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The potential virtue of garden bird feeders: More birds in citizen backyards close to intensive agricultural landscapes

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ABSTRACT

Farmland bird abundances have been declining for decades, an erosion associated with agricultural changes. Main drivers have already been identified: intensification of practices, modification of landscapes, leading to impoverished summer and winter food availability. In parallel, winter bird feeding in private gardens became a common practice. Such a food supplementation may represent a bonanza for seed-deprived bird communities. Using data collected by citizen providing food to wintering birds in >1100 backyards, we analyzed the temporal and spatial trends in abundance of 30 species at feeders during four core winters periods and along a gradient of local agriculture intensification. Garden feeders located within intensively cultivated landscapes attracted more birds, the relationship being strongest for farmland species. We further found a temporal trend which strengthens this pattern as the winter progresses. These results confirm that supplying winter food to garden birds has not only a recreational value, but can also improve bird numbers hence probably winter survival rates, chiefly in intensive agricultural landscapes.

1. Introduction

Changes in agricultural policies and practices provoked unprecedented losses in biological diversity and associated ecosystem services from local to continental scales (Pe'er et al., 2014). The continuous decline of common birds illustrates the decline of biodiversity facing agricultural intensification (Donald et al., 2001; Gamero et al., 2017). Farmland constitutes the bulk of winter seed

of garden feeders. Indeed, we expected birds to visit garden feeders in larger numbers if the adjacent agriculture is more intensive. We also expected species with a stronger dependency to agricultural habitats to visit garden feeders in lower numbers than other species – because they would prefer to forage in the agricultural countryside - but to do so in larger numbers if the garden is located close to more intensively farmed landscapes – because the availability of wild seeds in intensive farmland would not meet their demand. We could also expect

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resources for many granivorous species (Butler et al., 2010; Robinson et al., 2001), while the availability of such resources is strongly affected by agricultural intensification (Newton, 2004). Changes in crop rotations, in ploughing and harvesting practices, in conjunction with the increased use of herbicides, led to a decrease in spilled grains and over-winter stubbles, amounting in a reduced availability of winter seeds in farmed habitats (Gibbons et al., 2006; Gillings et al., 2005; Moorcroft et al., 2002).

Enhancing winter seed availability is a solution to stem farmland bird populations decline (Robinson et al., 2004; Stoate et al., 2003, 2004), though often fails to meet seed demand in late winter (Perkins et al., 2008; Siriwardena et al., 2008). Besides, providing winter food to wild birds in private backyards is one of the most popular forms of human-wildlife interactions in developed countries (Jones, 2011; Reynolds et al., 2017). Garden bird feeding is important for urban biodiversity conservation (Fuller et al., 2008; Galbraith et al., 2015), and can represent a subsidy to natural diets for the seed-eating birds, enhancing winter survival and further breeding performance (Jansson et al., 1981; Robb et al., 2008b). However, we do not expect all bird species to respond in a similar way, but rather, their dependency on wild seeds in their diet, in addition to the degree of the intensity of surrounding farmland, are likely to influence their use

this pattern to strengthen as the winter progress, due to “natural” seed depletion (Robinson and Sutherland, 1999; Siriwardena et al., 2008).

The goal of this study was therefore to test the following hypotheses. i) Our first hypothesis was that farmland species visit garden feeders in lower numbers than other species: farmland species were not supposed to feed in gardens if there are enough natural resources in adjacent agricultural fields and gardens are not their main habitat. ii) It should be especially the case in low-intensity farmland areas: this means that we expected all the bird species to visit garden feeders in fewer numbers if the adjacent agriculture is less intensive, assuming that only intensive production practices reduced seed availability, but also that we expected an interaction between the bird species dependence to farmed habitat and to the degree of intensification of nearby agricultural practices. iii) We made the final hypothesis that birds species should visit garden feeders in larger number as the winter progress as seed scarcity augments during winter: this should mean that the temporal increase in the number of birds at feeders should be stronger/ faster if the natural seed depletion is steeper in more intensive farmland and potentially more so for species with a higher dependency to farmland habitats. To do, we compared the overall abundances of the species and the temporal trends of these

abundances by analyzing large scale bird counts recorded by volunteer citizen in their backyards. We used data collected by the French national garden birdwatch scheme in > 1100 private gardens with bird feeders and distributed across the whole country. We analyzed the spatial and temporal patterns of abundances for the 27 commonest bird species visiting the gardens, plus three less common seed-eating passerines. We compared their abundances during the core winter along a gradient of agriculture intensification characterized with a recent index of local agricultural Production Intensity developed for the French farmland (Teillard et al., 2012), associated with a species-specific index of dependency to agricultural habitats that we developed using data from the French Breeding Bird Survey (Jiguet et al., 2012).

2. Material and methods

2.1. Garden Birdwatch data

2.1.1. The French Garden Birdwatch scheme

Bird counts came from the French Garden Birdwatch scheme (see www.oiseauxdesjardins.fr), a citizen science program started in spring 2012 and operated by the Ligue pour la Protection des Oiseaux (LPO) and the French National Museum of Natural History (MNHN). The aim of this program is to register volunteer-based bird counts in private backyards throughout the year at a national scale. The program provides online resources to help participants to correctly identify gardens birds. These resources include forms, species description (including appearance, behavior or habitat) and pictures, and include warnings regarding common identification errors. Moreover, about a hundred of skilled ornithologists validate the data every day (from the LPO or others French naturalist NGOs).

2.1.2. Garden information and the correction for confounding effects

Each volunteer pinpoints his garden and provide a brief description of this garden online (including garden area, local urban/rural context, presence/absence of winter food supply, distance to the closest agricultural field, to the closest wood according to the perception of the observer himself); each garden has a unique garden identity. Each bird count is associated with a date, time and duration, and corresponds to the maximum simultaneous abundance of each species observed during the session. There is no standardization of the date, time, duration, meteorological conditions and spatial observation area for the observation sessions, but this information is recorded by observers, hence the effect of such confounding parameters can be considered prior to estimating the impact of landscape context and of the winter progress in statistical models.

2.1.3. Garden selection

This study considered 1180 gardens, with the subset of the 27 commonest bird species observed by the volunteer in winter. The garden selection process was done according to the following steps. Since 2012, > 20,000 gardens have been described across France, covering a representative range of garden types and geographic distribution, but less than half of these gardens following birds at least once during the winter season (our period of interest, here considering winter as the non-breeding period i.e. from September to March). Within the gardens surveyed in winter, we restrained our subset to garden with winter food supply (e.g. 90% of all gardens) and then to rural gardens (according to the observers themselves) as we wanted to explore the link between birds and agricultural landscape. After these considerations, the sample size then consisted of 6244 gardens followed at least once from September to March. When there was more than one session per year per garden, we retained only sessions separated by at least five days. To study the pattern of birds visiting the gardens in winter, we first explored all data collected from these 6244 gardens from September to March, more exactly from September 2012 to March 2016 (four winter periods). This preliminary study revealed that species abundance increased almost linearly from early November to the end of January (see Appendix A: A.1 for supplemental materials and methods and Fig. A.2), so we restricted our analysis to observations submitted from 1st November to

20th January (as the core winter period). Moreover, we did not consider the last ten days of January to exclude thousands of gardens counted only once a year during the annual national winter bird count, organized each year during the last week-end of January. During these events, the protocol is noticeably different as observation are only reported for one hour and for only one session per weekend. These events are widely promoted (media for the general public, naturalist networks...) and attract a lot of observers which participate only once. So, we excluded all bird counts before the 1st November and after the 20th January, excluding 5064 gardens which were surveyed only outside this core winter period. The final sample size was then of 1180 gardens.

2.1.4. Species selection and distribution validation

We considered the subset of the 27 commonest bird species observed by the volunteers, those detected at least once in > 10% of gardens (see the Table B1 in Appendix B) during the overall winter period, i.e. from September to March. We did not consider Brambling (*Fringilla montifringilla*) and Rose-ringed parakeet (*Psittacula krameri*) because we could not compute the species dependency for farmland habitats for these species. As volunteers report only the species they have seen, we zero-filled the dataset to include absence data. We further deleted observations corresponding to a true absence of the species in a region (species outside its winter range) by cross-referring the zero-amplified database with the distribution maps published recently in the latest French Winter Bird Atlas (Issa and Muller, 2015) and deleting those zeros obtained in gardens outside atlas cells where the species had been recorded in winter during the atlas period (2009–2013).

2.1.5. A second species and gardens subset to confirm detected trends

To further confirm the detected trends on more farmland seed-eating species, we conducted a second analysis where gardens were only included if at least one of the following three species was recorded at least once during the core winter period: Cirl Bunting (*Emberiza cirlus*), Yellowhammer (*Emberiza citrinella*), Common linnet (*Linaria cannabina*) and Tree sparrow (*Passer montanus*). All but Tree sparrow were not considered in the first analysis because they were observed in < 10% of all gardens, as they are quite uncommon in gardens in winter, probably due to their stronger dependence to agricultural habitats. This second study then considered an enlarged set of 30 species (the same 27 previous ones plus three new) but was based on 200 gardens only (see Appendix C - Fig. C.1) and aimed to confirm trends detected with the global dataset where there were fewer farmland species.

2.2. Species Farmland Dependency to agricultural landscape

To compute a species Farmland Dependency index to agricultural habitats (FarmDep), we used bird data from the French Breeding Bird Survey (FBBS) collected between 2010 and 2013. The FBBS is a standardized monitoring scheme based on skilled volunteer ornithologists counting birds following a standardized protocol at the same plot for several years, detailed in (Jiguet et al., 2012). In each plot of 2x2km squares, ten points separated by at least 300 m were surveyed by 5-min counts during which observers recorded all birds seen or heard. Only individuals detected within 100 m radius around the observer were considered so that the birds were seen in their habitat. Following a standardized list of habitats, observers were also asked to classify the surroundings within a fixed 100 m radius of each point count. The first level of classification presents 10 major habitat types, simplified here as “agricultural habitat” (farmland habitats only) versus “non-agricultural habitat” (i.e. all the other habitats: woodland, scrubland, marshland, rocks, human settlements...). Data from 1455 FBBS-squares were used and our dataset was artificially zero-filled to take into account zero-bird counts (absence). Assuming that species with a stronger dependency to farmland habitats would be more abundant in agricultural habitats than in other habitats, our index was simply calculated as the ratio between the estimated species mean abundance in agricultural habitats divided by the estimated species mean abundance in all habitats; these estimated species mean abundance were computed in a preliminary work (see

Appendix A.3 for further details on this index computation). The specific Farmland Dependency indices are reported in the Table B.1 in Appendix B.

2.3. Index of agricultural Production Intensity and proportion of farmland area

In this work, we used an index of agricultural Production Intensity developed by (Teillard et al., 2012) for French farmlands, which is an aggregated intensity indicator corresponding to the Input Cost by hectare (“IC/ha”, expressed in euros). This index was defined as the ratio between the sum of different categories of input costs (IC) and the total Utilized Agricultural Area (UAA) of a farm per year. IC categories include fertilizers, feedstuff, pesticides, seeds, fuel, veterinary products, and irrigation water (see (Teillard et al., 2012) for further details). This index of agricultural Production Intensity, which we call PI, was available at the scale of French Small Agricultural Regions (SAR; France is composed of e.g. 714 SARs where agricultural production systems are homogeneous) for the year 2006. Moreover, we also used the proportion of farmland area within the landscape surrounding each garden using the CORINE Land Cover (CLC) raster data from 2012 in 100 m resolution; farmland areas were defined using the CLC-nomenclature: level two - “agricultural area”. Both environmental variables (PI and the proportion of farmland area) were extracted within the surrounding landscape of each garden identity, here considering landscape located within a spatial scale of a 1 km radius circle area from the garden geographic coordinates. When the 1 km radius circle surrounded garden spread over more than one SAR, the retained value for the index of agricultural Production Intensity was the average of values of each intersected SAR weighted by the overlaid area (and the same was done with the CLC raster for the proportion of farmland).

2.4. Meteorological data

Because the number of birds visiting garden feeders can be affected by the weather, we included weather data in our statistical models to consider such potential biases. Temperature (°C) and precipitation (mm) daily data were obtained from the E-OBS gridded dataset version 14.0 – a daily gridded observational dataset based on the European Climate Assessment and Dataset (ECA&D) – and were available on a 0.25 degree regular grid (<http://www.ecad.eu/>; (Haylock et al., 2008)). Using the spatial coordinates for each garden identity, we extracted daily mean temperature (°C) and daily sum precipitation (mm) at a given location every day and then associated them with garden observation sessions.

2.5. Statistical analyses

All analyses were performed with R version 3.2.5 (R Core Team, 2016). We used a Negative Binomial Generalized Linear Mixed Model (GLMM) (Zuur et al., 2009) with a log link function to model variations in bird species abundances as a function of the Production Intensity of the landscape, while accounting for the multisite time-series structure of the monitoring program. Thus, the fixed-effect structure included our three continuous variables: Julian day of the core winter period (1st November = 1), the Production Intensity index (PI) and Farmland Dependency index (FarmDep), and all possible interactions between these variables. To correct for potential biases and further standardized

count data, we added the time duration and the garden area (both logtransformed as we expect a saturation of the observation effort with time and space), the distance to the closest farmed field and to the closest forest, the proportion of farmland area, the daily mean temperature and precipitations of the count session as covariates. To account for the non-independence of our data, we considered, species identity, garden identity and year as random effects. We further added as covariates the latitude and longitude of garden identity to consider the potential spatial correlation structure. Spatial autocorrelation can influence inference from statistical models (Mauricio Bini et al., 2009) but we did not find one in the residuals of the GLMM using Moran's I correlogram. Collinearity among the covariates was assessed using the Variance Inflation Factor (VIF) analysis and with a Correlation Coefficient Panel For Pairs Function; all VIF values were well below the threshold of two, suggesting low collinearity among them (Zuur et al., 2009). GLMM were fitted using the function “glmmPQL” (Dormann et al., 2007) of the package “MASS” (Crawley, 2013; Venables and Ripley, 2002). We adopted a statistical hypothesis testing approach based on the full model, where all variables had a standardization purpose or a biological meaning. The overall goodness-of-fit of the model was assessed by calculating the variance explained (R²) for GLMM models using “r.squaredGLMM” function in R-package “MuMIn” (Bartoni, 2017) following computational procedure from (Nakagawa and Schielzeth, 2013). Both marginal and conditional R² were obtained. The same model was run for the two datasets.

3. Results

The sample sizes in terms of observations used in the two models (the first one with 1180 gardens and 27 species and the second one with 200 gardens and 30 species) were 68,381 and 18,480 respectively. Most species were not frequent visitors to gardens and to help understanding this, Table B2 in Appendix B reported the mean abundance and the overall occurrence rates expressed at the level of the visit (i.e. corresponding to that used in the analyses). The outputs of the two GLMMs are presented in Table 1.

3.1. Control of observation effort

As expected, some variables included to control for the varying observation effort between gardens and sessions had significant effects on species abundances, in the two models we performed (see Table 1): duration of the observation session (increasing abundance with duration) and temperature (more birds at lower temperature); the latitude and the area of the garden (more birds in larger gardens) were only significant when analyzing the largest dataset. The distance to the closest agricultural field and forest, as recorded by the observers, and the proportion of farmland area within the landscape surrounding each garden did not influence the number of birds visiting the gardens.

3.2. Results from the global dataset: 27 species in 1180 gardens

The marginal R² (R² for fixed effect part) of the model was 2.69% and the conditional R² (R² for the entire model, i.e. variance explained

Table 1

Summary of effects of all parameter included in both models on bird abundance: on the left side, results from the first model (species =27, gardens = 1180) and on the right side, results from the second model focusing on more farmland seed-eating species but fewer gardens (species =30, gardens = 200). In part a) parameters to deal with biases and to correct bird abundance; whereas in part b) parameters of interest; significant effects in bold (p-value < 0.05).

| | | First analysis (species = 27, gardens= 1180) | | | Second analysis (species = 30, gardens= 200) | | |
|----|--------------------|---|----------|---------|---|----------|---------|
| | | Parameter estimate | SE | p-Value | Parameter estimate | SE | p-Value |
| a) | Intercept | -5.484411 | 1.320616 | < 0.001 | -2.200495 | 2.799641 | 0.431 |
| | log(time duration) | 0.351784 | 0.009071 | < 0.001 | 0.366217 | 0.016578 | < 0.001 |

| | | | | | | | |
|----|----------------------------------|-----------|----------|---------|-----------|----------|---------|
| | log(garden area) | 0.234547 | 0.067561 | < 0.001 | 0.032822 | 0.162137 | 0.840 |
| | Daily mean temperature | -0.018231 | 0.001614 | < 0.001 | -0.014784 | 0.002924 | < 0.001 |
| | Daily total precipitation | -0.001223 | 0.001181 | 0.301 | 0.000821 | 0.002130 | 0.700 |
| | Distance to closest farmed field | 0.056041 | 0.035393 | 0.114 | 0.150254 | 0.073331 | 0.042 |
| | Distance to closest forest | -0.044121 | 0.034131 | 0.196 | -0.102906 | 0.068053 | 0.132 |
| | Proportion of farmland area | 0.073507 | 0.167523 | 0.661 | 0.456085 | 0.332188 | 0.171 |
| | Latitude | 0.000001 | 0.000000 | 0.013 | 0.000000 | 0.000000 | 0.863 |
| | Longitude | 0.000000 | 0.000000 | 0.146 | -0.000000 | 0.000000 | 0.593 |
| b) | Winter day | -0.000303 | 0.001703 | 0.859 | -0.000662 | 0.002666 | 0.804 |
| | Production Intensity (PI) | -0.000358 | 0.000313 | 0.252 | -0.000509 | 0.000599 | 0.397 |
| | Farmland Dependency (FarmDep) | -0.817204 | 0.128253 | < 0.001 | -0.890320 | 0.172641 | < 0.001 |
| | Winter day * PI | 0.000008 | 0.000004 | 0.019 | 0.000010 | 0.000006 | 0.070 |
| | Winter day * FarmDep | 0.006421 | 0.001735 | < 0.001 | 0.005416 | 0.002285 | 0.018 |
| | PI * FarmDep | 0.000809 | 0.000258 | 0.002 | 0.000961 | 0.000366 | 0.009 |
| | Winter day * PI * FarmDep | -0.000010 | 0.000004 | 0.007 | -0.000010 | 0.000005 | 0.045 |

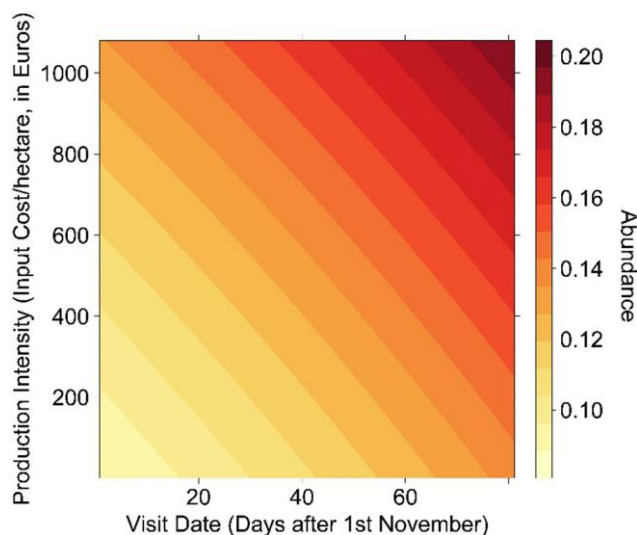


Fig. 1. Filled contour plots showing the estimated bird abundance during the core winter (winter day) depending to the agricultural Production Intensity (PI). y-axis: the PI index (in Input Cost per hectare, in Euros). x-axis: the visit date (in winter days). Color-filled: bird abundance response, the warmer the color is, the higher the value is, and conversely. These graphs were obtain using the predicted abundance from the model on the first data set with all the most seen species (species =27, gardens =1180). Beta estimates and p-values are available in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

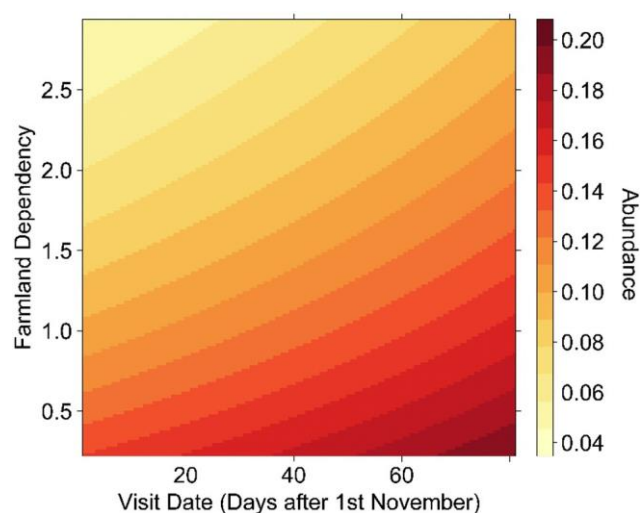


Fig. 2. Filled contour plots showing the estimated bird abundance during the core winter (winter day) depending to the species Farmland Dependency to agricultural landscape (FarmDep). y-axis: the FarmDep index. x-axis: the visit date (in winter days). Color-filled: bird abundance response, the warmer the color is, the higher the value is, and conversely. These graphs were obtain using the predicted abundance from the model on the first data set with all the most seen species (species = 27, gardens = 1180). Beta estimates and p-values are available in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

by both fixed and random effect parts) was 98.81%, meaning that the variance explained with the fixed effects was tiny but that including species identity and gardens identity improved a lot the variance explained by the model. Contrary to our expectations, the winter day and the Production Intensity had no significant effect on species abundance, though their interaction was significant with a positive estimate (Fig. 1): the average number of individuals per species increased as the winter progresses in gardens located within a more intensive agriculture. As expected, we also found that species Farmland Dependency had a strong negative effect on abundance: species that are more dependent to farmland habitats are less numerous in gardens, while more generalist and woodland species are more numerous. There was a

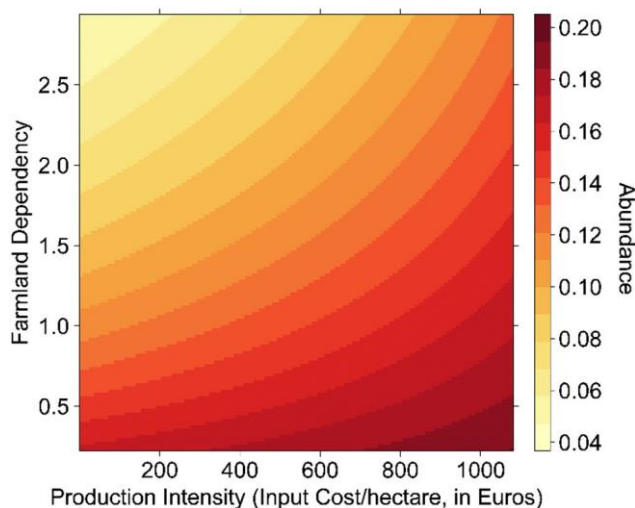


Fig. 3. Filled contour plots showing the estimated bird abundance depending of the index of agricultural Production Intensity (PI) depending of the species Farmland Dependency to agricultural landscape (FarmDep). y-axis: the FarmDep index. x-axis: the PI index (in Input Cost per hectare, in Euros). Colorfilled: bird abundance response, the warmer the color is, the higher the value is, and conversely. This graph was obtained using the predicted abundance from the model on the first data set with all the most seen species (species = 27, gardens = 1180). Beta estimates and p-values are available in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

results are reported in Appendix D.

3.3. Confirming the detected trends on more farmland seed-eating species: 30 species in 200 gardens

Interestingly, results of this second model were very similar to those of the larger dataset, confirming the robustness of the effects (Fig. C.5, Fig. C.3 & C.4 in Appendix C). Only the interaction between the winter day and the Production Intensity was not significant (Fig. C.5 in Appendix C), even if the estimate was also positive and close to significance. The marginal R^2 and the conditional R^2 of this model were 4.41% and 98.7% respectively.

4. Discussion

4.1. Few farmland birds at garden feeders

By analyzing four years of winter bird counts in private backyards where owners provide food supply, we first highlighted that the abundances of visiting species were related to their dependency to farmland habitats. Indeed, farmland

significant interaction between the winter day and the species Farmland Dependency, with a positive estimate (Fig. 2): the more a species depends on agricultural habitats, the more its abundance is increasing in gardens as the winter progresses. As expected, a positive interaction was also found between the Production Intensity and the species Farmland Dependency (Fig. 3 & Fig. C.2 in Appendix C): species with a higher dependency to farmland habitats are more abundant in gardens located within more intensive agriculture, as illustrated by the response of four species presented in Fig. 4. A three-way negative interaction on bird abundance between all these main variables was also found, indicating that the previous positive two-way interactions are further moderated in their effects along the studied gradients. This analysis was repeated for species with $\text{FarmDep} > 1$ and $\text{FarmDep} < 1$ separately,

birds are expected to forage mainly in farmland habitats, in summer (by construction of the index estimating the species dependency to farmland habitats here) but also in winter, as most species are expected to feed mainly on wild seeds in the countryside. As a consequence, farmland birds are not numerous at garden feeders in winter, though even small variations in their numbers might carry important ecological information. The strong effect of this habitat index is also driven by species with a low farmland dependency, which are mostly woodland specialists, according to previous analyses on French breeding birds (Jiguet et al., 2012). Indeed, the 8 species with the lowest dependency to farmland habitats are contributing to the national indicator of woodland birds (see (Jiguet et al., 2012); from Great Spotted Woodpecker (*Dendrocopos major*) to Crested Tit (*Lophophanes cristatus*) in Table S1). Woodland birds are therefore those visiting garden feeders in larger numbers in winter, where the provision of seeds is certainly a major food resource outside forests.

4.2. Spatial and temporal trends in winter garden bird abundances

Beyond this pattern, we then hypothesized that the presence and abundance of such species in gardens in winter could carry an information on the availability of wild seeds in adjacent agricultural fields, with a higher abundance of farmland species at garden feeders in case of seed depletion, either linked to the intensification of nearby agricultural practices, and/or as the winter progresses (Siriwardena et al., 2006, 2008). Both conducted analyses concluded that farmland species visited garden feeders in higher numbers when adjacent agriculture was more intensive, while the same pattern was observed for all species but with a smoother pattern. We interpret this result as a global winter food depletion for birds in intensive farmed landscapes, driving especially seed-eating birds to forage in rural backyards and concentrate at supplementary feeding stations. The potential of food provisioning in gardens to attract bird in winter in case of surrounding resource scarcity has been documented for woodland birds (Chamberlain et al., 2007). Here we can extend this pattern to seed resource availability in agricultural habitats.

In both performed models, we failed to identify a direct increased frequentation of backyard feeders as the winter progresses. However, we found an increased frequentation as the winter progresses related to the agricultural Production Intensity of the landscape, supporting that intensive agricultural habitats fail to meet demand in late winter (Siriwardena et al., 2008). This result is in line with the theory of a temporal dimension of food depletion though with a spatial heterogeneity component linked to farmland intensity. The temporal trends in species abundances during the core winter was also related to the species dependency to farmland habitats, with those farmland species becoming more abundant as the winter progresses. Again, this supports the theory of progressive food depletion for seed-eating farmland species during the winter, and the necessity to find supplementary food resources, namely at backyard feeders. Indeed, (Chamberlain et al., 2005) reported that declining seed-eating

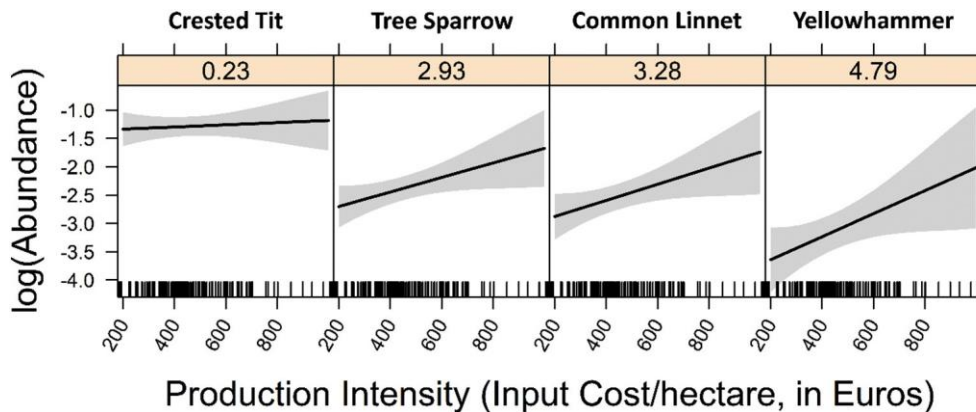


Fig. 4. Response of the bird abundance (in log(Abundance)) depending to the interaction between the agricultural Production Intensity (PI, in Input Cost per hectare, in Euros) with the species Farmland Dependency to agricultural landscape (FarmDep) (species = 30, gardens = 200). Beta estimates and p-values are available in Table 1. From the left side to the right side: index for Crested Tit (*Lophophanes cristatus*, the lowest value of the index: FarmDep = 0.23); index for Tree Sparrow (*Passer montanus*, FarmDep = 2.93); index for Common Linnet (*Linaria cannabina*, FarmDep = 3.28) and index for Yellowhammer (*Emberiza citrinella*, the highest value of the index: FarmDep = 4.79).

passerines, notably Tree sparrow and Yellowhammer, have increased their winter visits to gardens as their breeding populations have declined. Furthermore, late winter food resources were often highlighted as a critical determinant of winter survival and breeding population trends for many seed-eating passerines (Siriwardena et al., 2008). In this context, providing food at the end of the winter period attracts more birds in gardens, especially those more dependent to seed resources and needing alternative food supply, such as farmland species.

4.3. Conservation implications

Food supplementation in winter can have immediate benefits for survival (Kallander, 1981). However, there are contradictory results regarding the impact of supplementation on breeding performance which can be enhanced (Robb et al., 2008b) but also reduced (Plummer et al., 2013). Such trends depend on the carry-over effects of a better winter survival, potentially leading to increased breeding densities hence increased density-dependent competition (Crates et al., 2016), to recruitment of lower quality individuals within the breeding population hence reduced average breeding parameters (Plummer et al., 2013). The winter availability of seeds in cereal stubbles drives farmland bird numbers in winter but also in summer (Gillings et al., 2005). Further effective winter food provision to farmland bird populations within farmland has the potential to halt and reverse declines in abundance (Siriwardena et al., 2007), and here we suggest that the same might hold true with winter food provision in rural private backyards. However, the amount of variation in abundance of birds visiting gardens in winter suggests that landscape and winter period effects are probably less important than the effect of the garden itself, e.g. garden management and characteristics (Chamberlain et al., 2004; Daniels and Kirkpatrick, 2006) but also the type (Rosenberg and Bonney, 1994), the quantity and the frequency of bird food provided (Chamberlain et al., 2005). This suggests that our results and conclusions could be mitigated considering practices of the garden where an observer counts birds itself, but also by the gardens in vicinity. Further works considering garden characteristics are needed as an example by the comparison between gardens with or without food supply.

As backyard bird-feeding is a very common practice in developed countries (Davies et al., 2009), where farmland birds are most declining (Donald et al.,

2006), farmland species visiting garden feeders in winter could benefit from such food supplementation, especially if the adjacent agriculture has high Production Intensity. Although long-term food supplementation for birds has been recommended in urban habitats and is used as a tool to increase reproductive output in endangered species (Schoech et al., 2008), spring food supplementation can have negative impacts on breeding performance (e.g. reduced brood size in tits; (Harrison et al., 2010)). So if garden feeders might be necessary for birds to better survive the winter, as a default conservation strategy for the wider countryside bird communities, food supplementation should stop as the breeding season starts to avoid potential ecological trap created by the feeders themselves by providing resources not adapted or maintained during the whole breeding season (Robb et al., 2008a) but also as cat predation is known to be higher in gardens during the breeding season

(Blancher, 2013). However, garden bird feeding can also increase disease transmission (Galbraith et al., 2014) and concentrate predation pressure (van Heezik et al., 2010), favour exotic introduced species (Galbraith et al., 2015) and modify migratory behavior (Plummer et al., 2015), so that estimating the real impact of garden feeding on bird population dynamics needs again more investigations. Moreover, if food supply could attract birds, it could modify species interactions at the feeders and in the surrounding, as a result of food competition for such non-natural food resources (Cooper et al., 2007; Wojczulanis-Jakubas et al., 2015). Anyway, garden bird feeding should be promoted as a method for conserving declining wild bird populations, including farmland birds in rural areas. Supplying food to birds in garden during the winter is important for biodiversity conservation (Cannon, 1999), but also for community engagement, in establishing personal connections with nature and their associated benefits (Reynolds et al., 2017).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocon.2018.03.033>.

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