Ecological value of different vegetated strip types in providing valuable insect-rich habitats for grey partridge chicks

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Abstract

The intensification and specialisation of agriculture has contributed to farmland wildlife decline, including farmland birds. Grey partridge is a farmland species which has experienced a significant decline across Europe in recent decades. Chick survival rate is a key determinant of grey partridge population change and depends essentially on the availability of insect food. In this study, ground-dwelling and canopy-dwelling insects were collected using pitfall trapping and sweep netting methodologies, respectively, on different strip types in an area established for the conservation of grey partridge. The aim was to further our understanding of the value of different vegetated strip types in providing insect-rich habitats for grey partridge chicks. Overall, wildflower strip (WS) provided the greatest insect abundance. Significantly more ground-dwelling insects were found on WS, natural regeneration (NS) and leguminous strips (LS) than on grass strip (GS). Canopy-dwelling insects were also significantly more abundant on WS compared to all other strip types. This study highlights that WSs may represent important habitats in providing insect-rich food for grey partridge chicks and sowing these strips may therefore play a key role in decreasing chick mortality and supporting grey partridge conservation. It also demonstrates that other different vegetated strip types may still provide strip-specific insect taxa, in addition to other valuable resources. This study recommends a complex mosaic of different strip types to provide key resources for grey partridge, such as insect and plant food, nesting habitats and overwinter cover.

Keywords

Canopy-dwelling insects • chick insect food • grey partridge (*Perdix perdix*) • ground-dwelling insects • vegetated strips

Introduction

Agricultural production in Western Europe has experienced significant intensification over recent decades (Batáry *et al.*, 2015). The intensification of agriculture based on increased agrochemical use, mechanisation and homogenisation of agricultural landscapes has led to the rapid decline in farmland wildlife across a wide range of taxa (Stoate *et al.*, 2001; Benton *et al.*, 2003; Kleijn & Sutherland, 2003), including farmland birds (Siriwardena *et al.*, 1998; Donald *et al.*, 2001; Vickery *et al.*, 2004; Gilbert *et al.*, 2021) and their food sources such as insects (Vickery *et al.*, 2001; Benton *et al.*, 2002; Holland *et al.*, 2006). The availability of insect food is an important factor influencing farmland birds (Vickery *et al.*, 2001; Bowler *et al.*, 2019), including grey partridge (*Perdix perdix* L.) (Benton *et al.*, 2002; Holland *et al.*, 2006).

The grey partridge is a farmland species and one of the most iconic game birds in Europe (Bro *et al.*, 2004; Joannon *et al.*, 2008; Aebischer & Ewald, 2012). It is often described

as an archetypal farmland bird closely linked with open-farmed landscapes (Potts, 1986) and sensitive to changes in farming practices and agricultural intensification (Sotherton *et al.*, 2014). The grey partridge was a common bird species of agricultural landscapes across Europe but in the recent decades has shown dramatic declines (Tucker & Heath, 1994; Birdlife International, 2004). Due to these steady and significant declines, the status of the European grey partridge population is now considered threatened with a decreasing breeding population (Article 12 European Assessment, available at <https://nature-art12.eionet.europa.eu/article12/>). In Ireland from the 1950s onwards, the grey partridge was sparsely distributed, while just a few decades later the native population consisted of less than 200 breeding pairs (Whilde & Partridge, 1993). However, in those areas in which no releases from game farms had taken place, local extinction had already occurred years earlier (Buckley *et al.*, 2012). At

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the beginning of the 1990s, a survey of the last two wild grey partridge populations was carried out in two cutaway peat land bogs at Boora (County Offaly) and Lullymore (County Kildare). In 1994, the Lullymore population comprised only 3–4 pairs, and by 2000, grey partridge in this area were extinct (Buckley *et al.*, 2012). In 1996, a joint conservation project was established in Boora with the aim of conserving and enhancing the last remaining wild grey partridge population in Ireland (Kavanagh *et al.*, 2001; Egan, 2008; Buckley *et al.*, 2012). Although the initial response of this recovery project was encouraging with a slight increase in the total autumn grey partridge population, due to bad weather conditions in the three successive summers and the loss of habitat for forestry and grassland, the population in Boora significantly declined to 22 individuals in autumn 2001 (Buckley *et al.*, 2012).

In 2005, with the purchase of 250 ha of cutaway bog at Boora by National Parks and Wildlife Service (NPWS) from Bord na Móna, the initial conservation project further expanded with the establishment of the new NPWS Grey Partridge Project (NPWS GPP) in 2006. The NPWS GPP has had mixed success in terms of grey partridge numbers so far with an estimate of density between 25 and 30 pairs per 100 ha in spring 2020. However, current indications are that the population is not expanding into surrounding farmland areas (personal communication), confirming the findings reported in a report in 2017 that there were no grey partridge individuals outside the core NPWS GPP area and a low population within the project area (Kavanagh, 2017).

Despite numerous attempts to conserve the Irish grey partridge population, this farmland species has been included in the red list of birds of conservation concern (Colhoun & Cummins, 2013; Gilbert *et al.*, 2021), with an average population in Ireland between 106 and 116 pairs in 2018–2019 (Article 12 European Assessment tool, available at <https://nature-art12.eionet.europa.eu/article12/>). The grey partridge population decline is related to the intensification of agriculture and farming practices (Potts, 1986). Three main causes were identified: the increase in the predation pressure, especially during nesting which may result in both adult and nest losses; the destruction of nesting habitats due to the loss of ecological valuable agricultural areas, including farmland linear habitats such as species-rich field margins and vegetated strips; and the reduction of chick food insects due to the intensification of farming practices, such as the diffuse application of insecticides and herbicides which is associated with the reduction in chick survival through direct and indirect effects (Potts, 1986).

Grey partridge chick survival has been identified as a key determinant of population change, with annual chick survival rates explaining over two-thirds of the annual variation in the population index (Aebischer & Ewald, 2012). Similarly,

previous studies have highlighted that the population crash after 1950 in the UK and in other European countries is closely linked to chick survival (Potts, 1986). Average chick survival in the period 1903–1950 was 51%, while only a few years later it had dropped to less than 20% (Potts & Aebischer, 1995), remaining at a constant low level with an average of 33% from 1955 to 1993 (Kuijper *et al.*, 2009).

Although grey partridge adults feed mainly on plant food, the chick diet during their first 2–3 wk of life is composed predominantly of insects (Potts, 1986; Brewin *et al.*, 2020). Preferred insect chick food includes among others, plant bugs (Hemiptera: Miridae), ground beetles (Coleoptera: Carabidae), weevils (Coleoptera: Curculionoidea), plant hoppers (Hemiptera: Fulgoromorpha), leaf beetles (Coleoptera: Chrysomelidae), ant pupae (Hymenoptera: Formicidae), sawfly larvae (Hymenoptera: Symphyta) and lepidopteran caterpillars (Lepidoptera) (Potts, 1986; Moreby *et al.*, 2006). Research involving nutrition experiments indicated that high protein intake from insects is crucial for chick survival and development (Southwood & Cross, 2002). Other studies have reported that chicks fed on an insect-rich diet grew faster and were heavier than other chicks. Furthermore, their primaries developed earlier, while chicks fed on an insect-poor diet cooled faster resulting in greater mortality over time (Liukkonen-Anttila *et al.*, 2002). There is therefore a close relationship between chick survival and insect abundance (Potts, 1986; Moreby *et al.*, 2006; Aebischer & Ewald, 2012).

The main factors which may cause a significant decrease in chick survival rate have shown to be related to the intensification of farming practices, including the widespread use of agrochemicals, such as insecticides and herbicides, and the loss and fragmentation of important chick-rearing habitats, such as vegetated strips and species-rich field margins (Kuijper *et al.*, 2009; Aebischer & Ewald, 2012). These ecologically enhanced habitats have shown to improve the availability of crucial foraging resources for both grey partridge chicks and adults, in addition to providing nesting sites (Buner *et al.*, 2005; Brewin *et al.*, 2020). Previous studies have shown that grey partridge quickly profit from these habitats with greater densities in these non-crop habitats in comparison to crop habitats and conventional agricultural fields (Bro *et al.*, 2004; Buner *et al.*, 2005).

In this study, the effects of five differently vegetated strips on insect density were investigated with the aim of understanding their role in providing valuable insect-rich habitats for grey partridge chicks. This study is important because the knowledge of insect occurrences in different vegetated strip types within agricultural areas and the factors influencing habitat selection and food availability may assist in maximising the value of foraging habitats for farmland birds such as grey

partridge (Douglas *et al.*, 2009). In particular, the objectives of this study were to:

- (1) Compare the value of diverse strip types for insect assemblages, including grey partridge chick key prey items, with reference to ground- and canopy-dwelling insects
- (2) Evaluate the effects of different strip types on Carabidae and Staphylinidae abundance within the ground-dwelling insect group
- (3) Describe how different strip types affect the occurrences of the most abundant canopy-dwelling insect taxa, such as Diptera, Hemiptera, Coleoptera and Hymenoptera. By addressing these research questions, conservation measures for grey partridge can be more informed and effective

Materials and methods

Study sites

The study was carried out in Boora, County Offaly (Ireland). Most of the area was formerly described as a peatland, which has been harvested by the semi-state company Bord na Móna to produce energy, domestic fuel and horticulture peat (Kavanagh *et al.*, 2001; Egan, 2008). The extraction of the peat resource in the area lasted for approximately 40 yr leaving an open and impoverished area described as cutaway peat land (Buckley *et al.*, 2012). Although initially the re-use of this site was focused on the development of grasslands and coniferous plantations, numerous large areas were not suitable for these land use options due to the soil characteristics, including drainage conditions. Therefore, in 1995, a group composed of representatives from Bord na Móna and local communities developed an integrated land use plan which included the natural recolonisation and development of a wide range of wetland and wildlife habitats (Egan, 2008). In 2006, the NPWS GPP further developed the area with the establishment on bare peat areas of a heterogeneous landscape characterised by cereal crops interspersed with different linear habitat types, including grass (GS) and wildflower strips (WS). These habitats were designed to provide the fundamental resources required by grey partridge such as seed-rich and insect-rich habitats and nesting cover (Kavanagh *et al.*, 2001).

In this study, insect abundances were analysed between July and September 2019 in five different strip types: cereal strip (CS), GS, WS, natural regeneration strip (NS) and leguminous strip (LS). These strip types have been chosen to represent the main strip types present in the area of study. The CS and WS were established in 2018, LS in 2017, and GS was established in 2013. The NS was a grass field margin that has been set aside for a few years. Strips were sown with seed mixtures commercially available and were not

sprayed with agrochemicals. All the strips were bounded by other linear features. The CS, WS, LS and NS were bounded by grassy field margins on one side and by greenways on the other. The GS was bounded by a green way and a WS. The most dominant plant species present in each strip type were assessed using direct visual assessment in three different 1-m² quadrats placed randomly in each strip. Strips dimensions did not vary considerably between the different strip types, with an average length between 50 and 75 m and an average width between 2 and 5 m.

Sampling protocol

Ground-dwelling insects were sampled using pitfall traps. Pitfall trapping was carried out because it is the best-known cheap and easy sampling methodology for the capture of large samples of ground-dwelling insects, including Carabidae and Staphylinidae (Schmidt *et al.*, 2006; Kotze *et al.*, 2011). One group of six traps was set up in the centre of each strip type along a transect parallel to the strip margin in order to optimise the catch and minimise occasional trap losses (Kotze *et al.*, 2011). Each trap within every trap group was placed at a distance of 10 m from each other. The minimum distance between each trap group was 200 m to allow sample independence. Plastic cups (depth: 10 cm; diameter: 8.5 cm) were situated just below the soil surface. Pitfall traps were half filled with 70% ethylene glycol and a few drops of unscented and uncoloured detergent to break the surface tension. Traps were covered to prevent flooding, desiccation, scavenging and by-catch (Lange *et al.*, 2011). During the sampling period, the ethylene glycol was rarely diluted further by rainwater and no trap overflowed. Ground-dwelling insects were collected after 10 d in three sampling periods from July to September. All samples collected were kept in 70% ethylene glycol and taken to laboratory for further analysis. Carabid beetles were identified to species level using Luff (2007), while staphylinids were separated into morphospecies according to morphological characteristics using the protocol described by Oliver & Beattie (1993). Rapid biodiversity evaluation methodologies such as those based on morphospecies have been widely and effectively used for the rapid identification of numerous and diverse insect groups that otherwise would have required time and specific expertise not readily available (Carey *et al.*, 2017).

Canopy-dwelling insects were sampled by sweep netting the vegetation canopy. Sweep netting methodology was carried out because it has been preferentially used for the capture of chick food insects in previous studies (Itämiä *et al.*, 1996; Thomas *et al.*, 2001). In each strip type, three 10 m-transects parallel to the strip margin were walked at a slow speed and insects were collected using a standard sweep net of 0.4-m diameter with a 0.38-m wooden handle and a net bag with a curved tip to prevent insects escaping.

Each transect within the same strip type was at a distance of 10 m from each other. Strip types were randomly sampled in sunny and dry weather conditions twice on the same day (one in the morning and one in the afternoon) in two sampling periods from July to August. All insects captured were anaesthetised/killed using killing jars containing ethyl acetate and afterwards placed in sampling plastic bags and taken to the laboratory. All sampling bags were hand-sorted and all insects were removed and transferred to containers filled with 70% ethanol. Due to the large numbers and diversity of canopy-dwelling insects collected, all specimens were firstly sorted to order and afterwards separated into morphospecies. Although a very low number of the European honey bee (*Apis mellifera* L.) were captured, they were not included in the analysis because their occurrence largely depends on human factors such as hive management rather than merely ecological factors (Kremen *et al.*, 2004; Winfree *et al.*, 2007).

Data analysis

For statistical analyses, abundances of ground- and canopy-dwelling insects were treated separately. For both ground- and canopy-dwelling insect groups, statistical analyses were carried out using the cumulative total number of specimens collected in each strip type. Similar procedure was used to calculate the abundance of all taxa collected, including Carabidae and Staphylinidae within the ground-dwelling insect group, and Diptera, Hemiptera, Hymenoptera and Coleoptera within the canopy-dwelling insect group. Statistical analyses of Lepidoptera, Orthoptera, Odonata and Diplura abundances within the canopy-dwelling group were not performed due to the low number of specimens of these taxa collected. Abundances of the two main insect groups and of all insect taxa collected did not display a Poisson distribution and were assessed using general linear mixed models with normal error distribution (West *et al.*, 2014). Strip type was included as fixed factor in the models, while trap/transect identity was included as random factor. Where a significant effect of strip type was shown, *post hoc* Tukey tests were performed to determine significant differences between different strip types. For the analysis of the effects, significance was set at $P < 0.05$. Before running general linear mixed models, normal distribution of all insect taxa/group abundance was tested. Where data were not normally distributed, $\ln(x + 1)$ was used to transform the data and meet assumptions of normality. If data were not normally distributed even after $\ln(x + 1)$ transformation, non-parametric Mann–Whitney *U* tests were performed to test the effects of different strip types on insect abundances. Statistical analyses were carried out using the software SPSS v25 (IBM SPSS Statistics 2017, Armonk, NY, USA) for ground- and canopy-dwelling insect groups.

Results

The botanical assessment of the most dominant plant species carried out in each strip type found that CS was entirely dominated of cereal crop species (*Triticum* spp.), meanwhile GS was composed mainly of cocksfoot (*Dactylis glomerata* L.) and creeping red fescue (*Festuca rubra* L.). The WS was composed mostly of *Daucus carota* L., *Ranunculus* spp., *Trifolium* spp., *Achillea millefolium* L., *Lotus corniculatus* L. and *Chrysanthemum leucanthemum* Lam., interspersed with a few tussocky grass species consisting mainly of *D. glomerata*. The NS represented a transitional stage dominated almost completely of scrub species such as grey willow (*Salix cinerea* L.) and grass/herbaceous species such as *D. glomerata*, *F. rubra* and *Epilobium angustifolium* (L.) Scop. The LS was composed mostly of *Medicago sativa* L., *Trifolium* spp., *Melilotus* spp., *Malva alcea* L. and *Cichorium intybus* L. In total, 6,852 insects were collected during the sampling period. The WS harboured greater abundance of insects with 2,966 specimens, followed by LS with 1,747 individuals, NS with 1,046 insects and GS with 610 specimens. The CS had less insects with just 483 individuals (Figure 1). A total of 46 species/morphospecies (1,356 individuals) of ground-dwelling insects were captured using pitfall traps. The number of ground-dwelling specimens collected in the 10-d sampling period in each of the three collections ranged from a maximum of 597 individuals in the first collection (2 August), of which 224 were carabids and 373 were staphylinids, to a minimum of 291 individuals in the last collection (19 September), of which 201 were carabids and 90 were staphylinids. The list of Carabidae species collected in this study is reported in Appendix A1. Ground-dwelling insect abundance differed significantly among strip type ($P < 0.001$). *Post hoc* Tukey

Figure 1. Number of total insects collected across each strip type (cereal strip [CS], grass strip [GS], wildflower strip [WS], natural regeneration strip [NS], leguminous strip [LS]) in Boora, Co. Offaly (Ireland) in 2019.

tests showed significantly greater abundance on LS, NS and WS compared to GS. Although more ground-dwelling individuals were found on CS compared to those found on GS, there were no significant differences between these two strip types (Figure 2).

Analyses of Carabidae and Staphylinidae abundance showed different patterns for the two ground-dwelling insect groups. Within the family Carabidae, significantly greater abundance was found on NS, WS and LS compared to CS and GS. Among the family Staphylinidae, significantly more rove beetle specimens were found on LS and CS compared to NS and GS. Significantly greater staphylinid abundance was also found on LS compared to WS.

A total of 5,496 canopy-dwelling insects (121 morphospecies) were collected during the two sampling periods. The most abundant taxa were Diptera with 2,989 specimens separated into 40 morphospecies. Within the order Diptera, the most numerous individuals were small flies (<5 mm) belonging to the families Milichiidae, Periscelididae, Sciaridae, Sepsidae and Dolichopodidae. The second most abundant taxa were Hemiptera with 18 morphospecies and 1,764 specimens, of which the most abundant individuals were true bugs and plant hoppers belonging, respectively, to the suborders Heteroptera (family Miridae) and Homoptera (family Aphrophoridae). Hymenoptera were the third most abundant taxa with 468 individuals and 35 morphospecies followed in decreasing order by Coleoptera (252 individuals and 16 morphospecies, of which the most abundant specimens belonged to the family Curculionidae), Lepidoptera (17 specimens and 3 morphospecies), Orthoptera (4 individuals

Figure 2. Overall mean abundance of ground-dwelling insects collected across each strip type (cereal strip [CS], grass strip [GS], wildflower strip [WS], natural regeneration strip [NS], leguminous strip [LS]), with reference to Carabidae and Staphylinidae. Different letters over the bars indicate significant differences among strip types ($P < 0.05$).

Figure 3. Overall mean abundance of canopy-dwelling insects collected across each strip type (cereal strip [CS], grass strip [GS], wildflower strip [WS], natural regeneration strip [NS], leguminous strip [LS]), with reference to the most abundant insect taxa (Coleoptera, Diptera, Hemiptera, Hymenoptera and Others taxa). Different letters over the bars indicate significant differences among strip types ($P < 0.05$).

and 2 morphospecies) and Odonata and Diplura (both with just one individual).

Canopy-dwelling insect abundance differed significantly among strip type ($P < 0.001$). Significantly greater abundance was found on WS compared to LS, NS, GS and CS. Significantly more specimens were also found on LS compared to NS, GS and CS. Furthermore, GS and NS contained significantly more canopy-dwelling insects compared to CS (Figure 3). Significantly more Diptera specimens were found on WS compared to NS, GS and CS. Significantly greater Diptera abundance was also found on LS and NS compared to CS, and on LS compared to GS. Among the order Hemiptera, significantly greater abundance was found on WS compared to all the other strip types, while CS had significantly less Hemiptera specimens. Within the group Hymenoptera, significantly greater abundance was found on WS compared to NS and CS, on LS compared to CS and on GS compared to CS. Among the order Coleoptera, the Mann–Whitney U test found significantly more specimens on LS compared to NS, CS and GS, and on WS and NS compared to CS and GS.

Discussion

In this study, WS harboured more total insects than any other individual strip type. The beneficial influence of WSs on insect assemblages is supported by previous studies. These farmland linear habitats have been described as an effective and flexible tool to support insect occurrences in agricultural areas (Thomas & Marshall, 1999). In a recent review, Haaland

et al. (2011) reported that WSs tend to support greater insect abundance compared to other vegetated strip types. Greater insect abundances in these habitats are mainly due to factors such as plant diversity and flower abundance. Particularly, plant diversity is a key factor which may stimulate insect occurrences in differently vegetated strips, with beneficial effects on insect diversity (Marshall & Moonen, 2002; Woodcock *et al.*, 2005; Vickery *et al.*, 2009). This is mainly due to the provision of a wide variety of valuable resources such as pollen, nectar, seeds and larval food in areas with a rich variety of flowering plants, which has positive effects for a wide range of insects (Marshall *et al.*, 2006; Vickery *et al.*, 2009). Flower abundance also plays an important role in supporting insect assemblages (Haaland *et al.*, 2011). A greater number of flowering plants have shown to provide fundamental foraging resources for many insect species, including pollen and nectar feeders and predatory species (Zurbrugg & Frank, 2006; Carvell *et al.*, 2007). Another factor which may explain greater abundances on WS is the complex vegetation structure that characterises these linear habitats. The heterogeneous vegetation structure has shown to provide diverse niche for many species, thus promoting insect assemblages (Thomas & Marshall, 1999; Aviron *et al.*, 2006; Haaland *et al.*, 2011).

It is therefore not surprising that in this study more insects were found on those strips with greater plant diversity and a more complex structure such as WS and LS, and to a lesser extent NS, while significantly lower insect abundance was found on those linear habitats such as GS and CS with lower plant species and structural complexity. These findings are supported by previous studies in which simple sward strips were compared to more complex and diverse sward strips. Thomas & Marshall (1999) found greater arthropod abundances in wildflower plots compared to only grass plots. Similarly, Meek *et al.* (2002) reported a strong tendency for pollen and nectar-feeding insects, and to a lesser extent for predatory species, towards flower mixtures compared to tussocky grass mixtures. Other research found that species poor-vegetated strips resulted in lower abundances of pollinators, herbivores and predatory insects (Pywell *et al.*, 2011). In our study, lower insect abundances on GS may therefore be due to the fact that this strip was sown with competitive grass species, including mainly cocksfoot *D. glomerata*, which may significantly reduce the sward species variety and structural complexity and consequently negatively influence insect occurrences. This is supported by previous research in which the less diverse sward has shown to support a lower diversity of broad-leaved forbs (Smith *et al.*, 1997), thus providing fewer valuable habitats and resources for many species which may translate into significantly lower insect abundances (Vickery *et al.*, 2002). As with GSs, CSs have shown in the literature to rarely sustain the diverse insect assemblages that generally occur

in more botanically diverse strips (Vickery *et al.*, 2009). Pywell *et al.* (2007) reported lower abundances of a wide range of insect taxa in cereal field margins compared to field margins sown with a flower mixture. This may be due to two main reasons: CSs are usually ploughed and sprayed with herbicides and insecticides, which are disruptive management practices for many insect species, and the vegetation is mainly composed of crop plants resulting in a less diverse habitat (Vickery *et al.*, 2002).

A similar pattern to total insect abundances was found for ground-dwelling insects, with greater insect abundance on more complex sward strips compared to less diverse sward strips. Significantly more carabid beetles were found on NS, WS and LS compared to CS and GS. The beneficial effects of vegetated strips left to naturally regenerate on the occurrences of ground-dwelling insects such as carabid beetles have shown to be linked mainly to sward composition and structural heterogeneity (Vickery *et al.*, 2009). In our study, most ground beetles collected on NS belonged to the single large body size species *Pterostichus madidus* Fabricius. Large body size and flightless carabid species are known to be associated with more stable and persistent habitats (Gnetti *et al.*, 2015; Hiramatsu & Usio, 2018), because in these less disturbed areas dispersal is less important (Riley & Browne, 2011). However, grey partridge chicks seem to prefer smaller beetle species, such as those belonging to the genus *Trechus* and *Bembidion*, which have been reported to be key prey items in previous research (Potts, 1986; Moreby *et al.*, 2006; Kuijper *et al.*, 2009). In contrast to large body size carabid beetles, smaller species with flying capability have shown to be more closely linked to less stable habitats (Blake *et al.*, 1994). This is because the rapid colonisation of more disturbed open habitats reflects their high dispersal capability (Riley & Brown, 2011). It is not surprising therefore that in this study these small body size ground beetle species were more abundant on less stable habitats such as WS compared to more stable habitats such as NS, as supported by previous research (Meek *et al.*, 2002). These findings may therefore suggest the importance of WSs in providing key ground beetle preys for grey partridge chicks.

Slightly different results were found for rove beetles, with significantly more staphylinids on LS and CS. If high abundance on LS may be explained by the complex structure and greater plant diversity, large number of staphylinids on CS may be due to the absence of agrochemical applications in this linear habitat. These results are supported by previous research in which the absence of agrochemicals has reported to favour specific ground-dwelling insect taxa (Moreby & Southway, 1999). Furthermore, the extensification of agricultural practices on CSs, such as the strict restriction of agrochemical use, has shown to significantly increase the annual plant diversity (Critchley *et al.*, 2004), providing

valuable habitats for specific ground-dwelling insect species (Pywell *et al.*, 2007).

Significantly greater canopy-dwelling insect abundances were found on WS compared to the other differently vegetated strips, suggesting the importance of these strips in providing many valuable resources for a wide range of canopy-dwelling insect taxa. Similar pattern was found for insects belonging to the order Diptera with greater insect abundance on WS. In this study, the majority of dipteran insects collected were very small morphospecies (<5 mm), which may have relatively poor value as dietary item for grey partridge chicks. This is because grey partridge chicks seem to prefer relatively larger insects, including bigger taxa within the Diptera such as crane flies (Tipulidae) (Potts, 1986). However, very few large-size species were found, suggesting the lesser importance of WSs in providing summer dipteran dietary items for grey partridge chicks.

Significantly greater abundance of Hemiptera was also found on WS compared to any other individual strip type. This is supported by previous studies in which WSs have shown to positively influence true bugs (Heteroptera) (Haaland *et al.*, 2011). Key factors such as plant diversity, flower abundance and highly structured vegetation seem to play an important role in enhancing bug occurrences and predicting the presence of specific Heteroptera taxa (Frank & Künzle, 2006; Zurbügg & Frank, 2006). These factors may explain the findings in this study in which WS seems to provide a valuable habitat for a wide range of Hemiptera taxa, including plant bugs and plant hopper, which are both known as key prey items and preferred insect food for grey partridge chicks (Potts, 1986; Itämes *et al.*, 1996; Moreby *et al.*, 2006). The WSs may therefore represent valuable habitats in providing key hemipteran prey for grey partridge chicks.

More Hymenoptera insects were also found on WS, confirming previous research in which wildflower areas provided important habitats for these insect taxa, especially larger species such as those belonging to the family Apidae (Haaland *et al.*, 2011). However, in our study, most of the hymenopterans collected were very small parasitoid wasps. High abundance of parasitoid wasps on WS may be due to the fact that individuals of this wide hymenopteran group in the early stage of their life before ovipositing need a certain amount of energy obtained from flower nectar (Hatt *et al.*, 2018), and areas with high concentrations of flowers such as WSs seem to represent the best habitats in providing more valuable food resources. However, previous studies indicated that other Hymenoptera taxa are preferred grey partridge chick food, such as sawfly (larvae) and ants (pupae) (Potts, 1986; Itämes *et al.*, 1996; Moreby *et al.*, 2006), which were not abundant in our study. Thus, as with Diptera, WSs may represent less important habitats in providing preferred hymenopteran preys for grey partridge chicks.

Greater abundance of canopy-dwelling Coleoptera was found on LS and WS. Pywell *et al.* (2007) found similar results, with more canopy-dwelling beetles in pollen and nectar mixture field margins compared to other differently vegetated margins, with the exclusion of WSs. Similarly, Meek *et al.* (2002) found more beetles collected with sweep netting in field margins sown with flower mixture. In another study, more herbivorous insects collected by sweep netting, including specimens of Coleoptera, were more abundant on wildflower plots compared to other vegetated plot types (Pywell *et al.*, 2011). Most of the canopy-dwelling beetles collected in our study were herbivorous such as leaf beetles and weevil. These groups have been regarded as important grey partridge chick food components (Potts, 1986; Itämes *et al.*, 1996; Moreby *et al.*, 2006), suggesting therefore the importance of areas sown with flower mixture such as LS and WS in providing valuable Coleoptera prey for grey partridge chicks.

Although the results of this research showed quite clearly the importance of complex sward strips with higher plant diversity and flower abundance, such as WS, in providing valuable habitats for many grey partridge chick insect preys, this was a small-scale initial study. Due to the limited amount of resources available, it was impossible to enhance the number of replicates including more than one strip per type in the analysis, in addition to extending the sampling period from late spring to the beginning of autumn. A more complete and extended sampling protocol would have led to more robust results with a clearer and broader idea of the ecological value of different vegetated strip types. However, despite limited resources, this initial study has provided important preliminary results and new insights concerning the knowledge of the quite unique context of the area under study, in which original peat bogs and wetlands were cutover and then reclaimed for agricultural purposes.

Conclusion

Chick survival rate is a key factor determining grey partridge populations within agricultural areas and depends crucially on the availability of insect food. This study demonstrates that WSs may represent valuable habitats in providing insect-rich food for grey partridge chicks, including key prey items. Sown WSs may therefore contribute to decrease chick mortality and support targeted grey partridge conservation projects (Buner *et al.*, 2005).

Although other vegetated strip types seem to be less valuable habitats in terms of insect prey abundance, this study shows that they may still provide valuable strip-specific insect taxa. A diversity of strip types is therefore ideally required to provide the optimum food supply for grey partridge chicks, in addition to other important resources for adults such as nesting habitats,

brood-rearing and overwinter cover and food (Thomas *et al.*, 2001; Henderson *et al.*, 2004).

However, previous studies showed that these strips may act as ecological traps for grey partridge (Kuijper *et al.*, 2009), acting as movement corridors for predators which may pose a serious threat (Josefsson *et al.*, 2013). Therefore, it may be of greater value to place a range of different vegetated plot types adjacent to grey partridge nesting sites, including in the first place wildflower mixture, thus reducing the risk of predation (Holland *et al.*, 2014).

To conclude, although there is no a one-size-fits-all solution to arrange an ideal grey partridge landscape, a heterogeneous mosaic of cereal crops interspersed with different vegetated strips and plots may therefore represent a key landscape configuration for the conservation of grey partridge populations within agricultural areas.

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Appendix A1: List of Carabidae species collected during this investigation in 2019 in Boora, Co. Offaly (Ireland)

Carabidae species list	Overall abundance	Percentage of total abundance (%)
<i>Agonum thoreyi</i> Dejean	5	0.69
<i>Agonum emarginatum</i> Gyllenhal	1	0.14
<i>Amara apricaria</i> Paykull	3	0.41
<i>Amara aenea</i> De Geer	1	0.14
<i>Amara bifrons</i> Gyllenhal	2	0.28
<i>Amara eurynota</i> Panzer	36	4.98
<i>Amara fulva</i> Müller	1	0.14
<i>Amara lunicollis</i> Schioedte	6	0.83
<i>Amara ovata</i> Fabricius	2	0.28
<i>Anchomenus dorsalis</i> Pontoppidan	20	2.77
<i>Bembidion lampros</i> Herbst	56	7.75
<i>Blemus discus</i> Fabricius	3	0.41
<i>Bradycellus harpalinus</i> Serville	1	0.14
<i>Bradycellus verbasci</i> Duftschmid	8	1.11
<i>Clivina fossor</i> Linnaeus	2	0.28
<i>Curtonotus aulicus</i> Panzer	3	0.41
<i>Harpalus latus</i> Linnaeus	1	0.14
<i>Harpalus rufipes</i> Degeer	29	4.01
<i>Nebria brevicollis</i> Fabricius	5	0.69
<i>Oxypselaphus obscurus</i> Herbst	1	0.14
<i>Patrobus assimilis</i> Chaudoir	1	0.14
<i>Poecilus versicolor</i> Sturm	212	29.32
<i>Pterostichus madidus</i> Fabricius	141	19.50
<i>Pterostichus melanarius</i> Illiger	1	0.14
<i>Synuchus vivalis</i> Illiger	3	0.41
<i>Trechoblemus micros</i> Herbst	1	0.14
<i>Trechus quadristriatus</i> Schrank	178	24.62