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Bird communities of an agricultural landscape in North-East Italy: implications for local conservation

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Abstract - This study, conducted between 2022 and 2024 in the Veneto plain (Italy) across 2000 hectares, monitored 142 bird species, including 27 of conservation concern and 37 indicators of High Nature Value (HNV) farmland. It examined how different agroecosystem habitats—wetlands, woodlands, croplands, hedges, and fallow fields—support bird biodiversity. Wetlands showed the highest species richness, especially for conservation-relevant birds, highlighting their ecological value. Hedges and fallow lands had the highest number of HNV species, acting as key biodiversity reservoirs. Woodlands, though less species-rich, hosted unique bird communities. Diversity indices (Shannon and β-diversity) were highest in wetlands and hedge/fallow areas, indicating both richness and species turnover. Principal coordinates analysis showed clear differences in community composition among habitats. Although the analysis of variance results were not statistically significant, ecological trends were evident. Constrained correspondence analysis confirmed a strong relationship between bird communities and habitat types. Some waterbirds were also found in croplands near microhabitats like ditches. Overall, the study emphasizes the importance of habitat heterogeneity in agricultural landscapes and recommends conserving wetlands, woodlands, and ecotones to support bird diversity and ensure sustainable land use.
Key words: agroecosystem, birds' diversity, habitat heterogeneity, conservation, wetlands.

Riassunto - Il presente studio è stato condotto tra il 2022 e il 2024 in un'area di 2000 ettari nella pianura veneta, dove sono state censite 142 specie di uccelli, di cui 27 considerate di interesse comunitario e 37 indicatori di aree agricole ad Alto Valore Naturale (HNV). È stata analizzata la capacità di diversi habitat dell'agroecosistema — zone umide, boschi, campi coltivati, siepi e terreni incolti — di sostenere la biodiversità ornitica. Le zone umide hanno mostrato la maggiore ricchezza di specie, soprattutto tra quelle di rilevanza conservazionistica, evidenziandone l'importanza ecologica. Siepi e incolti hanno registrato il numero più alto di specie HNV, fungendo da importanti

serbatoi di biodiversità. I boschi, sebbene meno ricchi di specie, ospitavano comunità ornitiche uniche. Gli indici di diversità (Shannon e β-diversità) sono risultati più elevati nelle zone umide e nelle aree con siepi/incolti, indicando sia una maggiore ricchezza sia un alto ricambio di specie. L'analisi PCoA ha evidenziato chiare differenze nella composizione delle comunità tra i vari habitat. Sebbene i risultati dell'ANOVA non siano stati statisticamente significativi, sono emerse tendenze ecologiche rilevanti. L'analisi a corrispondenza vincolata (CCA) ha confermato una forte relazione tra le comunità di uccelli e i tipi di habitat. Alcuni uccelli acquatici sono stati osservati anche nei campi coltivati, in prossimità di microhabitat come fossati. In generale, lo studio sottolinea l'importanza dell'eterogeneità degli habitat nei paesaggi agricoli e raccomanda la conservazione di zone umide, boschi e fasce di ecotono per sostenere la diversità ornitica e promuovere un uso sostenibile del suolo.
Parole chiave: agroecosistema, diversità di uccelli, eterogeneità degli habitat, conservazione, zone umide.

Introduction

The avifauna of agroecosystems is extremely threatened at a global and European level (Burfield *et al.*, 2023). Several species that characterize the agricultural areas of Europe and Italy are in an unfavorable state of conservation and show strong declining trends. It is estimated that the expansion of agriculture and land use change are responsible for the decline of approximately 60% of the birds included in the IUCN (International Union for Conservation of Nature) Red List (Norris 2008).

The decline in bird populations is primarily attributed to the widespread adoption of industrial agricultural practices (Wilson *et al.*, 2005; Johnson *et al.*, 2011), particularly the intensification of arable farming and grassland management. The abandonment of traditional agricultural practices has been a major driver of this decline, resulting in greater field and landscape homogenization, shorter crop rotations, the loss of semi-natural and uncultivated habitats, heavy use of agrochemicals, a shift from spring to autumn sowing, land drainage, a transition from haymaking to silage, early harvesting of crops, and a reduction in grassy field margins. All these factors have significantly influenced bird communities across Europe (Donald *et al.*, 2001; Benton *et al.*, 2003; Boatman *et al.*, 2004; Wilson *et al.*, 2009; Butler *et al.*, 2010; Wretenberg *et al.*, 2010).

As agricultural expansion and intensification continued to impact bird populations and broader biodiversity, research began to focus on how bird conservation could be effectively pursued within agricultural landscapes. This included identifying appropriate environmental enhancement measures to support avian biodiversity (Newton, 1998; Vickery *et al.*, 1999; Schulte *et al.*, 2006; Askins *et al.*, 2007).

Although habitat diversification is widely recognized as the most effective approach (Benton, 2003), in contexts where financial resources are limited and a fully diversified agroecosystem is not feasible, it becomes crucial to carefully evaluate which environmental enhancement measures can yield the greatest benefits for bird conservation.

In this context, a three-year dataset collected from an agroecosystem in the Po-Veneto plain enabled a series of reflections on which habitat types are particularly important for avifauna. The aim is to guide conservation efforts by prioritizing the creation of habitats that offer the highest value for bird communities and how environmental improvements should be carefully planned within agricultural landscapes.

Methods

This study was conducted in a farmland area of about 2000 ha on the estates of Cattolica agricola s.a.r.l. (Roncade, TV, Italy; 45°35'06.8"N 12°25'40.9"E). According to the Köppen-Geiger classification system (Kottek et al., 2006), the area's climate is classified as temperate subcontinental (Cf).

To detect the bird community present, the point count method was employed (Bibby *et al*., 2000; Gregory *et al*., 2004), using a radius of 100 meters from each sampling point. Over the course of three consecutive years (2022–2024), 12 surveys were conducted annually, covering all phenological phases of bird life. The surveys were carried out during the early morning hours: approximately from 8:00 to 12:00 for wintering species, and from 6:00 to 10:00 during the rest of the year.

The 16 monitoring points were distributed across the area based on logistics considerations, aiming to cover the entire agricultural landscape. Points were spaced at least 300 meters apart and represented a variety of environmental settings (Fig. 1). Each sampling point was assigned to one of four environmental categories—"crops," "woodland," "wetland," or "hedges and fallow"—based on the dominant habitat at the site. Birds observed flying overhead in high directional flight were excluded from the analyses.

Data analysis

Firstly, to visualize differences in species composition across habitats, data analysis was conducted using α-diversity (the average no. of species in a group), β-diversity, and the average Shannon-Wiener index (Magurran, 2004). To compare also the average Shannon indices between habitats the Hutcheson t test was performed (Hutcheson, 1970). In addition to assessing the overall bird community, diversity indices were also calculated for two key subgroups: indicator species of high

nature value (HNV) agricultural areas (Paracchini *et al*., 2008), and species of conservation concern at the European level (Annex I of the "Birds Directive").
Tukey's Honestly Significant Difference test (Tukey's HSD) was applied following ANOVA to assess whether differences in species means among the various habitat types were statistically significant. The test was performed using the TukeyHSD() function.
To explore and visualize similarities and dissimilarities in species composition across different habitats, Principal Coordinates Analysis (PCoA) was conducted using the *vegan* package. To test for statistically significant differences between groups, the *adonis* test (Anderson, 2001) was employed.
The relationship between bird communities and habitat characteristics was further examined using Canonical Correspondence Analysis (CCA) (Ter Braak, 1986). This multivariate method links species assemblages (dependent variables) to environmental variables (independent variables) through corresponding data matrices. The analysis aimed to identify associations between specific habitat types and the abundance of particular bird species.
All analyses were performed using RStudio, version 4.2.3 (RStudio Team, 2020).

Results

A total of 29393 observations representing 142 bird species were recorded; 27 species included in Annex I of Directive 147/09/EC and 37 indicator species of high nature value agricultural areas were contacted (Paracchini *et al*., 2008). Monitoring points characterized by wetland environments recorded the highest average number of total species as well as species of conservation interest (Tabs. 1 and 2). In contrast, points characterized by hedges and fallow land showed the highest average number of HNV indicator species (Tab. 3). Regarding β-diversity, agricultural habitat (crops) showed the highest value (0.88), suggesting a strong heterogeneity among sites, while woodlands showed the lowest β-diversity (0.53), indicating a greater uniformity among sampled communities. The average Shannon index is highest in wetlands (3.01), suggesting not only a high species richness but also a more equal distribution among species. In comparison, woodlands showed the lowest value (2.16), consistent with the other diversity indicators.
The analysis conducted using the Hutcheson test allowed to compare the average values of the Shannon diversity index among the different habitats. The results show that in some habitat pairs (woodland – wetland) the differences in diversity are statistically significant ($p < 0.05$), suggesting an effective variation in the composition of biological communities (Tab. 4). In particular, habitats with higher values of H are characterized by greater heterogeneity and equally distributed abundance among species. On the contrary, in many comparison pairs no significant differences emerged,

indicating a similar level of diversity among the environments considered. These results suggest that some habitats exert a more marked influence on the structure of communities than others.
Tukey's honestly significant difference test was performed anyway even though the ANOVA p-value>0.05, but still close to the threshold value (0.07449). Looking at the Tukey HSD output, differences approaching significance are observed for woodland-crops, wetland-woodland and hedges and fallow-woodland pairs.
Principal Coordinates Analysis (PCoA) shows a substantially differences in the ornithic composition of the different environmental typologies, with partial overlaps between crops-wetland-hedges and fallow. A different composition is recorded for the woodland category. Observing results from adonis test we can see that groups have significantly different compositions (R^2 0.36, $p < 0.02$).
According to the CCA analyses, there is a significant association between agroecosystem habitat categories and birds' community (Costrained = 0.3598, $p < 0.01$). Hawfinch *Coccothraustes coccothraustes* (Linnaeus, 1758), Black kite *Milvus migrans* (Boddaert, 1783), Pied flycatcher *Ficedula hypoleuca* (Pallas, 1764) are some of the birds that were associated with woodland habitat; *Curruca curruca* (Linnaeus, 1758), *Tringa glareola* (Linnaeus, 1758), Ruff *Calidris pugnax* (Linnaeus, 1758) and others were associated with wetland habitat.

Discussion

The 142 bird species observed represent approximately 25% of the total avifauna of Italy (Baccetti *et al.*, 2021). Although most of the recorded species are considered common in Italy, the number of species of conservation interest is significant. These species appear to be primarily associated with the presence of wetland habitats, which should therefore be prioritized when planning environmental improvements.
Nevertheless, in well-managed agricultural systems, wetlands are considered valuable assets that support food production, efficient water management, and overall ecosystem resilience (Stroud, 2022). Wetlands are highly vulnerable and among the most threatened natural resources; it is estimated that over 21% of these habitats have been lost, primarily due to their conversion into cropland (Fluet-Chouinard *et al.*, 2023).
The analysis of bird diversity in different habitat types shows drastic variability in species richness and turnover between communities, which highlights the ecological significance of some land-use categories. The evidence for all bird species (Tab. 1), High Nature Value (HNV) farmland birds (Tab. 3), and species of conservation concern (Annex I of the EU Birds Directive, Tab. 2) collectively point to wetlands, hedgerows, and fallow land as critical habitats for avian diversity.

Wetlands seem to be the most diverse environment in alpha ($\alpha = 73$) and gamma diversity ($\gamma = 117$) with an optimal mean Shannon index value (3.01) suggesting not only species richness but also an balanced community structure (Magurran, 2013). This finding is in line with the well-documented biodiversity hotspots of wetlands (Gibbs, 2000; Mitsch & Gosselink, 2015), which offer stable food sources and structurally complex environments.

Hedgerows and fallows have high α and γ values, and have moderate to high β-diversity between species groups. Both are structurally complex and semi-natural, and provide nesting, foraging, and corridor functions that can be of value to both specialist and generalist birds (Hinsley & Bellamy, 2000; Benton *et al*., 2003). These features are especially valuable for farmland birds and Annex I species, where β-diversity scores of 1.16 and 1.31, respectively, reflect high site heterogeneity.

Croplands, while sometimes with high γ-diversity (e.g., 98 for all species), also have high β-diversity values (1.46 for HNV species, 1.19 for Annex I species), indicating that community composition among sites is extremely variable. The variation should be expected to be a reflection of the effect of management intensity, crop types, and landscape setting. These patterns are consistent with earlier work that has shown that intensively managed or mixed farmland can support significant biodiversity (Donald *et al*., 2001; Kleijn *et al*., 2006).

In contrast, woodlands always have the lowest species richness and diversity for all groups with α values of 51, 8.25, and 3.5 for all species, HNV species, and Annex I species, respectively. Although their β-diversity is very high for conservation species (1.29), woodlands are less favorable for farmland birds as they possess a closed canopy and a narrow herbaceous layer (Fuller *et al*., 2005).

Indicator bird species of high nature value (HNV) agricultural areas (Paracchini *et al*., 2008) also appear to be somewhat linked to the presence of wetlands in agricultural landscapes. The average values for this group, recorded in the farm's wetlands, are only slightly lower than those observed in areas characterized by hedges and fallow land. This may be attributed to the presence of ecotone environments between humid zones and crops, which provide suitable habitats for species such as the Common Reed Bunting *Emberiza schoeniclus* (Linnaeus, 1758), Ruff *Calidris pugnax* (Linnaeus, 1758), Garganey *Spatula querquedula* (Linnaeus, 1758), Eurasian Bee-eater *Merops apiaster* (Linnaeus, 1758), Common Snipe *Gallinago gallinago* (Linnaeus, 1758), and others. For these reasons, the creation and restoration of wetlands should be among the top priorities in projects aimed at rehabilitating degraded agroecosystems. Wetlands are crucial for supporting birdlife in agricultural settings, offering essential resources such as food, shelter, and breeding grounds (Czech & Parsons, 2002; Ma *et al*., 2010; Panuccio *et al*., 2017).

Hedges and fallow lands were also found to be species-rich environments and generally more biodiverse than wooded areas. Woodland habitats appear to be less utilized by birds than cultivated fields (Tab. 1); however, the bird community associated with woodlands is markedly different from that of other habitat types (Figs. 2 and 3), making them worthy of conservation as they function as habitat islands (Opdam *et al*., 1985). For this reason, promoting the presence of wooded green structures is important for improving the overall ornithological composition of agroecosystems (Edo et al., 2024).

Habitat heterogeneity within agroecosystems plays a key role in shaping bird community structures across agricultural landscapes (Brambilla *et al*., 2019; Anderle *et al*., 2023). Even small-scale features such as isolated trees, scattered shrubs, and erratic boulders can make a significant contribution to local biodiversity (Pustkowiak *et al*., 2021). These elements can act as keystone structures, disproportionately enhancing habitat quality and availability for various species despite their limited spatial extent (Tews et al., 2004).

The habitat categories reflecting landscape heterogeneity examined in this study appear to influence bird communities at a local scale (Fig. 4). Forest-associated species, such as the Hawfinch *Coccothraustes coccothraustes* (Linnaeus, 1758), Woodcock *Scolopax rusticola* (Linnaeus, 1758), Pied Flycatcher *Ficedula hypoleuca* (Pallas, 1764), and Goldcrest *Regulus regulus* (Linnaeus, 1758), were mostly observed in points dominated by woodland. In contrast, open-habitat species such as the Crested Lark *Galerida cristata* (Linnaeus, 1758), Whinchat *Saxicola rubetra* (Linnaeus, 1758), and Water Pipit *Anthus spinoletta* (Linnaeus, 1758) were found in both cultivated fields and fallow areas. Waterbirds were almost exclusively linked to wetlands, although occasional observations occurred in cultivated fields—especially along grassy margins, near vegetated ditches, or in waterlogged areas. These findings suggest that local bird population dynamics are strongly affected by human-related land use practices, such as mowing vegetation along canals and roads, tree planting or removal, and the construction of rainwater collection basins.

Conclusions

The results presented in this study emphasize, one more time, the importance of habitat heterogeneity for bird species in the agriculture as a management practice, even in those situations in which anthropic actions are unavoidable such as the agroecosystems. When choosing which environmental improvement interventions in agriculture are best for a greater number of species, wetlands seem the ones to choose. We cannot ignore the role of mature woods which, although they do not appear to be as populated as other environmental categories taken into consideration, have a bird community which is quite different from that found in the rest of the company.

Contributions

AN led the planning and designing of the research, formal analysis, visualization, supervision and data collection; CB contributed to data collection and supervision.

Conflict of interest

The authors declare no conflicts of interest.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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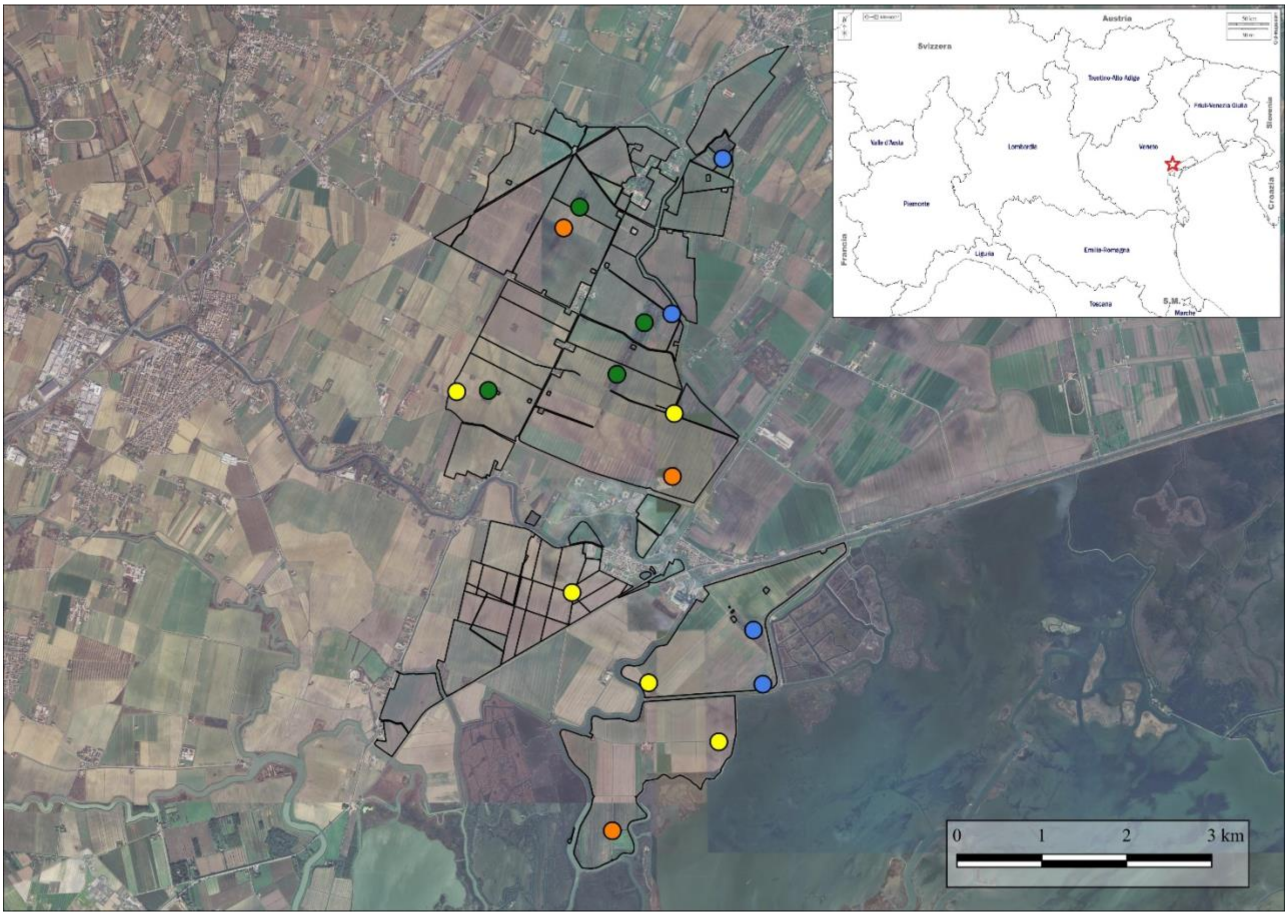

Fig. 1 – Location of sampling points within the boundaries of the farm. The subdivisions of the various plots of property are shown in black. The yellow dots represent the crops category points, the green ones the woods, the orange ones the hedgerow and fallow areas and the blue ones the wetland. Base map from Google Satellite.

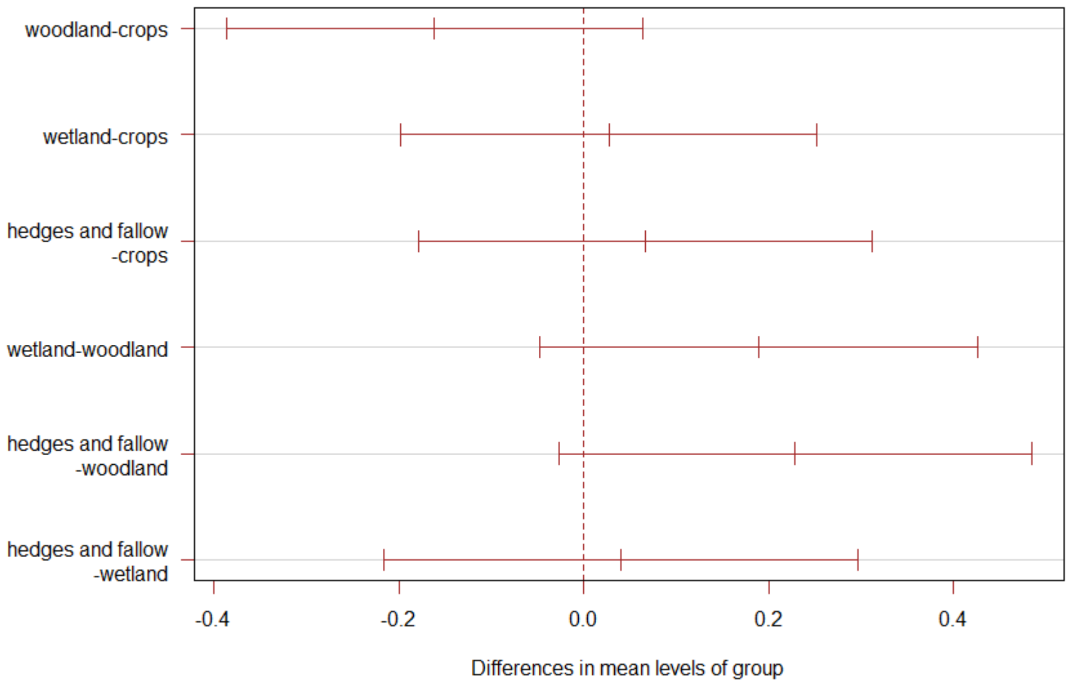

Fig. 2 – Tukey test compares all possible pairs of means for an environmental category. None of the pairings show significant differences, which would be represented by segments that do not intersect the zero line. Nevertheless, levels close to significance are observed for woodland-crops, wetland-woodland, and hedges, as well as fallow-woodland.

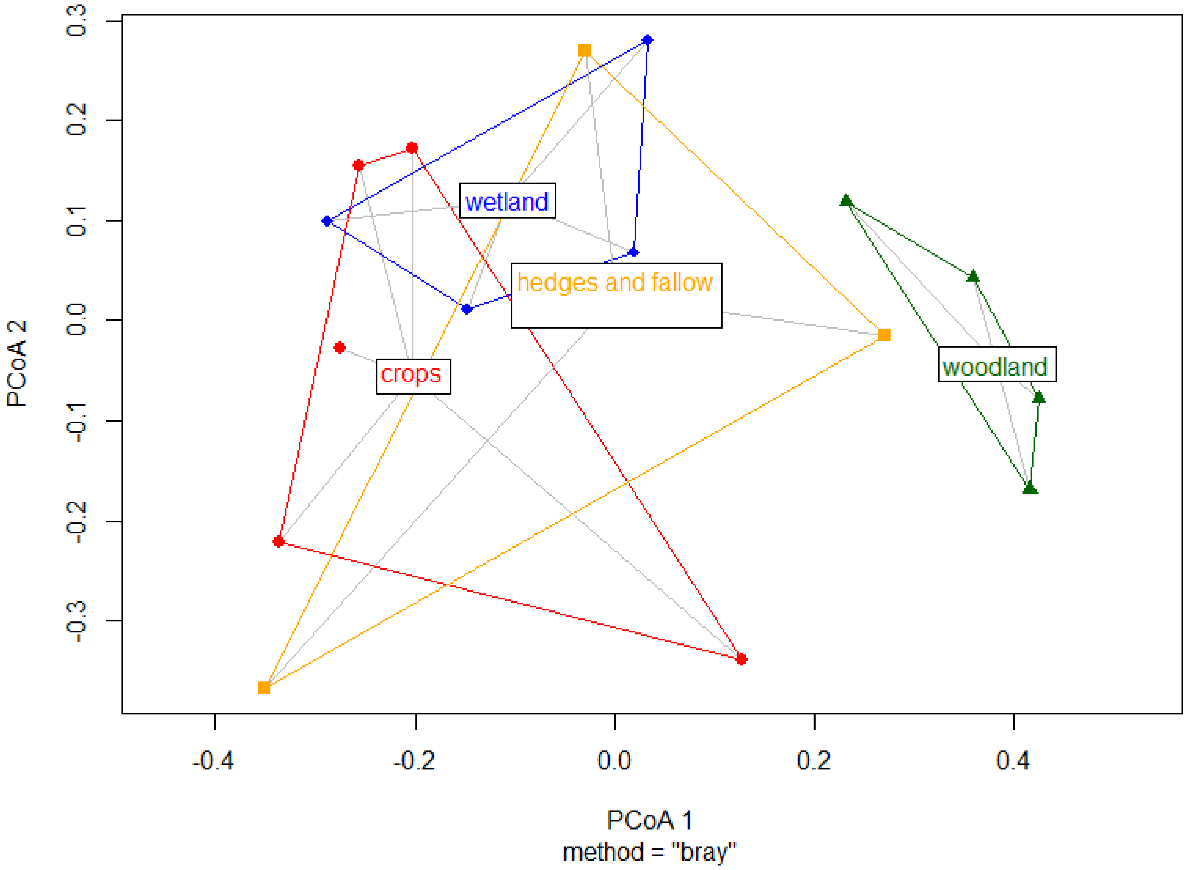

Fig. 3 – Principal coordinate analysis (PCoA) shows similarities or dissimilarities of data. Woodland ornithic composition seems different from the others, which instead, partially overlap.

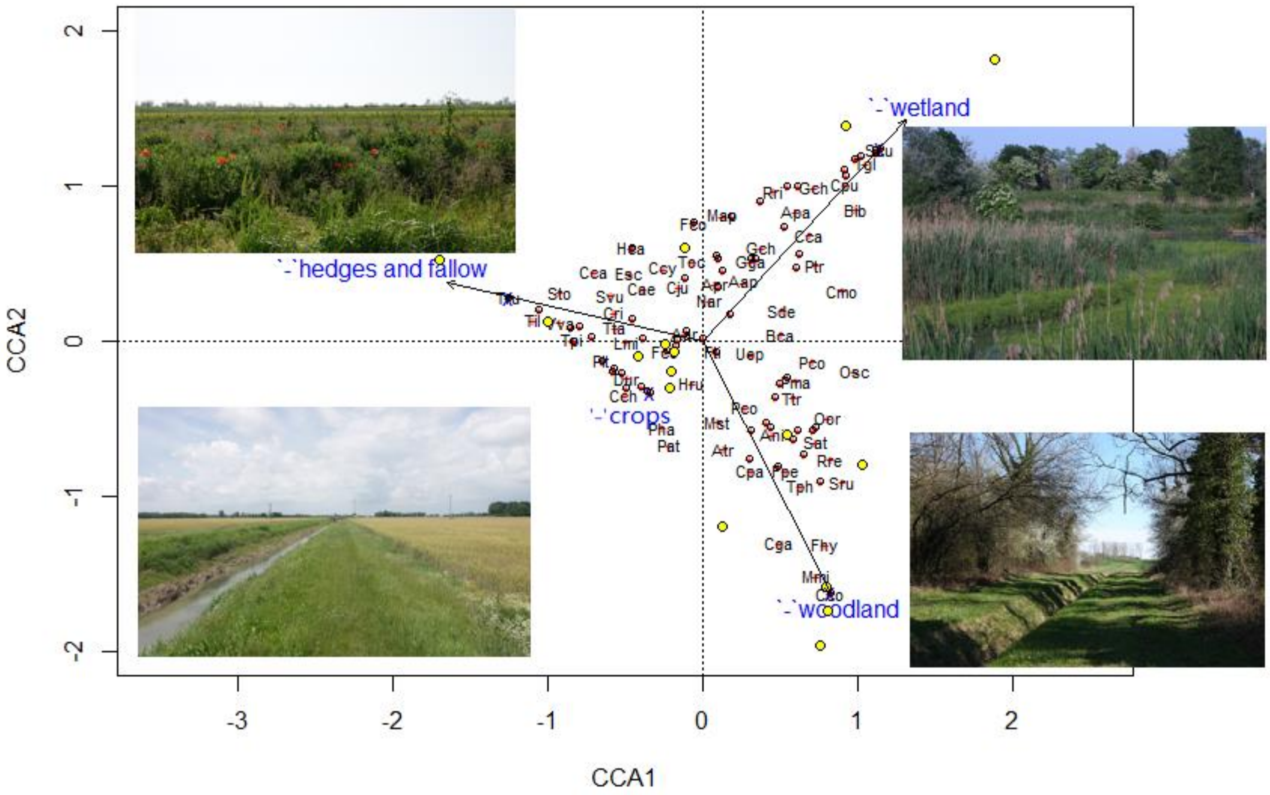

Fig. 4 – Association between habitat categories and birds' abundance. The position of the species in relation to the arrows indicates the environmental preference (illustrated by the photographs). For reasons of space, the species names have been abbreviated with the first letter of the genus and the first two of the species, e.g. blackbird = Tme. The yellow dots represent the monitoring sites. All acronyms and the respective full *English* names of the species are reported *below:* Great egret = Aal; Grey heron = Aci; Cattle egret = Bib; Purple heron = Apu; Hen harrier = Ccy; Skylark = Aar; Eurasian teal = Acr; Eurasian scops owl = Osc; Red-backed Shrike = Lco; Pied avocet = Rav; House martin = Dur; Pied flycatcher = Fhy; White wagtail = Mal; Grey wagtail = Mci; Barn owl = Tal; Eurasian woodcock = Sru; Eurasian Oystercatcher = Hos; Common snipe = Gga; Garden warbler = Sbo; Zitting cisticola = Cju; Short-toed snake eagle = Cga; Lesser whitethroat = Scu; Gadwall = Mst; Melodious Warbler = Hpo; Icterine warbler = Hic; Common reed warbler = Asc; Marsh warbler = Apa; Great reed warbler = Aar; Blackcap = Sat; Crested lark = Gcr; European goldfinch = Cca; Black-winged stilt = Hhi; Fieldfare = Tpi; Eurasian curlew = Nar; Whimbrel = Nph; Mute swan = Col; Coal tit = Pat; Great tit = Pma; Blue tit = Bca; Little owl = Ano; Long-tailed tit = Aca; Common redstart = Pph; Black redstart = Poc; Common wood pigeon = Cpa; Ruff = Cpu; Great cormorant = Pca; Hooded crow = Cco; Cuckoo = Cca; Northern wheatear = Ooe; Western yellow wagtail = Mfl; Common pheasant = Pco; Western marsh harrier = Cae; Peregrine falcon = Fpe; Osprey = Pha; Common firecrest = Rig; Eurasian coot = Fat; Sedge warbler = Asch; Eurasian chaffinch = Fco; Hawfinch = Cco; Black-headed gull = Cri; Mediterranean gull = Ime; Yellow-legged gull = Lmi; Common moorhen = Gch; Little egret = Gch; Eurasian magpie = Lmi; Mallard = Ega; Common kestrel = Fti; Eurasian jay = Ggl; European roller = Cga; Common crane = Ggr; European bee-eater = Map; African sacred ibis = Tae; Eurasian hobby = Fsu; Eurasian siskin = Ssp; Willow warbler = Ptr; Common chiffchaff = Pco; Wood warbler = Psi; Pygmy cormorant = Mpy; Common kingfisher = Aat; Garganey = Squ; Blackbird = Tme; Northern shoveler = Scl; Common reed bunting = Esc; Black kite = Mmi; Black-crowned night heron = Nny; Greylag goose = Aan; Common greenshank = Tne; Italian sparrow = Pit; Eurasian tree sparrow = Pmo; Dunnock = Pmod; Northern lapwing = Vva; Eurasian penduline tit = Rpe; Brambling = Fmo; Redshank = Tto; European robin = Eru; Great spotted woodpecker = Dma; Green woodpecker = Pvi; Domestic pigeon = Cli; Spotted flycatcher = Mst; Wood sandpiper = Tgl; Green sandpiper = Toc; Common sandpiper = Ahy; Meadow pipit = Apr; European golden plover = Pap; Common buzzard = Bbu; Water rail = Raq; Tree pipit = Atr; Common quail = Cco; Goldcrest = Rre; Eurasian golden oriole = Oor; Barn swallow = Hru; Common swift = Aap; European stonechat = Sto; Eurasian wren = Ttr; Squacco heron = Ara; Merlin = Fco; Eurasian sparrowhawk = Ani; Water pipit = Asp; Common tern = Shi; Caspian tern = Hca; Gull-billed tern = Gni; Common whitethroat = Ccu; Whinchat = Sru; Common starling = Svu; Corn bunting = Eca; Eurasian jackdaw = Cmo; Little bittern = Imi; Sand martin = Rri; Eurasian wryneck = Jto; Song thrush = Tph; Redwing = Til; Eurasian collared dove = Sde; European turtle dove = Stu; Spotted redshank = Ter; Little grebe = Tru; Eurasian hoopoe = Uep; Common nightingale = Lme; Cetti's warbler = Cce; European greenfinch = Cch; European serin = Sse; Common shelduck = Tta; Snow bunting = Pni.

Tab. 1 – Values of diversity indices calculated by environmental category for all species recorded; β diversity defined as γ/α – 1, α is the average no. of species in a group, and γ is the total number of species in the group.

All species				
Habitat category	**α**	**γ**	**β-diversity**	**Average Shannon index**
Crops	52.00 ± 5.23	98	0.88	2.60 ± 0.34
Woodland	51.00 ± 4.87	78	0.53	2.16 ± 0.29
Wetland	73.00 ± 6.14	117	0.60	3.01 ± 0.38
Hedges and fallow	67.33 ± 5.78	117	0.74	2.45 ± 0.31

Tab. 2 – Values of diversity indices calculated by environmental category for species of conservation interest; β diversity defined as γ/α – 1, α is the average no. of species in a group, and γ is the total number of species in the group.

Annex I Species			
Habitat category	**α**	**γ**	**β-diversity**
Crops	9.60 ±	21	1.19
Woodland	3.50 ±	8	1.29
Wetland	11.00 ±	21	0.91
Hedges and fallow	8.67 ±	20	1.31

Tab. 3 – Values of diversity indices calculated by environmental category for HNV Farmland Bird Species; β diversity defined as γ/α – 1, α is the average no. of species in a group, and γ is the total number of species in the group.

HNV Species			
Habitat category	**α**	**γ**	**β-diversity**
Crops	11.40 ±	28	1.46
Woodland	8.25 ±	16	0.94
Wetland	13.25 ±	27	1.04
Hedges and fallow	14.33 ±	31	1.16

Tab. 4 – Results of the Hutcheson test for the comparison of the average Shannon diversity index between habitat pairs. For each comparison, the mean values of the average Shannon index (H1 and H2), the t-test value, the degrees of freedom (d.f.f.) and the associated p-value are reported. Comparisons with p-value < 0.05 are considered statistically significant.

H1	H2	t_value	df	p_value	Habitat 1	Habitat 2
2.60	2.16	1.49	6.88	0.18	crops	woodland
2.60	3.01	-1.33	6.77	0.23	crops	wetland
2.60	2.45	0.49	5.22	0.65	crops	hedges and fallow
2.16	3.01	-2.80	5.98	0.03	woodland	wetland
2.16	2.45	-0.98	4.71	0.38	woodland	hedges and fallow
3.01	2.45	1.79	4.82	0.14	wetland	hedges and fallow