aculeate Hymenoptera species richness was found on extensive than on intermediate and intensive farms. Significantly more species and specimens were collected on the side of the traps adjacent to the linear habitats compared to the side which opened onto the fields. Aculeate Hymenoptera species richness was also significantly greater in dense hedgerows than in open hedgerows. Furthermore two out of six Vespinae species, *Vespula rufa* and *Vespula vulgaris*, had significantly more individuals on extensive than intensive farms.
4. This study highlights that low-intensity farming practices and farmland linear habitats, especially dense hedgerows, may enhance aculeate Hymenoptera occurrence in agricultural areas. It also demonstrates that Malaise traps set up along linear habitats

across a range of farming intensities can make a significant contribution to knowledge regarding the biodiversity value. Given that selected Vespinae species follow similar trends to aculeate Hymenoptera, the possibility of using them as simple biodiversity indicators is worthy of further exploration.

Key words

Bi-directional Malaise traps, farm hedgerows, farm watercourses, farming intensity, social wasps (Vespinae), wild bees (Apidae), biodiversity

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Introduction

During the last few decades agricultural production has undergone significant intensification (Robinson & Sutherland, 2002). The intensification of farming practices through the utilisation of high agrochemical inputs and monocultural cropping systems, in addition to the loss and fragmentation of semi-natural habitats, are the primary causes of the rapid decrease of farmland biodiversity (Stoate *et al.*, 2001; Benton *et al.*, 2003; Fahrig, 2003; Kleijn *et al.*, 2009). Furthermore, it is one of the major causes of insect decline worldwide over the past sixty years, including flower-visiting aculeate Hymenoptera (Sánchez-Bayo & Wyckhuys, 2019).

The ecological consequences of aculeate Hymenoptera decline is a current topic because they affect important ecosystem services such as pollination of crops and wild plants (Biesmeijer *et al.*, 2006; Klein *et al.*, 2007; Potts *et al.*, 2010; Vanbergen & Insect Pollinators Initiative, 2013), which are closely linked to food production and human well-being (Zhang *et al.*, 2007; Haines-Young & Potschin, 2010). The conservation and/or restoration of semi-natural habitats in agricultural areas are known to positively influence aculeate Hymenoptera counteracting their overall decline (Garibaldi *et al.*, 2011; Kennedy *et al.*, 2013). Farmland linear habitats (e.g. hedgerows/watercourses), particularly those in agriculturally productive agricultural areas (Morandin & Kremen, 2013; Garratt *et al.*, 2017), are recognised as valuable habitats providing essential resources for flower-visiting insects (Pollard & Holland, 2006; Herzon & Helenius, 2008; Hannon & Sisk, 2009). Furthermore these linear habitats have been reported to function as biological corridors facilitating flower-visiting insect movements (Cranmer *et al*., 2012). While the ecological value of farmland linear habitats for wild bees has been investigated in great detail in recent years, very little is known about the ecological interactions between these habitats and social wasps within agricultural areas. The study of social wasps has been much neglected worldwide largely due to their negative image (Sumner *et al*., 2018). The exceptions to this are countries such as New Zealand, Tasmania and Hawaii where social wasps are accidentally introduced pests with negative impacts on native species (Harris, 1991; Richter, 2000; Hanna *et al*., 2012; Potter-Craven *et al*., 2018). Studies elsewhere are mainly limited to tropical ecosystems where they have been shown to provide fundamental ecosystem services such as pest control (Pereira *et al*., 2007a, b; Picanço *et al*., 2011) and pollination (Heithaus, 1979; Hermes & Köhler, 2006; Clemente *et al*., 2012). However, little is known about the ecological interactions of social wasps within agricultural systems in temperate regions.

The decline of flower-visiting insects in general in recent years has led to the need to monitor their status in agricultural areas using appropriate sampling methods (Westphal *et al*., 2008; Grundel *et al*., 2011). Different sampling methods have shown to effectively collect flower-visiting insects, including coloured pan traps and Malaise traps (Ozanne 2005; Campbell & Hanula 2007; Westphal *et al*., 2008; Devigne *et al*., 2014). Although these two methods have demonstrated to deliver reliable indications of insect assemblages in agricultural areas, the coloured pan trap has been shown to provide valuable inventories of bees while Malaise trap catches reflect multiple groups of insects (Bartholomew & Powell, 2005).

In this study Malaise traps were set up with the aim of collecting as much information as possible on the ecological value of farmland linear habitats through the capture of a wide range of insect groups. Aculeate Hymenoptera were chosen for the purpose of this paper because they are an important ecological group in terrestrial ecosystems with a key role in providing fundamental ecosystem services such as pollination and pest control (LaSalle & Gauld, 1993). Furthermore, they have been proven to be good indicators of habitat quality and environmental change in agricultural areas (Tscharntke *et al*., 1998). The aims of this study were, therefore, to:

1. Describe aculeate Hymenoptera assemblages associated with farmland linear habitats across a range of farming intensities;
2. Compare the value of farmland linear habitats to the more abundant Apidae and Vespinae species;
3. Consider how aculeate Hymenoptera collected using Malaise traps contributes to our understanding of the ecological value of farmland linear habitats.

Materials and Methods

Study sites

The study was carried out in County Sligo, in the north-west of Ireland on farmlands dominated by cattle and sheep grazing. Fields were classified as extensive, intermediate and intensive using the HNV index after Boyle, Hayes *et al.*, (2015). The HNV index was calculated by incorporating different parameters such as the Livestock Units per hectare (LU/ha), the area of improved grasslands, the areas owned and farmed, and the size of fields and boundaries. Two Malaise traps of Townes design (Townes, 1972) were placed along linear habitats (hedgerows and/or watercourses) across five fields within each farm category (30 traps in total). One set of two traps was set up in each field at least 200 m apart to ensure that the adjacent set was independent (Gittings *et al*., 2006). Linear habitats within each intensity category were classified as “dense hedgerow” (< 50% gaps) or “open hedgerow” (> 50% gaps), with each hedgerow type consisting of a hedgerow with/without stonewall/bank and a hedgerow with an adjacent watercourse (ditch/stream). Gaps were defined as those spaces occupied by fences, brambles or non-structural hedgerow species, walls and dead sections of hedgerow (Defra, 2007). A third linear habitat (watercourse only) was selected according to Williams *et al*., (2004) based on the presence of ditches/streams and the absence of hedgerows. Dense hedgerows, open hedgerows and watercourses are, hereafter, referred to as DH, OH and W respectively (Appendix 1).

Sampling protocol

Aculeate Hymenoptera specimens were captured using Malaise traps. At each field two Malaise traps were positioned 20 m apart after Carey *et al*., (2017), and 2 m away from the linear habitat to prevent sampling bias after Wolton *et al*., (2014). Each bi-directional Malaise trap was placed parallel to the linear habitat on the southern side, thus separating invertebrates caught on the field side of the trap from those caught on the linear habitat side of the trap. Collection bottles were oriented in an easterly direction and filled with 70% ethanol solution to kill and preserve the catch. A portable electric fence was placed around each trap to prevent damage by livestock. Fortnightly sampling commenced when Malaise traps were set up on May 24th and ended on September 13th (2018), resulting in a total of eight collections during the whole sampling period. All samples collected were returned to the laboratory for identification. Aculeate Hymenoptera were identified to species level using Dvořák & Roberts (2006), Richards (1980), Yeo & Corbet (1983), and Falk & Lewington (2017). Due to the difficulties involved in separating workers of *Bombus lucorum* L. and *Bombus terrestris* L. (Prys-Jones & Corbet, 1991; Saville *et al*., 1997; Pywell *et al*., 2005; Öckinger & Smith, 2007), the specimens were collectively referred to as *B. lucorum* and treated as a single species due to the higher abundances of queens of *B. lucorum* collected compared to queens of *B. terrestris*. Furthermore, in order to have a formal rank name for all bees (Anthophila) and a more compatible classification with the higher-level system used for the aculeate Hymenoptera, all the bees collected in this study were included in only one family, the Apidae, as suggested by previous authors (Melo & Goncalves, 2005). Although a few individuals of the European honey bee (*Apis mellifera* L.) were present, they were not included in the analysis since they depend primarily on the management of hives rather than purely ecological factors (Kremen *et al*., 2004; Winfree *et al*., 2007). In addition, the family Formicidae, which also belongs to the aculeate Hymenoptera (Brothers, 1999), was not included in this study because of the small number of individuals collected. Hereafter, where the term “aculeate Hymenoptera” is mentioned, it is inferred that ants and the European honey bee are not included.

Data analysis

The data were analysed statistically for the above aculeate Hymenoptera species captured and then separately for the dominant Apidae and Vespinae species. Statistical analyses were performed using the SPSS v25 software (IBM SPSS Statistics 2017). Aculeate Hymenoptera species richness was shown to display a Poisson distribution using the non-parametric Kolmogorov-Smirnov test and was therefore analysed using Poisson error distribution and log link function. Aculeate Hymenoptera abundance which did not display a Poisson distribution, was log-transformed ($\ln(x + 0.1)$) before analysis to achieve normally distributed residuals and tested using General Linear Mixed Models with normal error distribution. Farming intensity, farmland linear habitat and trap side were included as fixed factors in the models. To account for the hierarchical study design, trap identity was included as random factor. Residual analyses were performed to assess model appropriateness and whether the models fitted the data. Post-hoc pairwise comparison among the levels of a factor was used to test the effects of farming intensity, linear habitat and trap side types on aculeate Hymenoptera species richness and abundance. For the analysis the effects significance was set at $P < 0.05$. Since the data of the dominant Apidae and Vespinae species were not normally distributed after logarithmic transformation, Mann-Whitney *U* tests were performed to test the effects of farming intensity and linear habitat types. PC-Ord version 6 (MjM Software Design) was also used to construct species-area curves and assess the adequacy of sampling across all selected fields for aculeate Hymenoptera.

Results

A total of 32 species (1334 individuals) of aculeate Hymenoptera were collected during the sampling period in the bi-directional Malaise traps placed between farm fields and linear habitats. Overall, more than twice the number of individuals (903) was collected on the linear habitat side of the Malaise traps compared to the field side (431). The number of individuals collected fortnightly in each of the eight collections ranged from a minimum of 57 specimens in the last collection (September 13th) to a maximum of 286 in the first collection (June 7th) (Table 1). Species-area curves demonstrate sufficient sampling for the collection of total aculeate Hymenoptera using bi-directional Malaise traps (Fig. 1).

Of all the specimens collected, the family Apidae was the most abundant group in terms of species richness (17) and abundance (954), with the highest numbers in terms of species and individuals belonging to the genus *Bombus* (Appendix 2). The three most abundant Apidae species, representing almost 90% of the total Apidae individuals collected, were *Bombus pascuorum* Scopoli (52.1%), *B. lucorum* (31.5%) and *Bombus pratorum* L. (5.8%). The sub-family Vespinae was the next most abundant group, with 6 species and 328 individuals. The three most abundant Vespinae species recorded, i.e. *Vespula vulgaris* L. (36.6%), *Vespula germanica* Fabricius (31.7%) and *Vespula rufa* L. (20.4%), constituted almost 90% of all Vespinae collected. All Vespinae species collected in this study represent the full spectrum of Vespinae species recorded in Ireland to date (Else et al., 2016). The (sub-) families Crabronidae (6 species) and Eumeninae (3 species) were less abundant with 36 and 16 individuals respectively.

Aculeate Hymenoptera species richness and abundance differed significantly among farming intensities, linear habitats, and trap side (see Table 2 for *P* values). Pairwise comparison indicated significantly greater species richness on extensive compared to intermediate (P = 0.015) and intensive farms (P = 0.004) (Fig. 2). Overall, significantly greater species richness (P = 0.011) and abundance ($P < 0.001$) were also found in the Malaise trap collecting bottles connected to nets which opened onto the side adjacent to the linear farm habitat compared to the side which opened onto the field (Fig. 3). A comparison of the different linear habitats across all farming intensities indicates that aculeate Hymenoptera species richness was significantly greater in dense hedgerows compared to open hedgerows (P = 0.012) (Fig. 4).

Analyses of the dominant aculeate hymenopteran species showed different patterns for Apidae and Vespinae species. Although some of the three most abundant Apidae species showed decreasing abundances with increases in farming intensity and with increasing openness of the linear habitats, the differences were not significant (Fig. 5: Appendix 3). Similarly, dominant Vespinae species showed no significant differences in abundance across the different linear habitat types (Fig. 6: Appendix 3). However, *V. rufa* abundance was significantly greater on extensive farms compared to intermediate ($P < 0.001$) and intensive ($P < 0.001$) farms, and significantly more *V. vulgaris* individuals were captured on extensive compared to intensive farms (P = 0.005) (Fig. 6).

Discussion

Species-area curves show adequate sampling for the collection of aculeate Hymenoptera using Malaise traps demonstrating the robustness of the sampling method employed in this study. Significantly greater species richness of aculeate Hymenoptera was found on extensive farms compared to intermediate and intensive farms. In addition, our results indicate the importance of farmland linear habitats for aculeate Hymenoptera where significantly greater species richness and abundance were recorded on the linear habitat side of the traps than on the field side. Further examination of linear habitat type demonstrates that dense hedgerows harboured significantly greater species richness of aculeate Hymenoptera than open hedgerows. Although there were no significant differences for aculeate Hymenoptera abundances across farming intensity and linear habitats types, more specimens were found on extensive farms and in dense hedgerows.

In this study farms were classified using the HNV index (see Appendix 1 for details). The main factors which determined the intensity of farming were the stocking rates and the total area of improved grasslands that had been ploughed and reseeded. Previous studies have shown that management practices such as increased stocking rates, ploughing and reseeding with agricultural grasses, in addition to the application of nitrogenous fertiliser, result in a reduction in grassland biodiversity (Plantureux *et al*., 2005). Heavy grazing associated with higher stocking rates have been reported to negatively affect field plant species richness in grasslands, thereby reducing valuable resources for many invertebrates (McMahon *et al*., 2012). Previous studies have shown that the reduction of plant diversity as a consequence of intensive grazing negatively influence invertebrate diversity and abundance (Vickery *et al*., 2001; Kruess & Tscharntke, 2002). Similarly, an increase of nutrient input levels has been found to influence plant and arthropod communities, causing a decrease of insect species richness (Haddad *et al*., 2000; Vickery *et al*., 2001). A study of 117 European grasslands by Klimek *et al*., (2007), has also shown that the reduction of both stocking rates and nitrogenous fertiliser input can contribute significantly to the conservation of biodiversity in agricultural grasslands, as supported by the current study with greater species richness and abundances of aculeate Hymenoptera in more extensively managed farms. The application of herbicides, which are commonly used on intensive farms to facilitate reseeding, control weeds and maintain grass growth, may also decrease plant diversity in grasslands (Plantureux *et al*., 2005), while its reduction has been shown to favour a richer flora within and around the farm fields providing more forage resources for invertebrates (Hyvönen *et al*., 2003). Although insecticides in grasslands are generally applied in lower amounts and frequency than in cultivated fields (Plantureux *et al*., 2005), they may also negatively affect aculeate Hymenoptera communities in intensively managed farms through direct lethal or sub-lethal effects and the modification of the habitat quality (Goulson *et al*., 2015). Given that low intensity grasslands have been demonstrated to be important for many invertebrate groups, including wild bees and solitary wasps (Carvell, 2002; Kruess & Tscharntke, 2002; Steffan-Dewenter & Leschke, 2003), it is not surprising that our results reveal significantly greater aculeate Hymenoptera species richness on extensive compared to intermediate and intensive farms.

Our results also indicate that farmland linear habitats are valuable habitats in agricultural areas with significantly more species and specimens found in the linear habitat side of the traps compared to those in the field side. This is supported by previous studies which demonstrate that farmland linear habitats such as hedgerows and ditches provide invertebrate species in general with resources for foraging, shelter from adverse conditions in addition to overwinteringand nesting sites (Pollard & Holland, 2006; Herzon & Helenius, 2008; Hannon & Sisk, 2009). The positive effects of farmland linear habitats are probably because aculeate Hymenoptera find the above resources primarily in the farmland linear habitats and not in the surrounding agriculturally productive grasslands. This is supported by Garratt *et al*., (2017) who suggest that wild bees in agricultural areas are likely to find essential resources for their occurrences predominantly in hedgerows. Even watercourses in agricultural areas have been shown to supply valuable resources for many invertebrate taxa otherwise absent in intensively managed areas (Herzon & Helenius, 2008).

Although we found that farmland linear habitats regardless of their type or quality were more valuable habitats than the fields, our results demonstrate that their value for aculeate Hymenoptera as a whole depends on their quality, with significantly greater species richness associated with dense hedgerows. Dense hedgerows seem, therefore, to be farmland linear habitats of greater value, providing more valuable resources to aculeate Hymenoptera compared to open hedgerows or watercourses only. This conclusion is supported by previous studies in which dense continuous hedgerows with a high diversity of structural hedge species and vegetation layers have been shown to provide essential resources to many invertebrate species (Graham *et al*., 2018), including wild bees (Garratt *et al*., 2017). In addition to increasing the provision of food resources, these complex hedgerows may also deliver a greater number of refuge sites against predators and adverse weather conditions (Dainese *et al*., 2015). Likewise, Amy *et al*., (2015) demonstrated that dense continuous hedgerows with higher foliage density positively influenced insect fauna, while the increase in hedge gap size was negatively correlated with invertebrate diversity and abundance.

The value of farmland linear habitats overall across a range of farming intensities to the dominant Apidae and Vespinae species in this study varies according to species. While two Vespinae species (i.e. *V. rufa* and *V. vulgaris*) show significantly greater abundances on extensive than on intensive farms, the three most abundant Apidae bumblebee species show no significant differences across farming intensities and linear habitat types. This may be explained by the fact that many bee species, and in particular large body sized bees such as bumblebees, seem to be more affected by factors at a broader scale, i.e. landscape scale than at the local scale (Happe *et al*., 2018). Similarly, other studies have shown that large body sized bees have larger foraging ranges than small sized bees, suggesting that they may exploit resources at a bigger scale and therefore be less influenced by local factors (Steffan-Dewenter *et al*., 2002). Unlike *B. lucorum* and *B. pratorum*, we found more *B. pascuorum* specimens on extensive farms compared to intermediate and intensive farms. This may be related with the habitat preferences of workers of *B. pascuorum* which seem to prefer farm fields including grasslands (Falk & Lewington, 2017). It is, therefore, likely that less disturbed agricultural areas such as those under extensive management may support greater densities of *B. pascuorum* workers compared to more disturbed areas under intensive management. This may explain why more *B. pascuorum* specimens were found on extensive farms, while more generalist species, in terms of habitat preferences, such as *B. lucorum* and *B. pratorum* (Falk & Lewington, 2017) showed less pronounced preferences for farming intensity types.

Similar to farming intensity, linear habitat types did not significantly influence the most dominant Apidae species, although more individuals of *B. lucorum* and *B. pascuorum* were found in dense hedgerows. Greater abundances of these species in dense hedgerows can be explained by the fact that these linear habitats may provide more valuable resources such as food resources and nesting opportunities. Rollin *et al*., (2013) demonstrated that in agricultural areas, wild bees prefer to forage mainly in woody habitats, including farmland linear habitats such as hedgerows because these habitats seem to provide more food resources and nesting sites for many species. Dense continuous hedgerows, in particular, have been shown to provide essential food resources such as flowering plants for bumblebees (Garratt *et al*., 2017). In addition to foraging resources, which have been shown to positively influence bee communities (Kleijn & van Langevelde, 2006), another important resource that may explain greater *B. pascuorum* abundances in dense hedgerows is the presence of more suitable nesting sites. Nest-site preferences are site-specific and queens of *B. pascuorum* seem to display a preference for nesting along sheltered boundaries running between agricultural fields and woody landscape elements such as hedgerows (Svensson *et al*., 2000; Kells & Goulson, 2003).

Vespinae species *V. rufa* and *V. vulgaris*, on the other hand, were captured in significantly greater abundances on extensive than on intensive farms. These contrasting responses to farming intensity between Apidae and Vespinae species may be explained by different feeding behaviours. Unlike bees, which depend primarily on floral resources such as pollen and nectar, social wasps have a more varied diet, ranging from nectar and pollen to invertebrate prey (Richter, 2000). Invertebrate prey, which include serious crop pests such as aphids and caterpillars, are found mainly in farm fields where they colonize and feed on crop plants (Hill, 1987). Low intensity managed grasslands are known to support greater plant species richness and therefore better foraging opportunities for many invertebrate species (McMahon *et al.*, 2012) which are potential prey for social wasps. It is therefore likely that extensive farms in this study may provide more food resources for social wasps, including a wider variety of prey, thus explaining greater Vespinae abundances on extensive compared to intermediate and intensive farms. It is also possible that social wasps may be more influenced by factors at a smaller scale than the Apidae. However, while the influence of landscape on bees has been well studied (Steffan-Dewenter *et al.*, 2002), little is currently known about this in relation to Vespinae species.

Although linear habitat types did not significantly influence the occurrences of the dominant Vespinae species, *V. germanica* and *V. vulgaris* were more abundant in dense hedgerows and on watercourses. High abundances of these two species on watercourses overall could have been due to the presence, in the vicinity of one of the watercourse sites in particular, of a range of habitats including a wet grassland and a dense, continuous hedgerow. The complex and heterogeneous landscape at this site may have provided wasp communities with a large amount of valuable resources resulting in large colonies with numerous individuals. Indeed, *V. vulgaris* and *V. germanica* are known to generally form large colonies with several thousand workers when the ecological conditions for the colony growth are optimal (Wenseleers *et al.*, 2005). However, further research is required to determine the influence of landscape features on such Vespinae populations.

Conclusions

This study demonstrates that extensive farms and farmland linear habitats, particularly dense hedgerows, represent important management conditions and valuable habitats for aculeate Hymenoptera. Furthermore, we have highlighted that farmland linear habitats, regardless of the type or quality, are of importance to aculeate Hymenoptera. While aculeate Hymenoptera, in general, reflect farming intensity and habitat quality in agricultural landscapes, certain Vespinae species may be used as possible indicators of farming intensity in temperate regions. The results of this study also demonstrate that Malaise traps set up along linear habitats in a range of farming intensities can make a significant contribution to knowledge regarding the biodiversity value. In conclusion, our results indicate that both extensive management and farmland linear habitats, especially high quality habitats such as dense hedgerows, can be used as tools to enhance aculeate Hymenoptera occurrence in agricultural areas. Therefore, the introduction of low-intensity farming practices and the conservation or restoration of farmland linear habitats are highly recommended to promote invertebrate diversity and counteract the worldwide insect decline.

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Tables and Figures

Table 1. Total numbers of aculeate Hymenoptera (Aculeate) captured on each sampling period (2018) across all selected farms in Co. Sligo (Ireland).

Aculeate	24 May 7 Jun	7 Jun 21 Jun	21 Jun 5 Jul	5 Jul 19 Jul	19 Jul 2 Aug	2 Aug 16 Aug	16 Aug 30 Aug	30 Aug 13 Sep	Abundance
Apoidea									
Apidae	239	162	87	155	189	68	39	15	954
Crabronidae	1	2	13	2	13	3	2	-	36
Vespoidea									
Eumeninae	3	-	12	1	-	-	-	-	16
Vespinae	43	17	38	48	54	49	37	42	328
Total	286	181	150	206	256	120	78	57	1334

Table 2. F-value (*F*) and level of significance (*P*) for aculeate Hymenoptera (Aculeate) species richness and abundance at farms in Co. Sligo (Ireland) in 2018 with regard to farming intensity (Intensity), farmland linear habitat (Habitat) and trap side (Trap Side). Numbers in bold indicate significance ($P < 0.05$).

	Intensity		Habitat		Trap Side	
	F	*P*	*F*	*P*	*F*	*P*
Aculeate						
Species Richness	5.43	**0.007**	3.49	**0.037**	6.97	**0.011**
Abundance	1.94	0.165	2.49	0.103	15.84	**<0.001**

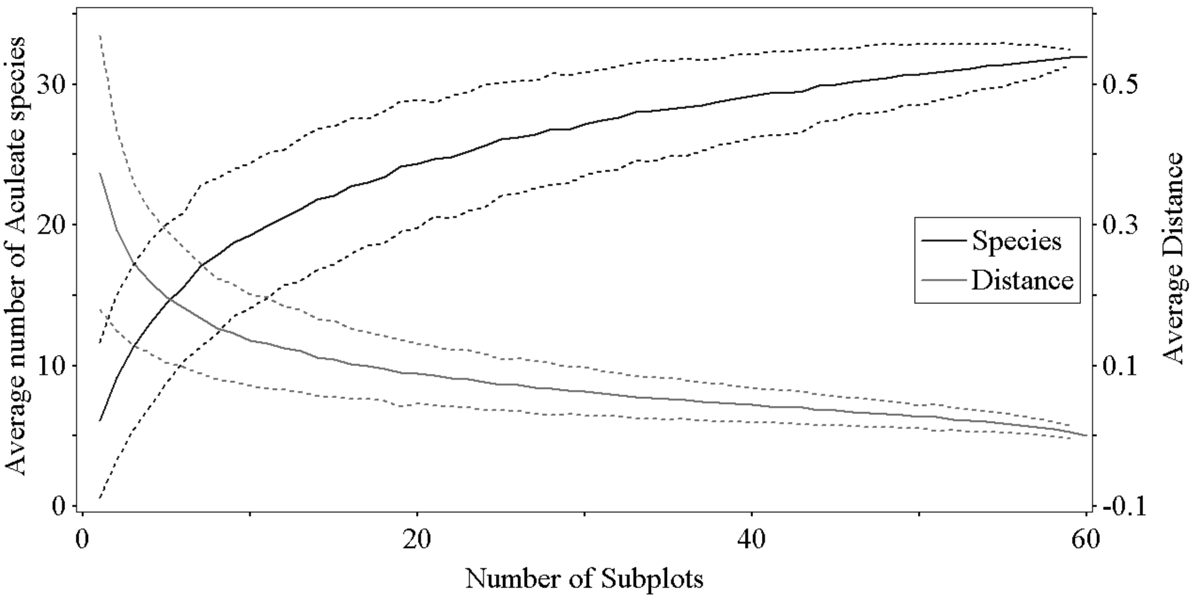

Fig. 1. Species-area curves for aculeate Hymenoptera (Aculeate) collected from Malaise traps across all selected farms in Co. Sligo (Ireland) in 2018. Dotted lines represent ± SDs. First-Order Jackknife estimate of total species richness was 38.88.

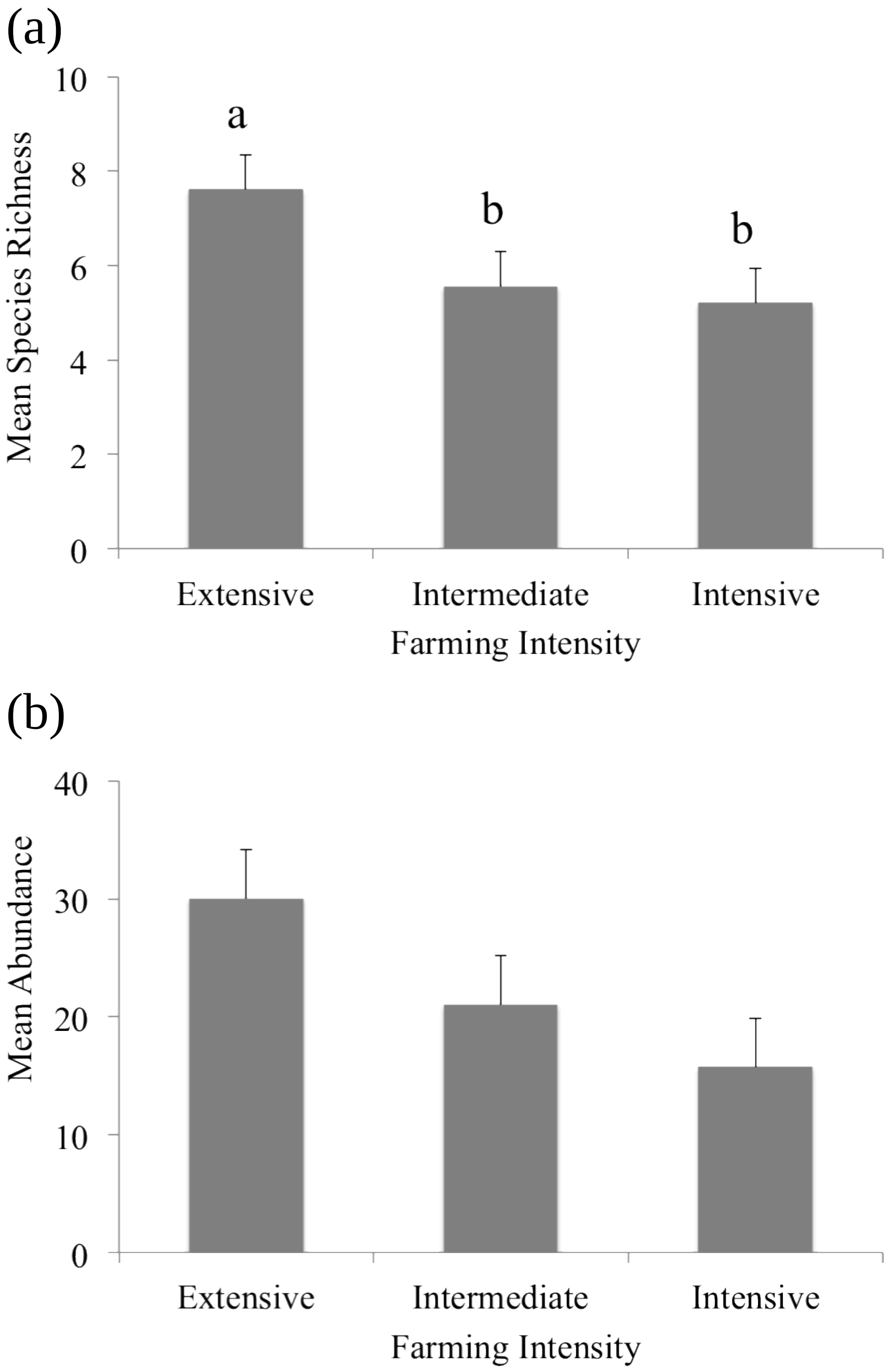

Fig. 2. Mean (a) species richness and (b) abundance of aculeate Hymenoptera across each farming intensity in Co. Sligo (Ireland) in 2018. Error bars represent SE. Different letters over the bars indicate significant differences between categories ($P < 0.05$).

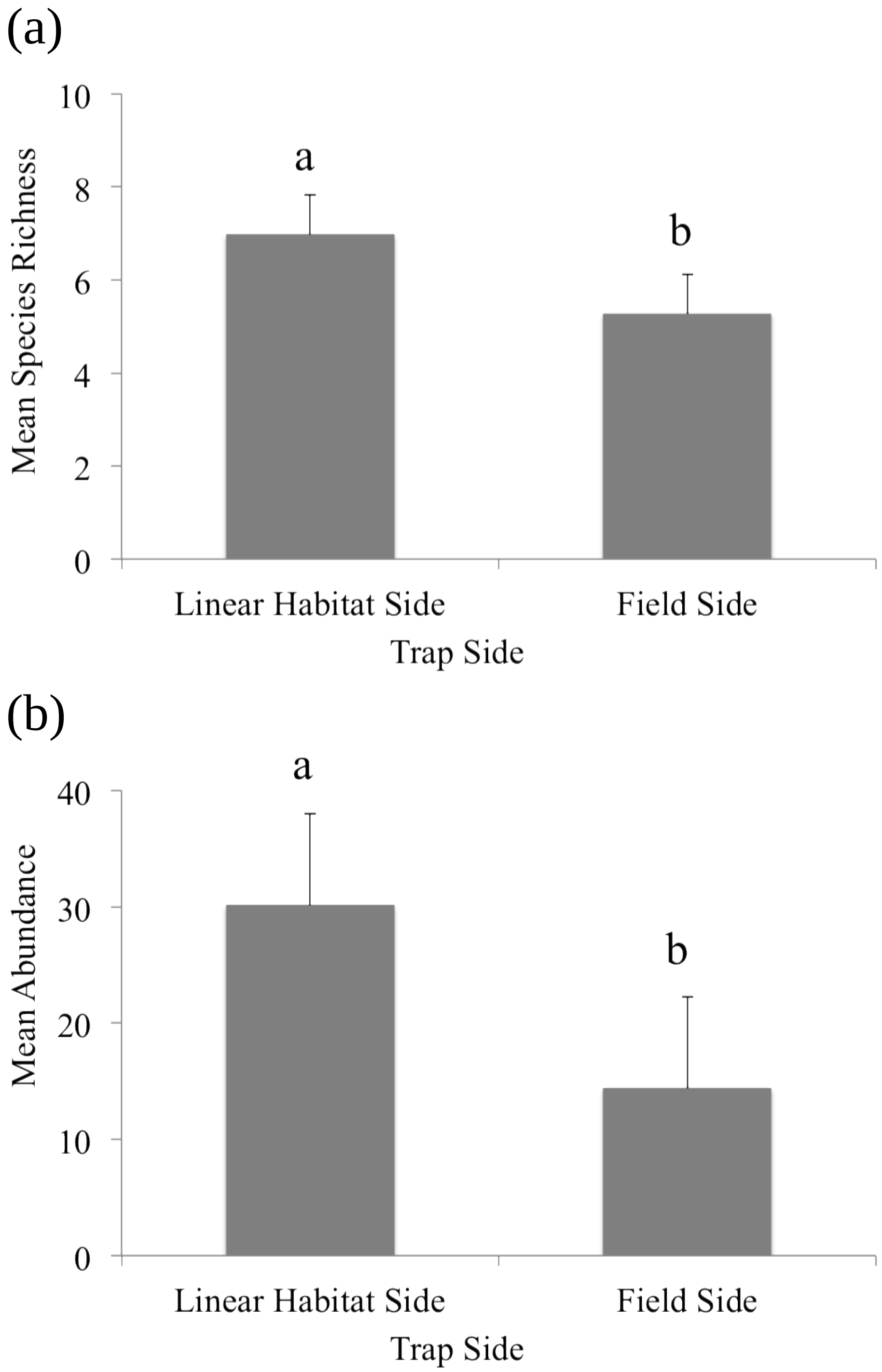

Fig. 3. Mean (a) species richness and (b) abundance of aculeate Hymenoptera with reference to trap side in Co. Sligo (Ireland) in 2018: side of the trap facing the farmland linear habitat (Linear Habitat Side) and side of the trap facing open field (Field Side). Error bars represent SE. Different letters over the bars indicate significant differences between categories (*P* < 0.05).

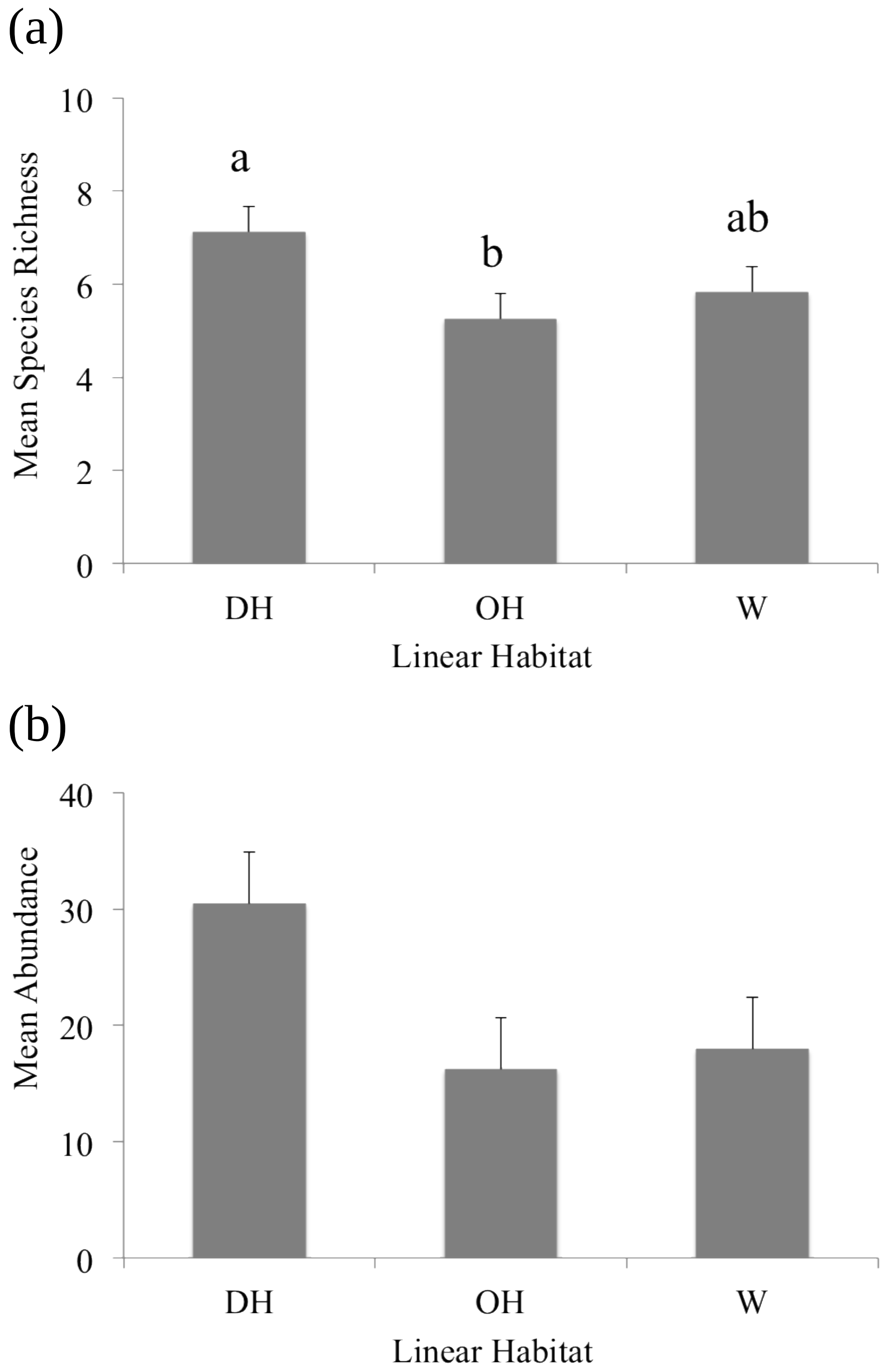

Fig. 4. Mean (a) species richness and (b) abundance of aculeate Hymenoptera across each farmland linear habitat type in Co. Sligo (Ireland) in 2018: DH (dense hedgerow); OH (open hedgerow); and W (watercourse). Error bars represent SE. Different letters over the bars indicate significant differences between categories (*P* < 0.05).

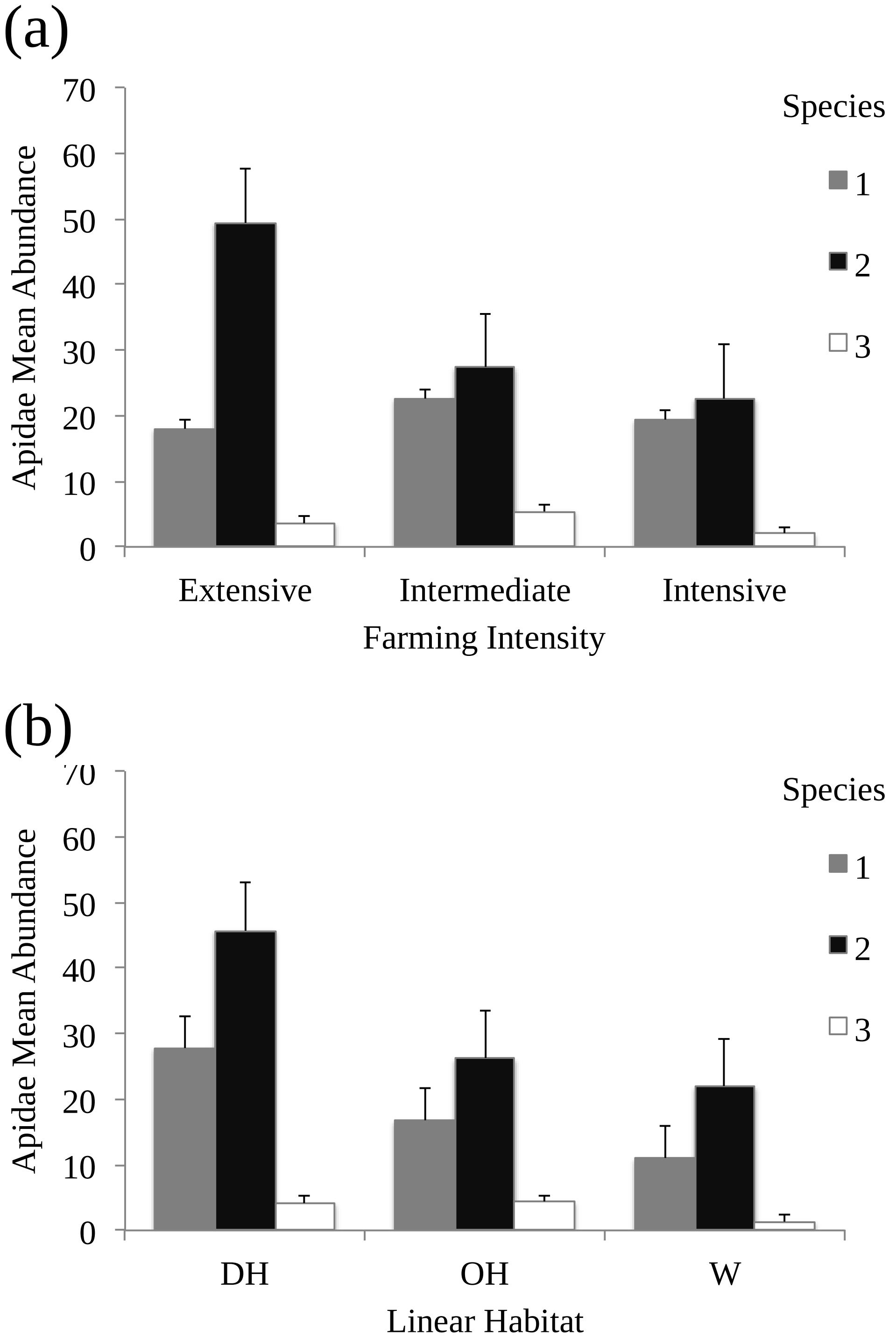

Fig. 5. Mean abundance of the three most abundant Apidae species across: (a) farming intensity and (b) farmland linear habitat at farms in Co. Sligo (Ireland) in 2018: DH (dense hedgerow); OH (open hedgerow); and W (watercourse). 1 (*Bombus lucorum*); 2 (*Bombus pascuorum*); 3 (*Bombus pratorum*). Error bars represent SE.

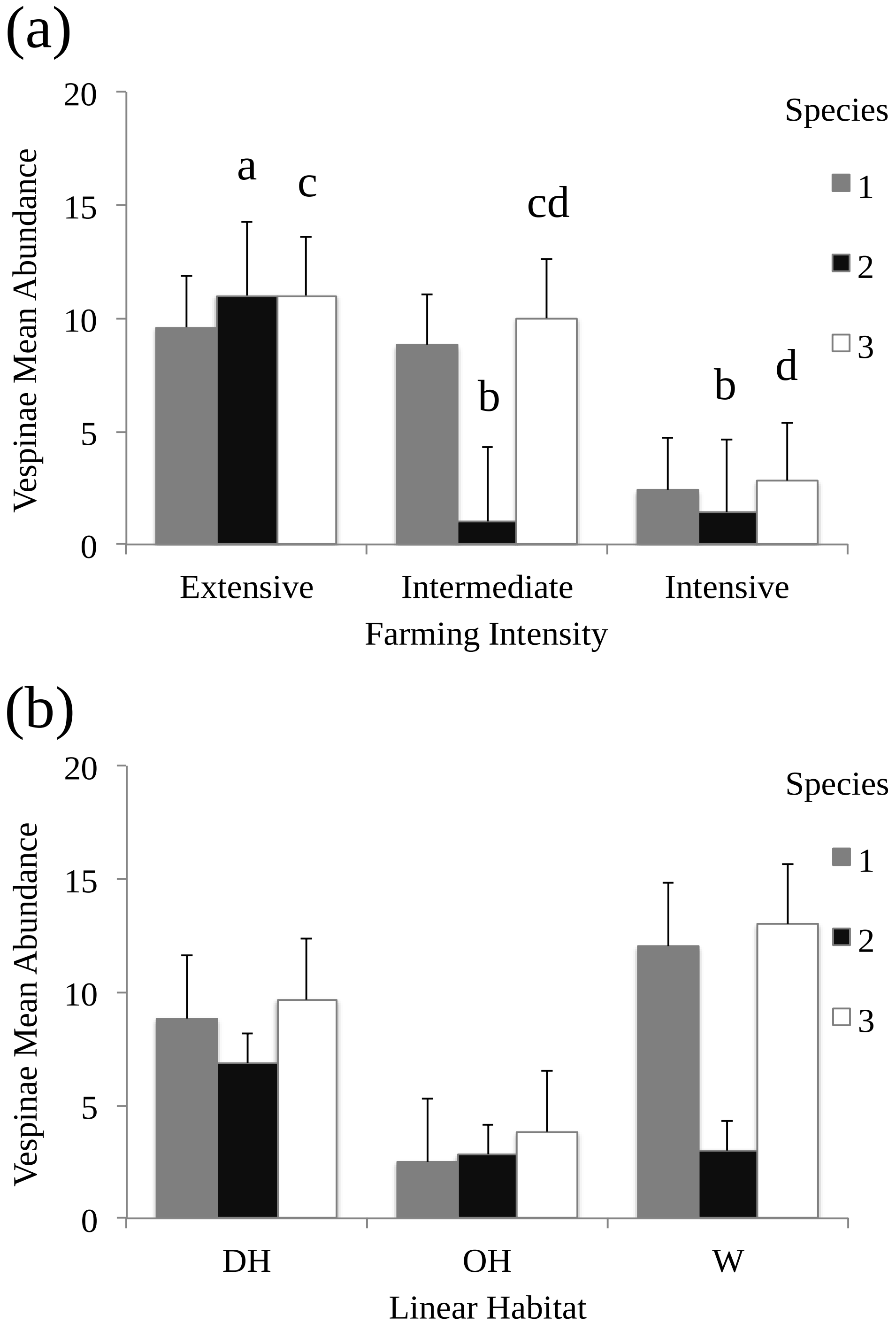

Fig. 6. Mean abundance of the three most abundant Vespinae species across: (a) farming intensity and (b) farmland linear habitat at farms in Co. Sligo (Ireland) in 2018: DH (dense hedgerow); OH (open hedgerow); W (watercourse). 1 (*Vespula germanica*); 2 (*Vespula rufa*); 3 (*Vespula vulgaris*). Error bars represent SE. Different letters over the bars indicate significant differences when they occur within each species ($P < 0.05$).

Supporting Information

Appendix S1. Site classification based on farming intensity across all selected farms in Co. Sligo, Ireland: extensive, intermediate and intensive; and farmland linear habitat type: (DH) dense hedgerow, (OH) open hedgerow, and W (watercourse).

Sites	Farmland Linear Habitat	HNV[1]
Extensive		
1	DH	6.9
2	OH	6.9
3	OH	7.5
4	DH	7.5
5	W	8.2
Intermediate		
6	DH	3.8
7	OH	3.8
8	DH	4.1
9	W	3.9
10	OH	4.6
Intensive		
11	DH	3.4
12	DH	3.4
13	W	3.4
14	OH	3.3
15	OH	3.3

[1] HNV (High Nature Value) indices were obtained from the maps of each farm and calculated through the web page http://www.high-nature-value-farmland.ie/is-your-farm-hnv/. The score is based on stocking rates (LU/ha), area of improved grasslands, area owned and farmed, and the visual observations of the size of the farm fields and field boundaries

Appendix S2. List of aculeate Hymenoptera captured during this investigation in 2018 at selected farms in Co. Sligo (Ireland) separated into each (sub-) family.

Apidae - Species List	Overall abundance	Percentage of total abundance
Andrena fucata Smith	7	0.7
Andrena haemorrhoa Fabricius	2	0.2
Andrena scotica Perkins	14	1.5
Bombus hortorum L.	22	2.3
Bombus jonellus Kirby	34	3.6
Bombus lapidaries L.	5	0.5
Bombus lucorum L.	300	31.5
Bombus muscorum L.	1	0.1
Bombus pascuorum Scopoli	497	52.1
Bombus pratorum L.	55	5.8
Bombus sylvestris Lepeletier	8	0.8
Lasioglossum albipes Fabricius	2	0.2
Megachile versicolor Smith	1	0.1
Nomada marshamella Kirby	2	0.2
Nomada ruficornis L.	1	0.1
Sphecodes ephippius L.	2	0.2
Sphecodes monilicornis Kirby	1	0.1

Crabronidae - Species List	Overall abundance	Percentage of total abundance
Crossocerus dimidiatus Fabricius	1	2.8
Crossocerus megacephalus Rossi	10	27.8
Ectemnius continuus Fabricius	3	8.3
Ectemnius lapidaries Panzer	8	22.2
Mellinus arvensis L.	13	36.1
Pemphredon lugubris Fabricius	1	2.8

Eumeninae - Species List	Overall abundance	Percentage of total abundance
Symmorphus bifasciatus L.	12	75.0
Ancistrocerus nigricornis Curtis	1	6.2
Ancistrocerus oviventris Wesmael	3	18.8

Vespinae - Species List	Overall abundance	Percentage of total abundance
Dolichovespula norwegica Fabricius	24	7.4
Dolichovespula sylvestris Scopoli	7	2.1
Vespula austriaca Panzer	6	1.8
Vespula germanica Fabricius	104	31.7
Vespula rufa L.	67	20.4
Vespula vulgaris L.	120	36.6

Appendix S3. Level of significance (*P*) from Mann-Whitney *U* test for the three most abundant Apidae species (*Bombus lucorum*, *Bombus pascuorum*, *Bombus pratorum*) and Vespinae species (*Vespula germanica*, *Vespula rufa*, *Vespula vulgaris*) at farms in Co. Sligo (Ireland) in 2018 with regard to farming intensity: extensive, intermediate and intensive; and farmland linear habitat types: DH (dense hedgerow), OH (open hedgerow) and W (watercourse). Numbers in bold indicate significance ($P < 0.05$).

	Intensity			Habitat		
	Comparison types		*P*	Comparison types		*P*
Apidae						
Bombus lucorum	Extensive	Intermediate	0.414	DH	OH	0.220
	Extensive	Intensive	0.805	DH	W	0.101
	Intermediate	Intensive	0.300	OH	W	0.454
Bombus pascuorum	Extensive	Intermediate	0.439	DH	OH	0.068
	Extensive	Intensive	0.170	DH	W	0.066
	Intermediate	Intensive	0.327	OH	W	0.625
Bombus pratorum	Extensive	Intermediate	0.400	DH	OH	0.833
	Extensive	Intensive	0.248	DH	W	0.156
	Intermediate	Intensive	0.075	OH	W	0.121
Vespinae						
Vespula germanica	Extensive	Intermediate	0.931	DH	OH	0.119
	Extensive	Intensive	0.119	DH	W	0.957
	Intermediate	Intensive	0.116	OH	W	0.399
Vespula rufa	Extensive	Intermediate	**<0.001**	DH	OH	0.351
	Extensive	Intensive	**<0.001**	DH	W	0.486
	Intermediate	Intensive	0.710	OH	W	0.124
Vespula vulgaris	Extensive	Intermediate	0.446	DH	OH	0.074
	Extensive	Intensive	**0.005**	DH	W	0.918
	Intermediate	Intensive	0.056	OH	W	0.183