Interreg
North Sea Region
PARTRIDGE
European Regional Development Fund
EUROPEAN UNION

PARTRIDGE MONITORING

Results from the monitoring programme of the Interreg North Sea Region PARTRIDGE project

By Fleur Petersen[1], Luc De Bruyn[1], Thomas Scheppers[1], Francis Buner[2], Lisa Dumpe[3], Julie Ewald[2], Eckhard Gottschalk[3], Cameron Hubbard[2], Miel Cnuts[4], Sander Devisscher[1], Koen Devos[1], Pieter Dhaluin[1], Emilie Gelaude[1], Ruben Mistiaen[5], Axel Neukermans[1], Thierry Onkelinx[1], Fien Oost[6], Naomi Oostinga[7], Dave Parish[2], Jimmy Pijcke[7], Jochem Slothaak[6], Filiep T' Jollyn[1], Fiona Torrance[2], Willem Van Colen[5], Suzanne van de Straat[7], Marc Van De Walle[1], Kathleen Vanhuyse[4], Jan Vercammen[1], Hilbran Verstraete[1], Yasmine Verzelen[1], Chris Vreugdenhil[7] , Mathias Wackenier[1] & Alex Wieland[7]

See imprint for affiliations

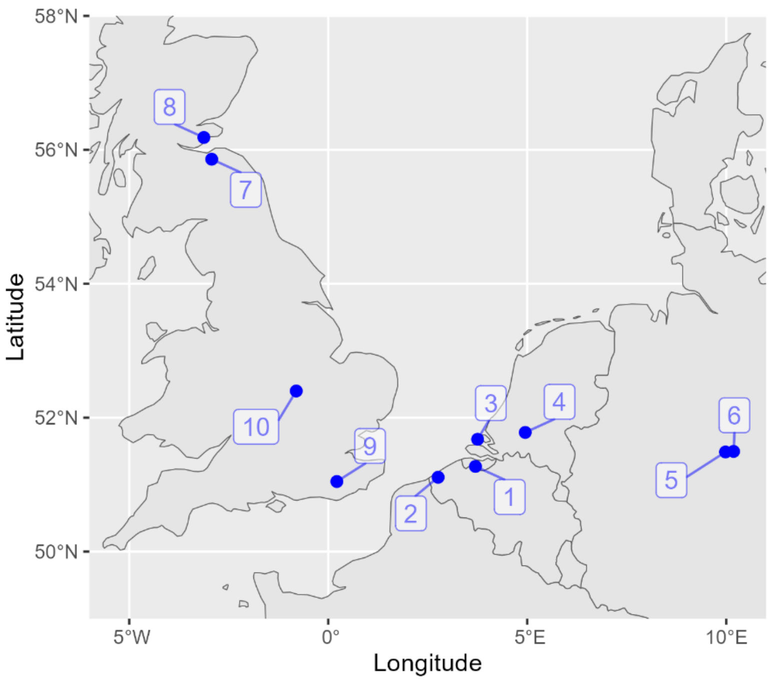
Table of contents

Preface

PARTRIDGE was a demonstration project with 13 European partners, 50% co-funded by the Interreg North Sea Region Programme, which ran from mid-2016 to mid-2023. The project worked across demonstration areas in five participating countries (two sites in each country: Belgium - Flanders, England, Germany - Lower Saxony, the Netherlands, and Scotland; Figure 1). Partners from Denmark joined the project in 2019, although there were no project sites there. For more information about the project please visit northsearegion.eu/partridge.

At each demonstration site, the aim was to increase beneficial habitat to a minimum of 7%. This was achieved through the implementation of a carefully curated mix of wildlife-benefitting habitat measures, tailored to aid grey partridge conservation - an umbrella species for farmland biodiversity and a key indicator of overall farmland ecosystem health. In addition, we provided supplementary winter food through feeders where possible. Predators were managed according to the local legislation, wherever feasible.

To demonstrate the effects of these measures on farmland biodiversity, key farmland biodiversity indicators were monitored at each demonstration site and at nearby, paired reference sites where no management was in place, using standardised protocols developed at the beginning of the project by the project monitoring expert team. In this report, we present the results of monitoring the project's indicator species: grey partridges, breeding and overwintering farmland birds, and hares.



Map 1. Location of the ten demonstration sites spread across the North Sea Region. 1: Isabellapolder (Belgium); 2: Ramskapelle (Belgium); 3: Burghsluis (The Netherlands), 4: Oude Doorn (The Netherlands); 5: Diemarden (Germany); 6: Nesselröden (Germany); 7: Whitburgh (Scotland); 8: Balgonie (Scotland); 9: Rotherfield (England); 10: Loddington (England).

Executive summary

Farmland birds are in decline in Europe and hence urgent action is needed to halt and reverse this decline. From mid-2016 to mid-2023, the Interreg PARTRIDGE project, improved the area of ten 500-hectare farmland demonstration sites - two each in Belgium-Flanders, The Netherlands, Germany, Scotland, and England - by enhancing existing and creating new wildlife-benefitting habitats, such as flower blocks with PARTRIDGE wild-bird mixes, and beetle banks, to levels above 7% of the farmed areas. In addition, we provided supplementary winter food through feeders, where feasible. The habitat improvements were tailored to our flagship and farmland biodiversity umbrella species the grey partridge and provided more and better breeding habitats for a wide range of farmland wildlife in summer, and more food and shelter overwinter. To demonstrate the expected effects of the project's habitat improvements, we monitored grey partridges, breeding, and overwintering farmland birds. and hares. To determine the effect of feeders, we monitored their use by the different species and assessed the effect of best-practice management.

Our key results show that:

1. significantly more grey partridges were observed in the managed demonstration sites compared to the reference sites where no or very little habitat management took place.
2. the number of breeding territories of farmland birds (abundance) and the number of species (diversity) were higher where the farmland habitat was enhanced with PARTRIDGE measures. Farmland bird species that live in small-scaled farmland landscapes with numerous hedgerows, wood edges, orchards benefited the most. Iconic farmland birds such as yellowhammer (30%), skylark (30%) and grey partridge (70%) had clearly more breeding territories in our demonstration sites than in the reference sites.
3. the number of wintering birds (abundance) and the number of wintering species (diversity) were higher where the farmland habitat was enhanced with wildlife-benefitting habitats. Birds that rely heavily on seeds during winter benefited the most.
4. increased good quality habitat coverage had a positive impact on local hare populations.
5. our data showed that when our best-practice guidelines for supplementary winter feeding were followed, the visits of 'un-welcome'species, such as rodents, were strongly reduced. The data also validated our recommendation that the use of feeders is most important from February through to the end of April.

1 General introduction

Europe's farmland has been dramatically transformed by modernisation over the past century. These changes have increased the efficiency of food production, but they have also contributed to a widespread decline in ecosystem health, affecting water, air, and soil quality as well as farmland biodiversity. Across society, this degradation is widely recognised as a serious problem, through to the highest political levels in Europe. The targets set in the European Union's Biodiversity Strategy aim to reverse these declines, with Target 3a specifically designed to 'increase the contribution of agriculture to maintaining and enhancing biodiversity' (European Commission, 2011). The mid-term review on reaching these targets (European Commission, 2015) clearly stated that these would not be met by 2020. Therefore, tested working solutions are urgently needed to ensure that the biodiversity crisis can be halted at least by 2030.

To demonstrate how farmland biodiversity can be recovered successfully, the Interreg PARTRIDGE project improved the area of ten 500-hectare farmland demonstration sites - two each in Belgium-Flanders, The Netherlands, Germany, Scotland and England between mid-2016 to mid-2023, by enhancing existing and creating new wildlife-benefitting habitats such as flower blocks with PARTRIDGE wild-bird mixes, and beetle banks to levels above 7% of the farmed areas (Hubbard et al., 2023). How we did this is covered in detail in our blogs and is described in our factsheets. Overall, we managed to meet the 7% target set everywhere except Whitburgh (Scotland). In most areas we achieved more than 10% and in three areas we exceeded 15% of the demonstration sites (Figure 1.1, Hubbard et al., 2023).

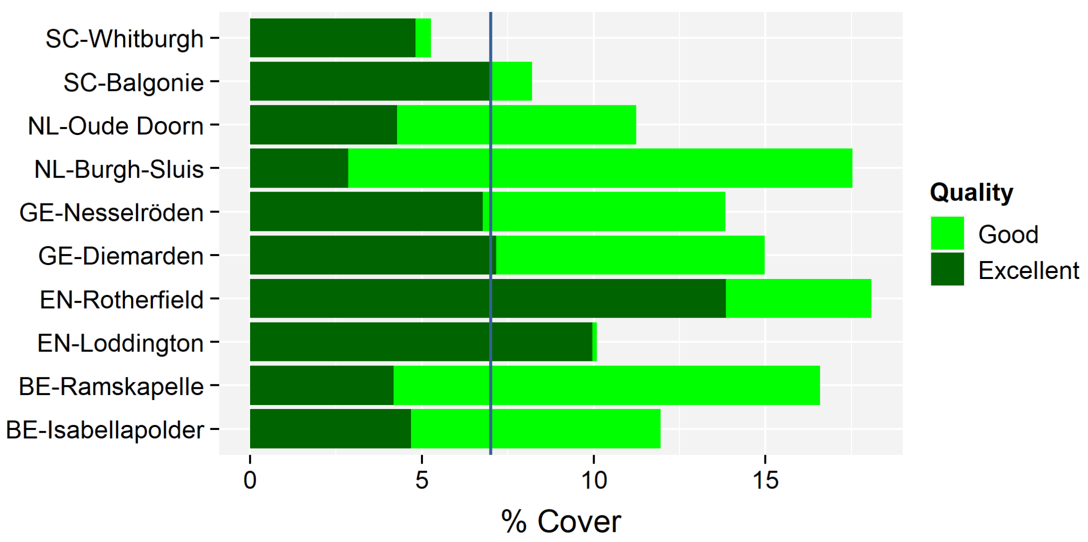


Figure 1.1. Realised habitat improvement at the PARTRIDGE demonstration sites.

Existing evidence has shown that these habitat improvements provide more and better breeding habitats in summer, and more food and shelter for the grey partridge, *Perdix perdix* overwinter (Brewin et al, 2020). Furthermore, the grey partridge serves as an umbrella species for farmland biodiversity in general and has been shown to be an indicator for farmland ecosystem health and it is expected that other farmland biodiversity has benefitted from the habitat improvements on our demonstration sites (Sotherton et al. 2014, Brewin et al, 2020).

To demonstrate the effects of the management, key farmland biodiversity indicators were monitored. In this report we present our monitoring results for grey partridge, breeding and overwintering farmland birds, and hares. We deployed several monitoring techniques. To estimate the size of the breeding bird populations, we collected information along line transect using playback to undertake counts for grey partridges (Chapter 2) and territory mapping for the other farmland breeding birds (Chapter 4). Breeding success of grey partridge was assessed by looking for coveys in autumn (Chapter 3). The use of the area in winter by farmland birds was monitored using point counts (Chapter 5). The wintering hare population was monitored by lamping along vehicle-driven transects or on counting points (Chapter 6). To improve overwinter food availability in the demonstration areas, feed barrels were installed. Camera traps were used to observe the use of these feeders by the different species present in the area (Chapter 7).

All indicator species were monitored in the demonstration sites and nearby reference sites (at a 2 - 16 km distance from the demonstration sites). These reference sites were managed in a 'typical' way for the region, with no special actions taken by the project to increase biodiversity. Comparing the monitoring data of the demonstration sites with the corresponding reference sites allowed us to separate the effects of the habitat enhancement from background conditions.

1.1 REFERENCES

Brewin, J., Buner, F., & Ewald, J. (2020). *Farming with Nature – promoting biodiversity across Europe through partridge conservation*. Fordingbridge, UK: The Game & Wildlife Conservation Trust.

European Commission. The EU Biodiversity Strategy to (2020). Luxembourg, 2011 http://ec.europa.eu/environment/nature/info/pubs/docs/brochures/2020 Biod brochure final lowres.pdf.

European Commission. Mid-term review of the EU biodiversity strategy to 2020. (2015) http://ec.europa.eu/environment/nature/biodiversity/comm2006/pdf/mid_term_review_summary.pdf.

Hubbard, C., Ewald, J., Buner, F., van Alebeek, F., Benders, M., Brown, B., Corvin-Czarnodolski, A., De Bruyn, L., Dienst, V., Dumpe, L., van Gernert, B., Gottschalk, E., Kimbrey, H., Mayall, E., Oost, F., Ots, M., Petersen, F., Raynor, E., Robertson, L., Scheppers, T., Sloothaak, J., Spivey, T., van de Straat, S., Torrance, F., Van Colen, W., Vanden Bussche, C., Verslyppe, K., Verzelen, Y., & Vreugdenhill, C. (2023). Landscape change on site in the PARTRIDGE Project. PARTRIDGE North Sea Region Interreg.

Sotherton, N. W., Aebischer, N. J., & Ewald, J. A. (2014). Research into action: grey partridge conservation as a case study. *Journal of Applied Ecology, 51*(1), 1-5. doi:https://doi.org/10.1111/1365-2664.12162

2 Grey partridge (*Perdix perdix*) – spring count

2.1 AIM

The PARTRIDGE project aimed to demonstrate how habitat measures tailored to grey partridge conservation management can enhance farmland biodiversity as a whole (we summarised these requirements based on scientific evidence in our project booklet 'Farming with Nature', Brewin et al., 2020). For this purpose, we carefully curated a mix of management measures, in particular a PARTRIDGE flower mix. Wherever possible the whole set of measures were implemented at ten demonstration sites spread across Europe, while the PARTRIDGE mix was introduced at all sites. The goal of planting this mix was to provide extra safe nesting cover, food availability and foraging cover for chicks, overwinter food, and protection from predators.

The grey partridge was chosen as the flagship species of the project due to its significance in the farmland ecosystem. It serves as an umbrella species for farmland biodiversity and an indicator of ecosystem health. Where grey partridges thrive, biodiversity is high, and ecosystem services are intact (Brewin et al., 2020).

To evaluate the effect of our measures on local partridge populations and farmland biodiversity in general, partridges were closely monitored across the demonstration sites, and their paired reference sites, where no or very few measures were present ("business as usual").

More specifically, information on the abundance of grey partridges was gathered in spring to address the following research questions:

1) Is the trend in the number of counted partridges per km more positive in the demonstration sites compared to the reference sites?
2) Is the number of counted partridges per km higher in the demonstration sites compared to the reference sites by the end of the project?

2.2 METHOD

2.2.1 METHOD SELECTION

Over the years, several methods have been developed to monitor grey partridge populations, from assessments of whole areas by driving (in four-wheel drive vehicles) across farmland to "flush counts", organised across whole areas or in sections of representative farmland, or point and line transect counts. Driven counts rely on the observation of birds, to identify and count individuals, pairs and coveys (family groups) – depending on the season. The goal is not to "flush" the birds but carefully observe them. It is a method commonly used in areas of farmland dominated by cereal farming – particularly in the UK (Potts, 1986). In contrast to these driving/observation counts, "flush counts" rely on the observation of partridges as they are flushed from across an area (total census counts) or subsets of an area ("belt" assessments) by a line of drivers, either in vehicles or on foot. This method tends to be used in areas of farmland with more mixed cropping – in France and parts of central Europe (Bro et al., 2000 & 2005; Husek et al., 2021; Pepin & Birkan, 1981). Although these methods provide an absolute number of individuals, they are often extremely labour-intensive and restricted to easily accessible, open areas.

In more densely vegetated areas, point and line transect methods provide an alternative. Here partridges are counted from predetermined points or along transects distributed throughout the area of interest. These counts require fewer personnel overall and are less hindered by denser vegetation, though can still be hampered by standing crops. In areas where direct observation of individuals is difficult, due to dense vegetation or behaviour, direct counts are often replaced (or supplemented) by indirect counting methods. For bird species this is often through counting bird calls instead of sightings. Grey partridge males demonstrate their highest vocal/calling activity during spring, when coveys break up and pairs start to form. Counting male partridge calls in spring has been used frequently for population monitoring in the past (Panek, 1998; 2006).

These call counts have been increasingly supplemented with the use of playback sounds to increase detectability (Gottschalk & Beeke, 2014; Jakob et al., 2010; Kasprzykowski et al., 2009; Pépin & Fouquet, 1992; Schoppers, 1996; Warren et al., 2018). The sound of a calling male partridge is played to provoke and subsequently count males in the field.

For the PARTRIDGE project, line-transect counting using playback was employed as the standard monitoring method across the project sites, because all other available methods were either deemed impractical, too labour intensive or not comparable between our project sites situated in five different countries. We therefore used playback calls to provoke and count the number of male partridges along predetermined transects spread throughout the project areas. This method was deemed most suited as a tool for large-scale monitoring across different areas that vary in vegetation and partridge density.

2.2.2 METHOD DESCRIPTION

See PARTRIDGE monitoring factsheet 'Best practice guidelines for successful grey partridge monitoring on farmland' on our Webpage: https://northsearegion.eu/partridge/output-library/.

2.2.3 DATA PROCESSING

All statistical analyses were performed in R v.4.3.0 (R Core Team, 2023).

2.2.3.1 Data preparation

To ensure the comparability of partridge counts across successive years, it was important to ensure that all designated transects were surveyed during each counting session. This involved distinguishing between two scenarios: transects where no partridges were counted (referred to as “true zero counts”) and transects that were skipped due to a lack of observers. When a transect was completed but no partridges were counted, they were documented as a "zero count." Conversely, if a transect was skipped, it was explicitly noted as "transect not done." Counting sessions in which transects were skipped were excluded from subsequent analyses.

Furthermore, ensuring accurate interpretation and reporting of the field observations was crucial for the reliability of the collected data. Since the analysis exclusively focused on male individuals, it was imperative to correctly translate field observations into male partridge counts. Difficulties often arose when birds were seen but not heard, heard but not seen, or multiple birds were seen. The rules we used to calculate the number of male partridges counted is outlined in Table 2.1, based on information provided in the counting form (refer to Appendix II) and assumptions discussed in the factsheet (Section 2.2.2). Any discrepancies in how field data was interpreted or reported were subject to a thorough examination and any errors were rectified for each counting session.

Table 2.1. Interpretation of partridge spring monitoring field data. Obs_Type = Observation Type, N/2 = total number recorded (seen or heard), divided by two, ↑= rounded up to the next full number, Ind = individuals.

Type of observation	Interpretation rule	N° seen	N° heard	N° males
SINGLE	OBS_TYPE = SINGLE → 1 male	0	1	1
		1	0	1
		1	1	1
PAIR	OBS_TYPE = PAIR → 1 male, 1 female	2	0	1
		2	1	1
COVEY	OBS_TYPE = COVEY & HEARD_N < (SEEN_N / 2) → males = (SEEN_N / 2)↑	*Ind. 7*	*Ind. 2*	*Ind. 4*
	HEARD_N > (SEEN_N / 2) → males = HEARD_N	*Ind. 3*	*Ind. 2*	*Ind. 2*

2.2.3.2 Trend analysis

Yearly index estimation

Based on the separate yearly counting sessions an estimate of male grey partridge numbers on an area can be calculated. To account for (i) the reliability of this estimate and (ii) the fluctuations over the years, we used a Bayesian model to simulate yearly estimates.

NOTE
In the factsheet (linked in Section 2.2.2) the field data is summarized by calculating a mean index per year from the separate counting sessions. However, for the analyses we used a more sophisticated approach.

The INLA package (Rue et al., 2009) was used to specify and fit this Bayesian model. The number of counted male partridges was used as the dependent variable. Site and Year were added as random factors, to account for the dependency of counts within each project site and year, respectively. To adjust for variations in total transect lengths among project sites, the natural logarithm of the total transect length (expressed in km) was used as an offset. The model utilizes a negative binomial error structure to account for the observed overdispersion in the count data. Based on this model, we simulated 1,000 values for the yearly estimates.

Trend comparison

To correct for the difference between demonstration and reference sites at the start of our monitoring period (namely 2017), we rescaled all estimates for the demonstration sites to this first year difference. As we were interested in comparing the trends between reference and demonstration sites, we subsequently calculated the yearly difference between the rescaled demonstration site estimates and the estimates of their paired reference sites. Next, we calculated the linear seven-year trend in these differences in the log-scale for each of the 1,000 simulated values. The median of this dataset represents the point estimate of the seven-year trend, and the 95% credibility interval corresponds to the 2.5% and 97.5% quantiles. Please refer to Appendix III.1.1 for further details.

2.2.3.3 Abundance

To evaluate the difference in the number of counted male partridges between demonstration and reference sites by the end of the project period (2021-2023), the lme4 package (Bates et al., 2015) was used to specify and fit a generalized linear mixed-effects model (GLMM). In this model, the number of counted males was used as the dependent variable and the site type (distinguishing between demonstration and reference sites) as the fixed, categorical, explanatory variable. The model also includes random effects to account for the variations among site pairs (demonstration/reference sites) within each year and across different sites, capturing site-specific and year-specific variations in the monitoring data. To adjust for variations in total transect length among project sites, the natural logarithm of the total transect length (expressed as km) was used as an offset. The model utilizes a negative binomial error structure to account for the observed overdispersion in the count data. Model estimates were obtained with the ggeffects package (Lüdecke, 2018). Please refer to Appendix III.1.2 for further details.

Overall, the GLMM provided a flexible and robust approach for analysing the difference in the number of counted partridges between demonstration and reference sites during the last three years of the project (2021-2023). It allowed us to test for the effects of site type while accounting for the total transect length and the distributional characteristics of the count data.

2.3 RESULTS

2.3.1 RAW DATA

Due to a shortage of observers at the English Loddington (demonstration) and Horninghold (reference) site pair, the counting protocol could not be followed. As a result, the count data available for this pair lacked replication and was not comparable to the data gathered at the other project sites. The Loddington spring count data was hence omitted from any further analyses. In addition, no surveys were performed at the Scottish Whitburgh demonstration site in 2021 due to challenges imposed by the Covid-19 restrictions. Given that monitoring was still in its testing phase at the Dutch Burghsluis site pair in 2017, the resultant data was deemed unreliable and excluded from the analysis.

In summary, the raw partridge spring monitoring dataset covered a total of 380 separate counting sessions. Throughout these sessions, a combined count of 4,525 male partridge observations were recorded across all project sites and years.

2.3.2 TREND

Figure 2.1 illustrates the fit of our model to the raw partridge spring monitoring data per site pair. For all analyses, we used the counted number of male partridges per walked kilometre as an index to account for the different total transect length across the project sites and years.

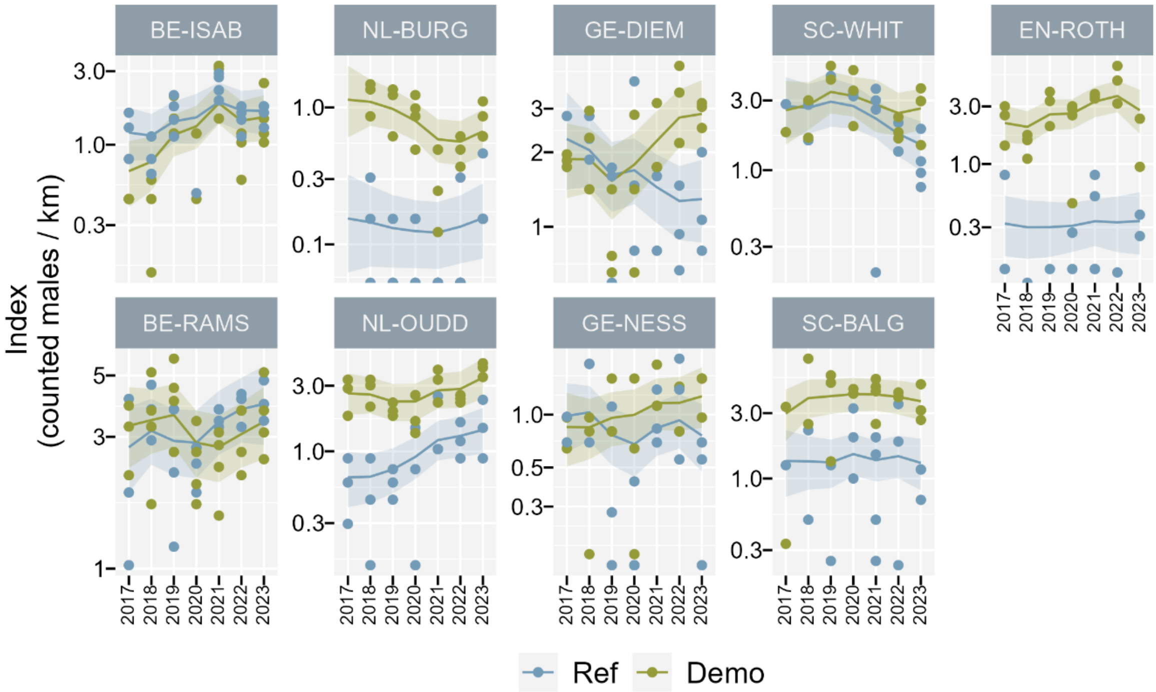


Figure 2.1. Raw partridge spring count data and modelled trend line (±95% interval) per site pair. Y-axis is presented on a log scale. BE-ISAB = Belgian Isabellapolder demonstration (demo) and reference (ref) site, BE-RAMS = Belgian Ramskapelle demo and ref site, NL-BURG = Dutch BughSluis demo and ref site, NL-OUDD = Dutch Oude Doorn demo and ref site, GE-DIEM = German Diemarden demo and ref site, GE-NESS = German Nesselröden demo and ref site, SC-WHIT = Scottish Whitburgh demo and ref site, SC-BALG = Scottish Balgonie demo and ref site, EN-ROTH = English Rotherfield demo and ref site.

Figure 2.2 presents the trend difference between demonstration and reference sites for each of the site pairs and for all sites combined (overall), expressed as a percentage. A 0% difference indicates that the trend in partridge numbers is equal in the demonstration and reference sites (no difference). Differences are considered statistically significant when the 95% credibility interval does not include the 0% reference or statistically non-significant if it does. Positive percentages indicate that the trend in the demonstration site is either more positive or less negative than in the reference sites, while negative percentages suggest the opposite. The 30% difference indicates the project's target to reach at least a 30% increase in demonstration sites compared to reference sites.

The overall trend difference between demonstration and reference sites was not significant. Although it leans towards the positive side, the wide interval also covers extremely negative values. This suggests that overall, the trend in number of male partridges counted per km was not significantly different between demonstration and reference sites and that it ranged from being highly negative to highly positive.

At the site pair level, the differences in the trends varied widely. Only one site pair, GE-DIEM, showed a significant positive difference in the trend between the demonstration and reference areas, exceeding the 30% project target. This indicates that the number of counted male partridges per km at the German Diemarden demonstration site increased significantly compared to the paired reference site (Bilshausen). For all other site pairs, the difference was not significant, with intervals either leaning towards the positive (GE-NESS, SC-WHIT, BE-ISAB, EN-ROTH), centring around 0% difference (SC-BALG) or leaning towards the negative (BE-RAMS, NL-OUDD, NL-BURG). Note that most site pairs are characterized by relatively wide intervals, presumably resulting from large annual fluctuations in the number of partridges counted.

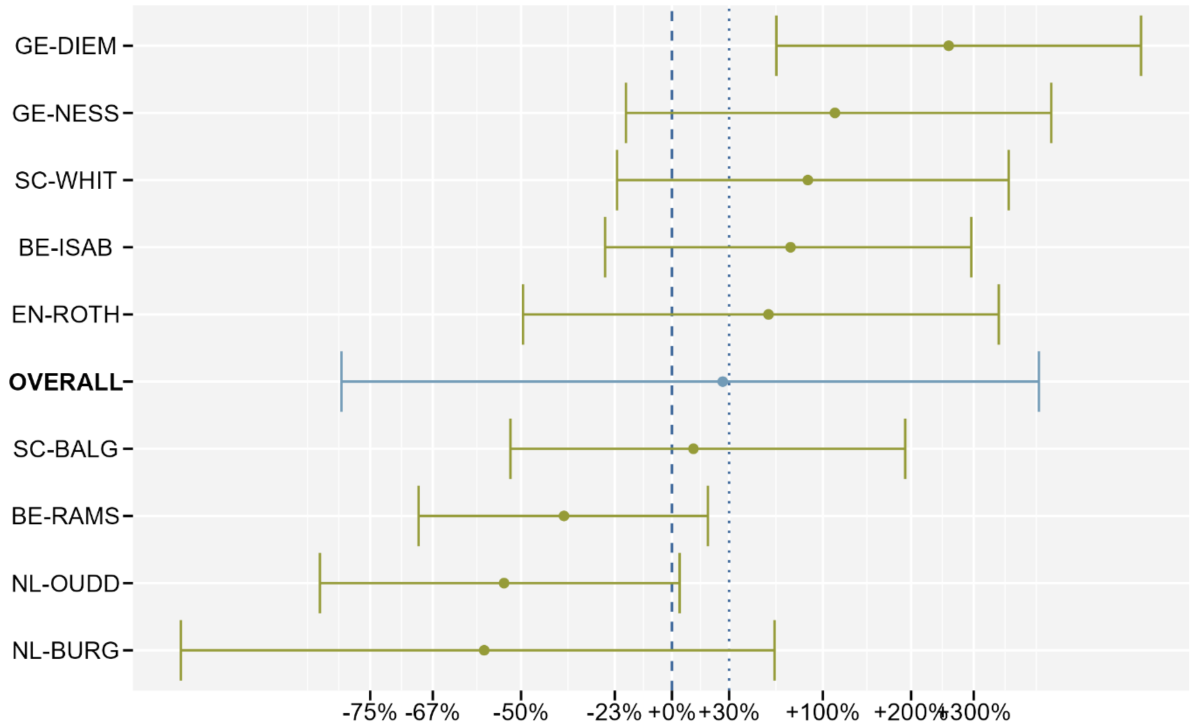


Figure 1.2. Difference in partridge spring monitoring trends (%) between demonstration and reference site pairs (green) and overall (blue) where the dots show the median value and the error bars the 95% intervals. The x-axis is presented on a log scale. The dashed line at 0% indicates no difference; the dotted line at 30% indicates the project's target. For explanation of site abbreviations please see Figure 2.1.

2.3.3 ABUNDANCE

Figure 2.3 shows the mean number of male partridges per kilometer for both the demonstration and reference sites, all sites combined. **By the end of the project period, the number of counted partridges was significantly higher in the demonstration sites compared**

to the reference sites with an estimated number of 2.1 (95% confidence interval: 1.25-3.55) partridges per kilometer at the demonstration sites, compared to 0.99 (95% confidence interval: 0.59-1.69) at the reference sites. The relatively wide confidence intervals are a result of large between-year variability.

At the site pair level, the number of counted partridges was higher in all demonstration sites, except at Isabellapolder and Ramskapelle (both in Flanders, Belgium). The difference between demonstration and reference site was highest in Rotherfield (England) and Burghsluis (the Netherlands), with respectively more than ten times in the former and close to five times more partridges counted at the latter (Appendix I.1).

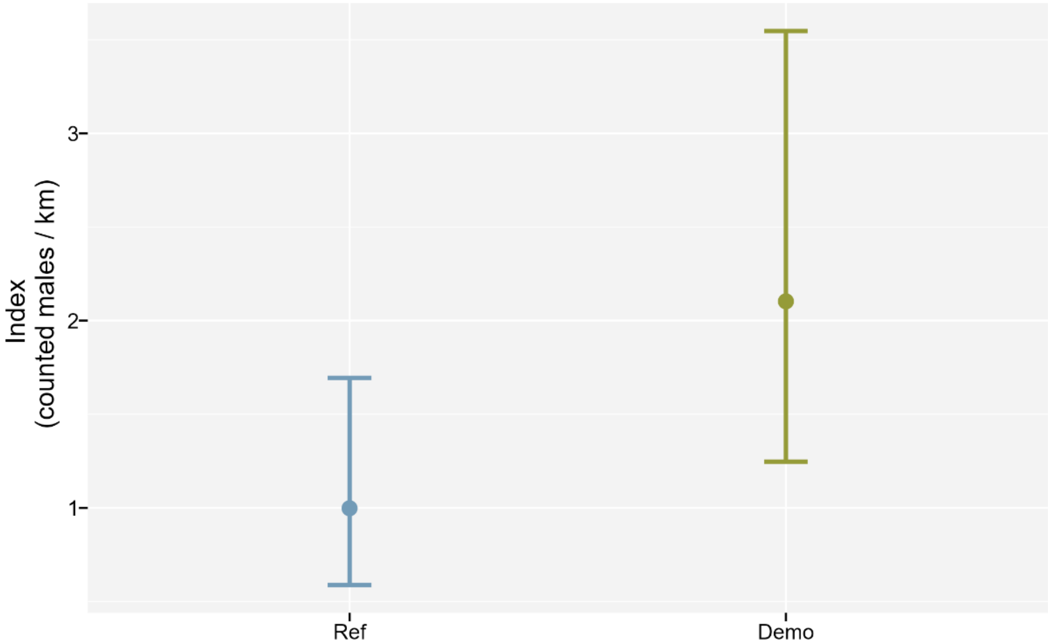


Figure 2.3. The number of male partridges counted per kilometer transect at the demonstration and reference sites for all sites combined (2021-2023). Error bars represent 95% confidence intervals.

2.4 DISCUSSION

By the end of the project period, partridge numbers were significantly higher in the demonstration sites compared to the reference sites. This result is in line with the findings of the breeding bird monitoring, revealing that, on average, our demonstration sites hosted 70% more breeding territories for grey partridges compared to the reference sites (Chapter 4). Combining these findings with the extensive habitat mapping data presented by Hubbard et al. (2023), which highlight that our demonstration sites consistently outperformed our reference sites across a spectrum of habitat quality metrics, further underscores the positive impact of increased habitat quality on local partridge populations in farmland. **Moreover, they demonstrate the benefit of wildlife-friendly habitat, such as flower blocks, grass margins, beetle banks, hedges, and more, in creating an environment supporting these ground-nesting farmland inhabitants.**

Despite these findings, identifying a substantial difference in the trend in grey partridge numbers between the demonstration and reference sites over the project period proved challenging. To be able to detect trend differences, it is important to not only implement sufficient habitat improvements at the demonstration sites, but also to look at the relative additive value of this habitat at the start of the project. The larger the differences, the more likely that trends will be detected. Our detailed habitat mapping revealed that while we succeeded in adding on average 4.9% of beneficial habitat during the project period, most of the demonstration sites we selected had started the project in a favourable condition, with close to or even exceeding the targeted 7% of beneficial habitat coverage in 2017 (Hubbard et al., 2023). It therefore might be that our additional habitat improvements did not manage to have a substantial enough impact on the local grey partridge population trend at our demonstration sites to be detectable by our monitoring efforts. Alternatively, local partridge populations might have already been close to or at carrying capacity (influenced by factors outside our control, such as predation pressure and the turnover of individuals on our sites – with our demonstration areas losing grey partridges to lower density areas, see also further below) due to the ample beneficial habitat present at the demonstration sites from the start, potentially explaining their lack of response to our additional habitat improvements.

Moreover, trend analyses are notoriously challenging, often necessitating extensive sampling efforts and long-term data collection to gather enough observations. This enables the differentiation between natural year-to-year fluctuations and the effect of our implemented management on the overall trend. This distinction becomes particularly crucial when dealing with species characterized by smaller population sizes and/or lower densities, such as the grey partridges in our project sites. Although the seven years of monitoring at our 500-ha demonstration sites, yielded valuable insights, it is important to acknowledge that achieving accurate assessments of population trends and their responses to habitat improvements might require an even longer observation period and even larger study areas.

Establishing a clear cause-and-effect relationship between our habitat enhancements and the trend in local partridge numbers could be further complicated by other factors that equally influence partridge populations at our project sites. Beyond habitat quality, local factors such as predation levels, dispersal, disease and human induced fatalities (e.g. mowing, ploughing, road casualties, etc.) can equally impact the number of partridges in an area. As these factors could not explicitly be quantified in our analysis of the partridge data, their influence remains speculative and intertwined with the effects of our management measures.

In addition to the influence of these local factors on partridge populations, the number of counted males is also highly dependent on the method used and how strictly the protocol was followed. The line-transect playback method relies on counting the number of calling males in the field as an indirect measure of partridge abundance in the area. While previous research demonstrates the effectiveness of this method in tracking population trends, it is important to note that the outcomes of these call counts can be strongly affected by factors such as weather conditions and the timing of monitoring.

Weather conditions can significantly diminish the detectability of male calls. This can result in a notable reduction in the number of individuals counted when conducting surveys under suboptimal weather conditions. Take, for instance, the counts carried out at the Dutch Burghsluis and Nieuwerkerke project sites in 2021. Due to an overlap between the monitoring period and an extended duration of rainy and windy weather, the counts had to proceed under less-than-ideal conditions. These counts yielded markedly lower results compared to counts in previous and subsequent years. This discrepancy was particularly evident at the Burghsluis demonstration site.

Furthermore, the timing of monitoring can exert a significant influence on the number of individuals counted. Male calling activity is closely tied to the time of year, with males calling most intensely after the break-up of coveys, during pair formation (February to mid-April) (Panek, 1998, Rotella & Ratti, 1988). Counting either too early, when coveys are still together, or too late, when pairs have already formed, can result in a substantial decrease in the number of calling males. Therefore, it is crucial to carefully choose the timing of monitoring and maintain the same period consistently throughout the years, with this timing to coincide with partridge behaviour, not necessarily a calendar date.

2.5 CONCLUSION

In conclusion, the results from the partridge spring monitoring provide compelling evidence for the vital role of enhanced habitat quality in supporting local partridge populations in farmland environments. The significantly higher number of counted partridges at the demonstration sites compared to the reference sites underscores the positive impact of wildlife-friendly habitat measures on local partridge numbers. Nevertheless, the challenges posed by trend analysis and the possible influence of other factors demonstrate the difficulties in working with small, local populations and their population dynamics and the complexities involved in evaluating the relationship between habitat enhancement and biodiversity.

2.6 REFERENCES

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48.

Brewin, J., Buner, F., & Ewald, J. (2020). *Farming with Nature – promoting biodiversity across Europe through partridge conservation*. Fordingbridge, UK: The Game & Wildlife Conservation Trust.

Bro, E., Sarrazin, F., Clobert, J., & Reitz, F. (2000). Demography and the decline of the grey partridge *Perdix perdix* in France. Journal of Applied Ecology, 37(3), 432–448.

Bro, E., Reitz, F., & Landry, P. (2005). Grey partridge *Perdix perdix* population status in central northern France: spatial variability in density and 1994–2004 trend. Wildlife Biology, 11(4), 287–298.

Gottschalk, E., & Beeke, W. (2014). How can the drastic decline in the Grey Partridge (*Perdix perdix*) be stopped? Lessons from ten years of the Grey Partridge Conservation Project in the district of Göttingen. Ber. Vogelschutz 51, 95–116.

Hubbard, C., Ewald, J., Buner, F., van Alebeek, F., Benders, M., Brown, B., Corvin-Czarnodolski, A., De Bruyn, L., Dienst, V., Dumpe, L., van Gernert, B., Gottschalk, E., Kimbrey, H., Mayall, E., Oost, F., Ots, M., Petersen, F., Raynor, E., Robertson, L., Scheppers, T., Sloothaak, J., Spivey, T., van de Straat, S., Torrance, F., Van Colen, W., Vanden Bussche, C., Verslyppe, K., Verzelen, Y.,

& Vreugdenhill, C. (2023). Landscape change on site in the PARTRIDGE Project. PARTRIDGE North Sea Region Interreg.

Husek, J., Boudreau, M. R., & Panek, M. (2021). Hunter estimates of game density as a simple and efficient source of information for population monitoring: A comparison to targeted survey methods. In PLoS ONE (Vol. 16, Issue 8 August). Public Library of Science.

Jakob, C., Ponce-Boutin, F., Besnard, A., & Eraud, C. (2010). On the efficiency of using song playback during call count surveys of Red-legged partridges (*Alectoris rufa*). European Journal of Wildlife Research, 56(6), 907–913.

Kasprzykowski, Z., & Goławski, A. (2009). Does the Use of Playback Affect the Estimates of Numbers of Grey Partridge *Perdix perdix*?. Wildlife Biology. 15. 123-128.

Lüdecke, D. (2018). ggeffects: Tidy Data Frames of Marginal Effects from Regression Models. Journal of Open Source Software 3:1-5.

Onkelinx, T., Vermeersch, G., & Devos, K. (2023). Trends op basis van de Algemene Broedvogelmonitoring Vlaanderen (ABV). Technisch achtergrondrapport voor de periode 2007-2022. Rapporten van het Instituut voor Natuur- en Bosonderzoek 2023 (1). Instituut voor Natuur- en Bosonderzoek, Brussel.

Panek, M. (1998). Use of call counts for estimating spring density of the Grey Partridge *Perdix perdix*. Acta om. 33, 143-148.

Panek, M. (2006). Monitoring Grey Partridge (*Perdix perdix*) Populations in Poland: Methods and Results. Wildlife Biology in Practice, 2(2).

Pépin, D., & Birkan, M. (1981). Comparative total and strip census estimates of hares and partridges. Acta Oecol. 2, 151-160

Pépin, D., & Fouquet, M. (1992). Factors affecting the incidence of dawn calling in red-legged and grey partridges. Behav Processes. 26(2-3), 167-76.

Potts, G.R. (1986). The Partridge: Pesticides, Predation and Conservation. Collins, London.

R Core Team (2023). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org.

Rotella, J. J., & Ratti, J. T. (1988). Seasonal Variation in Gray Partridge Vocal Behavior. The Condor, 90(2), 304–310.

Rue, H., Martino, S., & Chopin, N. (2009). Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. In J.R. Statist. Soc. B. (Vol. 71, Issue 2).

Schoppers, J. (1996). Cassetterecorder goed hulpmiddel bij inventarisatie Patrijs *Perdix perdix* in het broedseizoen. (In Dutch with an English summary: tape recorder useful in breeding season surveys of Partridge Perdix perdix). Limosa 69, 180–181.

Warren, P., Hornby, T., & Baines, D. (2018). Comparing call-playback to an observation-only method to survey Grey Partridge *Perdix perdix* on hill farms in northern England. Bird Study 65, 225-231.

3 Grey partridge (*Perdix perdix*) – autumn count

3.1 AIM

The main aim of grey partridge monitoring in autumn is to assess the breeding success of a local partridge population. It is the best measure to understand whether the conservation management measures implemented in a certain area result in increased grey partridge breeding success (in our case the PARTRIDGE measures), compared to a reference site, where no such measures were taken ("business as usual"). To test this, we were interested in the number of coveys at our demo and reference areas, their covey size, and their young/adult ratios (Ewald et al., 2009).

3.2 PROTOCOL

Unfortunately, counting partridge coveys in late summer and early autumn proved to be rather difficult in many of our continental PARTRIDGE project sites, despite it working perfectly in the UK. We have tried various types of monitoring to get an idea of the number of coveys per site, the covey size, and their young/adult ratio. However, we were unable to develop one single, best method for all study areas. Much of this had to do with the fact that crop type varied greatly between project sites. A large proportion of maize or cover crops on an area can make it difficult to near impossible to find coveys, as they tend to hide within those maize fields during daytime.

Especially at our German project sites, the abundance of cover crops has proven to be a major problem for counting partridge coveys. Consequently, no successful autumn counts were carried out in Germany, and we decided to curtail autumn counts there. The same decision was arrived at for the two Zeeland (the Netherlands) demonstration and reference sites, as no partridges were ever seen or heard during the autumn counts, even though we know from the spring counts that they were present earlier in the year.

The situation in the other two Dutch sites in Brabant couldn't be more different, as all coveys were followed closely by volunteer field workers during the summer months. Because of this, no special partridge autumn count was carried out at these sites. At the English and Scottish sites, autumn counting consisted of driving around and crossing each accessible field. This technique is called a 'stubble count' and has been used successfully in the UK for over 50 years (particularly in Sussex: Potts, 1986; Potts & Aebischer, 1995, but also across the UK through the national Partridge Count Scheme managed by the GWCT, mainly by gamekeepers, farmers, and land managers). According to the protocol (Ewald et al., 2009), autumn counts were conducted at our UK project sites each year. At the Belgian sites, we were unable to use this method because driving on the farmer's fields was not allowed. Instead, we tried to cover as much of the site as possible by driving along existing roads. The playback call was used to increase the chances of partridge detection. When a partridge was seen, we stopped and watched with binoculars, to count the total number of partridges in each covey. We distinguished adult males from females and attempted to age the chicks, in order to estimate their time of hatching, which proved to be difficult.

3.3 RESULTS

The lack of autumn data in some sites and non-standardized monitoring across the others made it impossible to analyse the autumn count data.

3.4 CONCLUSION

Despite our efforts, we were unable to find a standardized protocol for counting partridges during the autumn season. This emphasizes the difficulty of finding a standardized protocol that can be applied effectively across a diverse range of landscape types, regions, and indeed countries.

3.5 REFERENCES

Ewald, J.A., Kingdon, N., & Santin-Janin, H. (2009). The GWCT partridge count scheme: a volunteer-based monitoring and conservation promotion scheme. Pages 27 - 37 in Cederbaum SB, Faircloth BC, Terhune TM, Thompson JJ, Carroll JP, eds. Gamebird 2006: Quail VI and Perdix XII. 31 May - 4 June 2006. Warnell School of Forestry and Natural Resources, Athens, GA, USA.

Potts, G.R. (1986). The Partridge: Pesticides, Predation and Conservation. Collins, London.

Potts, G.R., & Aebischer, N.J. (1995). Population dynamics of the Grey Partridge *Perdix perdix* 1793–1993: monitoring, modelling and management. Ibis, 137 (Supplement 1): S29–S37.

4 Breeding birds

4.1 AIM

The key objective of the PARTRIDGE project was to improve the farmland habitat using methods tailored to grey partridge conservation management and in doing so, benefit a wide range of other farmland biodiversity, including other farmland birds. The implementation of various management measures aimed at providing more chick-food for chicks of partridges and other farmland birds and seeds for adult birds, more and better nest site opportunities and improved cover and food during winter. Based on existing research (see Brewin et al., 2020), we expected that other wildlife would also benefit, resulting in an overall biodiversity increase of up to 30% in the demonstration sites compared to the reference sites. In this chapter we focus on farmland birds as categorized by the Pan-European Common Bird Monitoring Scheme (2022) for the Atlantic region.

Here we tested the effect of the enhanced habitat on breeding songbirds.

1) Do more bird species breed in the enhanced demonstrations areas compared to the corresponding reference areas without the extra measures?
2) Do those birds have more breeding territories?

4.2 PROTOCOL

4.2.1 METHOD SELECTION

Two methods are commonly applied in bird surveys: distant sampling and territory mapping (Bibby et al. 2000, Buckland 2006). In brief, for distant sampling, all birds seen or heard from a counting point or line transect are recorded and the distance (used to calculate detectability) is estimated each time. These data are used to calculate bird densities. For territory mapping, all birds seen or heard in the monitoring area are noted on a map. The observations of several visits during the breeding season are combined based on a set of rules to delineate breeding territories.

Several studies have compared both methods in the field but did not find a clear pattern when comparing the results of each (Gillings et al. 1998, Shankar Raman 2003, Buckland 2006, Gottschalk and Huettmann 2011). Gregory (2000) compared line transects, point transects and territory mapping and concluded that territory mapping was much more precise than both transect methods. A drawback according to his paper is that territory mapping is not very efficient since the time required to analyse mapping data was seven times greater than for the transect data. However, at that time, no dedicated computer software was available that streamlined and standardised the translation of the field data into territories.

Gottschalk and Huettmann (2011) argue that territory mapping does not take detectability of the target species into account. Distance sampling includes a species-specific detection function based on the distance between the observed bird and the observer (Buckland et al. 2015). To derive this detection function reliably, it is postulated that at least 60-80 observations are needed along line transects and 75-100 for point transects (Buckland et al. 2015). Some authors claim that it might be possible to get useful estimates with fewer observations (Gottschalk and Huettmann, 2011), this approach is not without criticism, since it is impossible to get enough observations when species only have one or a few territories in the survey area, as is often the case for (threatened) farmland birds. Territory mapping accounts for imperfect detection by setting a minimum, required number of observations. Bibby et al. (2000) suggest at least two observations obtained during 8, or fewer, field visits. To define a territory based only on a fixed number of observations, usually equal for the different bird species, might be problematic. According to Gottschalk and Huettmann (2011) better criteria, such as a species-specific minimum number of observations and a species-specific maximum distance between registrations, should be used to set a territory.

An advantage of territory mapping is that it is spatially explicit. It gives fine spatial details as to where the territories of the birds are situated which can be correlated with environmental variables such as farmland agreement measures (Douglas et al. 2009, Burgess et al. 2015).

Based on these arguments, it was decided to use territory mapping to monitor the presence of breeding birds in the study areas. We deployed the territory mapping method used in The Netherlands (van Dijk and Boele 2011), slightly adapted to the local situations in the partner countries of our project.

4.2.2 FIELD METHODS

Field work was carried out in both the demonstration and reference areas in the five partner countries Belgium, England, Germany, Scotland, and The Netherlands (https://northsearegion.eu/partridge/). There were two demonstration sites and two reference sites in each country (20 sites overall). Demonstration and reference sites were (geographically) selected in pairs in a way that the environmental situations were comparable, except for the measures. Since it was impossible to cover the whole site (± 500 ha) in one morning, it was decided to observe the birds along a fixed 6-7km transect. The transects were selected in a way to maximise the area that could be seen from them (i.e., viewshed) and so that they covered areas with and without measures in the demonstration sites and a representative area of the reference sites.

The focus was on farmland birds because these were the main targets of the project's farmland habitat agreements. Therefore, at least five field visits (minimum 10 days apart) between early April and end of July were required. Field surveys took place in the morning, starting around sunrise on days when preferentially calm, sunny weather and average temperatures was predicted. The starting point of the transect was changed each visit, rotating across the area to avoid confounding recording with time.

To simplify and standardise the fieldwork, SOVON, the Dutch Centre for Field Ornithology, developed an AVIMAP-app to enter the observations in the field (SOVON 2015). The app runs on a smartphone/tablet with GPS. After ending the survey, the data were uploaded to a server.

To collect the data, a skilled bird ecologist or volunteer walks slowly along the transect. Every bird that is seen or heard is noted carefully on a map of the region, presented on the smartphone/tablet. Each observation is given a breeding code from 0 to 16. A higher number indicates an observation with a higher certainty of breeding (Table 4.1). When two birds are seen/heard simultaneously, or when two birds are seen along the transect and it is unlikely that these observations belong to the same bird, these are exclusive observations that indicate that these birds belong to two different territories.

Table 4.1 Breeding codes. Adapted from SOVON (2016).

Breeding code	Description
0	Other / outside breeding habitat
Birds seen in breeding habitat	
1	Adult bird in breeding habitat
3	Pair (when singing/display, use code 2 or 5)
Territory indicating behaviour	
2	Singing / displaying male
5	Courtship and display behaviour
Nest indicating behaviour	
6	Visiting probable nest site
7	Agitated behaviour or anxiety calls (adults)
8	Adult with brood patch
9	Nest building
10	Distraction display or injury feigning
11	Recently used nest
12	Recently fledged young
14	Transport of food or feacal sac
Nest found	
13	Used nest (adult entering or leaving)
15	Nest with eggs
16	Nest with young

4.2.3 DATA PROCESSING

After the field season, once all data are uploaded to the server, the observations are clustered to obtain breeding territories. In 2013, SOVON developed an auto-cluster tool (Van Dijk et al. 2013). This automated technique standardises the interpretation of the observation clustering which makes the results comparable across survey areas and years. Clustering is based on nearest neighbourhood agglomerative clustering. In subsequent steps, the nearest observations are grouped, considering species-specific characteristics (Table 4.2). The values of the species-specific criteria are listed in van Dijk and Boele (2011) and Vergeer et al. (2016).

Table 4.2 Species specific characteristics used when clustering observations into territories.

Date limits	To exclude migrants or vagrants, an observation must fall within these date limits to be valid.
Fusion distance	Maximum distance between two non-exclusive observations to allow inclusion in the same territory.
# valid observations	The minimum number of valid observations needed. Valid observations indicate territory and/or nest presence. Breeding code 2 or higher (Table 4.1).

4.2.4 SELECTED SPECIES

From the Atlantic farmland bird list, 18 species were recorded on our demo and reference sites. For the analysis we divided the species in three groups (Table 4.3). Farmland species associated with small-field arable landscapes (9 species) with numerous hedgerows, wood edges, orchards, etc. Some of these species also occur in areas with sparse upright green elements, but these areas of green are relatively small. As a result, the total length of plot edges in these landscapes is large. At the other extreme, species of open farmland (5 species) prefer wide-open landscapes and breed at least 100m from linear elements like hedges or trees. Semi-open landscape species (4 species) are somewhere in between, ie. a mix of open and rather closed landscape.

Table 4.3 Farmland bird species encountered during the present study.

Landscape	**Species**
Small-scaled	Linnet *Carduelis cannabina*, Tree Sparrow *Passer montanus*, Turtle-Dove *Streptopelia turtur*, Goldfinch *Carduelis carduelis*, Whitethroat *Curruca communis*, Grey Partridge *Perdix perdix*, Lesser Whitethroat *Curruca curruca*, Red-backed Shrike *Lanius collurio* , Yellowhammer *Emberiza citrinella*
Semi-Open	Kestrel *Falco tinnunculus*, Stonechat *Saxicola rubicola*, Rook *Corvus frugilegus*, White Wagtail *Motacilla alba*
Open	Corn Bunting *Emberiza calandra*, Meadow Pipit *Anthus pratensis*, Lapwing *Vanellus vanellus*, Sky Lark *Alauda arvensis*, Yellow Wagtail *Motacilla flava*

4.2.5 STATISTICAL ANALYSES

To assess whether bird abundances were higher in the demo sites compared to the reference sites we used the monitoring data of the breeding seasons of 2020 to 2022. By 2020 the, all environmental measures were implemented and had time to develop. We deployed generalised linear mixed model analysis. We used the number of territories of a species group in a breeding season as the dependent variable is. The fixed explanatory variables were site type (Demonstration site versus reference site), species group (the three bird categories), and the interaction between site and species group.

We analysed the data, both at the local level (individual site pairs) and at the “European” level (all sites combined). To account for the fact that two sites (demonstration and reference) belong to the same site pair, pair was added as a random effect in the model for the overall analysis. The same applied for sites monitored during the same breeding season since weather conditions can differ strongly between years. Since conditions can differ among regions (e.g., Balgonie is much further north than the sites in Belgium), we added a random site-couple x year effect to the overall analysis. At the local level, the year of the breeding season was added as a fixed effect since there were not enough years to add them as a random effect.

The viewing distances from the transect line differed between sites. In Belgium and The Netherlands, for instance, the landscape is flat with hardly any tree line or hedge. In England or Germany, the landscape is hilly with numerous hedges which hampers the view. Therefore, log(area) of the viewshed area (in ha) was added as an offset to account for the differences in observation areas between sites. We used a negative binomial error structure to account for the observed overdispersion in the count data.

Beside abundance we also tested whether species richness differed between treatments and species groups. The same model was deployed as above except that a Poisson error distribution was used since these data were not overdispersed.

All statistical analyses were performed in R v.4.3.0 (R Core Team 2023). The generalised mixed models were run with the glmmTMB function (glmmTMB package, Brooks et al, 2017). Overdispersion and zero inflation were tested with the DHARMa package (Hartig, 2022). Model estimates were obtained with the ggeffects function (ggeffects package (Lüdecke 2018)) and graphically displayed with the ggplot function (tidyverse package, Wickham et al, 2023) and the patchwork package (Pedersen, 2023) or tabulated with the flextable package (Gohel, 2023).

4.3 RESULTS

During the three breeding seasons considered here, the English sites recorded the most farmland bird species with breeding territories (16/18) (Appendix 1.2.1.). In Belgium, Germany and The Netherlands 14 species were recorded and in the Scottish sites 11. Eight species (Linnet, Tree Sparrow, Goldfinch, Whitethroat, Grey Partridge, White Wagtail, Meadow Pipit, Sky Lark) were found in all five countries, while Turtle-Dove (Belgium), Red-backed Shrike (Germany) and Corn Bunting (England) were only recorded in a single country.

4.3.1 ABUNDANCE

For all three bird categories, there were, on average, more breeding territories in the demonstration sites compared to the reference sites (Figure). For birds from small-field landscapes abundance is almost twice as high in the demonstration sites. For semi-open and open landscape species it was 51% and 32% higher, respectively.

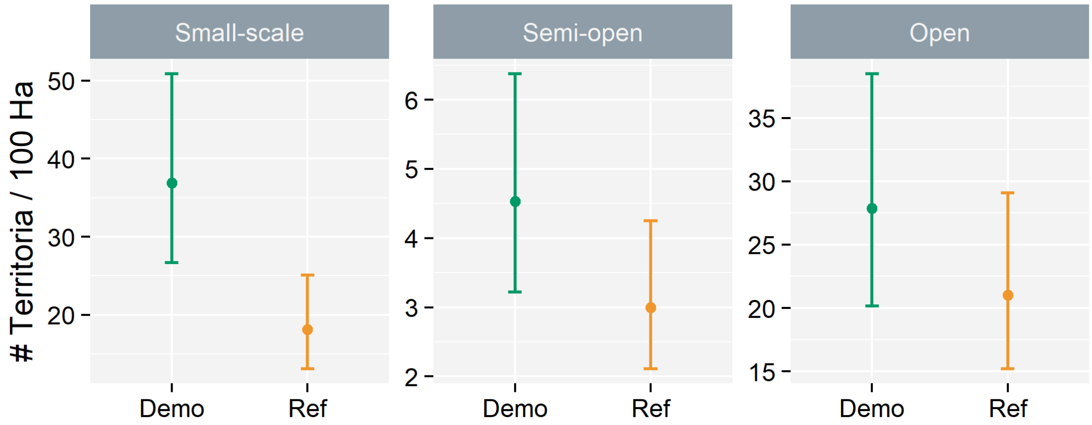


Figure 4.1. Annual abundance - Mean number of breeding territories in the demonstration and reference sites for all site-couples combined per species group. The vertical lines show the variation between counts.

At the site-pair level, abundance of the small-field bird species was higher in all demonstration sites, except for Isabellapolder. The difference between demonstration and reference sites was highest in Oude Doorn (The Netherlands) Rotherfield (England) and Balgonie (Scotland) with respectively nearly 8-times, more than 3 times and 3-times more breeding territories in the demonstration sites compared to the reference sites (Appendix 1.2.2). For the bird species of semi-open habitats, there were more breeding territories in the demonstration sites except for the two Belgian sites Isabellapolder and Ramskapelle. The largest differences for these species were observed in Nesselröden (Germany) and Oude Doorn (The Netherlands) with respectively more than 5-times and more than 4 times more territories in the demo sites. The species of semi-open habitats were absent in the demo and reference site of Loddington. The outcome for the open landscape species is more heterogenous. The highest positive effect is found at Oude Doorn (The Netherlands) and Balgonie (Scotland). In the first of these we found five times more territories in the demonstration area, for Balgonie it was slightly more than twice as much. On the other hand, fewer territories were recorded in the demonstration areas than in the reference areas in both the German areas (Nesselröden -19%, Diemarden -16%) and at Whitburgh (Scotland, -39%).

4.3.2 DIVERSITY

The number of species observed annually in the demonstration sites was, overall, for all sites combined, also slightly higher than in the reference sites, and this held true for all three species groups (Figure). In all three species groups there were on average slightly more than 20% more bird species in the demonstration sites. However, at the individual site-pair levels, differences were small (Appendix 3). For the small-field species differences were highest in Oude Doorn (The Netherlands) and Balgonie (Scotland). For the other species groups (semi-open and open landscape), the differences between the demo sites and the reference sites were much smaller and did not differ across the sites.

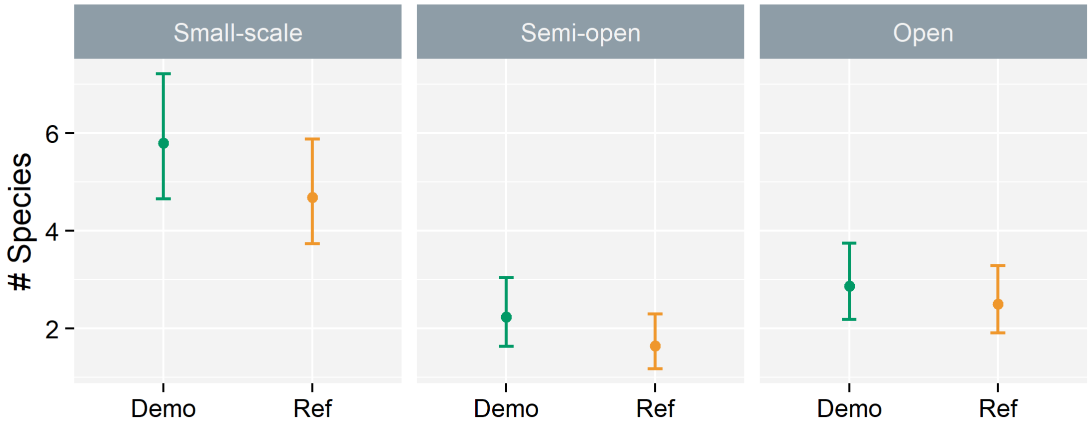


Figure 4.2. Annual diversity - Mean number of bird species with breeding territories for all sites combined per species group. The vertical lines show the variation between counts.

4.3.3 INDIVIDUAL SPECIES

For three species there was not enough data to run a statistical analysis. We only recorded one red-backed shrike breeding territory in 2021 and 2022 in the demonstration site Nesselröden (Germany), For turtle-Dove there was only one breeding territory in 2020 in the demonstration site Isabellapolder (Belgium) and for corn bunting we recorded six territories in 2022 only in the reference area of Rotherfield (i.e., Cheriton, England).

Overall, for all sites combined, the number of territories was clearly higher in the demonstration areas compared to the reference sites for 10 of the 13 species (Figure). The number of territories was 30% or more higher in the demonstration sites for all 11 species. The largest differences were noted for lesser whitethroat (5-times more territories), lapwing (3-times more), whitethroat and stonechat (both more than 2-times more territories). Linnet, goldfinch, grey partridge, meadow pippet, skylark and yellowhammer had between 30% and 80% more territories in the demonstration sites compared to the reference sites. There was no difference between demonstration and reference sites for yellow wagtail, white wagtail and Eurasian tree sparrow.

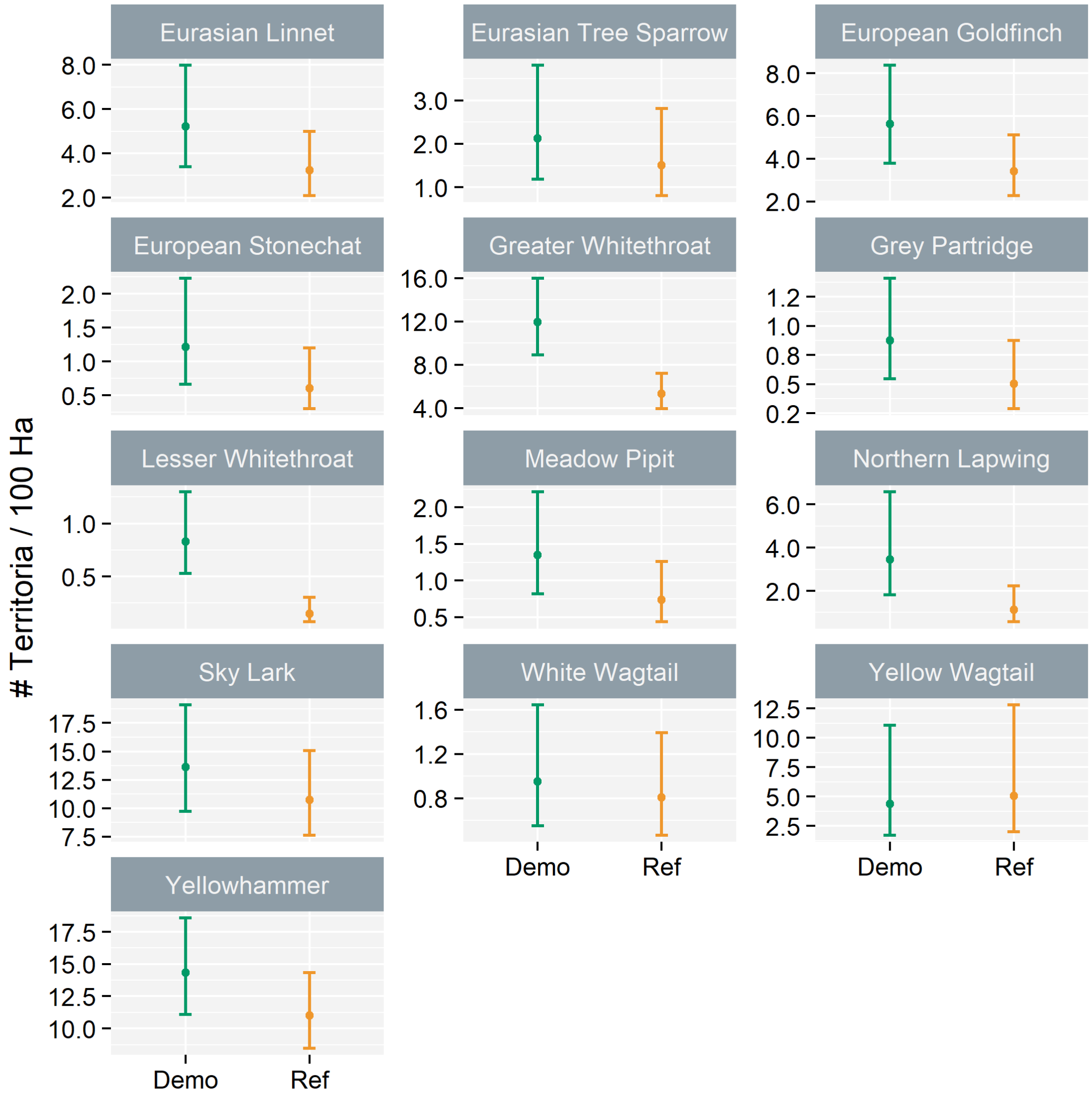


Figure 4.3. Annual abundance - Mean number of breeding territories (corrected for differences among site-pairs) of the recorded farmland birds in the demonstration and reference sites for all site-pairs combined. The vertical lines show the variation between counts.

4.4 CONCLUSION

Our study demonstrated that both the number of birds (abundance) and the number of species (diversity) are higher when the farmland habitat is enhanced with beneficial wildlife habitats such as flower blocks and beetle banks. Farmland bird species that live in small-scaled farmland landscapes with numerous hedgerows, wood edges, orchards benefited the most. Iconic farmland birds such as lesser whitethroat (500%), linnet (60%), yellowhammer (30%), skylark (30%) and grey partridge (70%) had clearly more breeding territories in our demonstration sites than in the reference sites.

4.5 REFERENCES

Bibby, C. J., Burgess, N. D., Hill, D. A. & Mustoe, S. (2000). *Bird census techniques*, 2nd edn. Academic Press, London.

Brewin, J., Buner, F., & Ewald, J. (2020). *Farming with Nature – promoting biodiversity across Europe through partridge conservation*. Fordingbridge, UK: The Game & Wildlife Conservation Trust.

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Maechler, M. & Bolker, B. (2017). glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. The R Journal 9(2): 378-400.

Buckland, S. T. (2006). Point-Transect Surveys for Songbirds: Robust Methodologies. The Auk 123:345-357.

Buckland, S. T., Rexstad, E. A., Marques, T. A. & Oedekoven, C. S. (2015). *Distance Sampling: Methods and Applications*. Springer, Cham, Ch.

Burgess, M. D., Bright, J. A., Morris, A. J., Field, R. H., Grice, P. V., Cooke, A. I. & Peach, W. (2015). Influence of agri-environment scheme options on territory settlement by Yellowhammer (*Emberiza citrinella*) and Corn Bunting (*Emberiza calandra*). Journal of Ornithology 156:153-163.

Douglas, D. J. T., Vickery, J. A. & Benton, T. G. (2009). Improving the value of field margins as foraging habitat for farmland birds. Journal of Applied Ecology 46:353-362.

Gillings, S., Fuller, R. J. & Henderson, A. C. B. (1998). Avian community composition and patterns of bird distribution within birch-heath mosaics in north-east Scotland. Ornis Fennica 75:27-37.

Gohel, D. (2023). flextable: functions for tabular reporting. https://ardata-fr.github.io/flextable-book/,

Gottschalk, T. K., & Huettmann, F. (2011). Comparison of distance sampling and territory mapping methods for birds in four different habitats. Journal of Ornithology 152:421-429.

Gregory, R. D. (2000). Development of breeding bird monitoring in the United Kingdom andadopting its principles elsewhere. Ring 22:35-44.

Hartig, F. (2021). DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. https://cran.r-project.org/web/packages/DHARMa/vignettes/DHARMa.html

Lüdecke, D. (2018). ggeffects: Tidy Data Frames of Marginal Effects from Regression Models. Journal of Open Source Software 3:1-5.

Pan-European Common Bird Monitoring Scheme. (2022). Species selection and classification (version 2022). https://pecbms.info/methods/pecbms-methods/3-multispecies-indicators/species-selection-and-classification/.

Pedersen, T. (2023). patchwork: The Composer of Plots. https://patchwork.data-imaginist.com, https://github.com/thomasp85/patchwork.

R Core Team. (2023). R: A language and environment for statistical computing. ISBN 3-900051-07-0, R Foundation for Statistical Computing, Vienna, Austria, URL https://www.R-project.org/

Shankar Raman, T. R. (2003). Assessment of census techniques for interspecific comparisons of tropical rainforest bird densities: a field evaluation in the Western Ghats, India. Ibis 145:9-21.

SOVON. (2015). Handleiding voor het gebruik van Avimap bij BMP-broedvogelinventarisaties. Versie 2.1.10.

SOVON. (2016). Handleiding Sovon broedvogelonderzoek: Handmatige registratie en interpretatie van BMP-resultaten. Sovon Vogelonderzoek Nederland, Nijmegen, NL.

van Dijk, A. J. & Boele, A. (2011). Manual SOVON breeding bird reserach in The Netherlands (in Dutch). SOVON Vogelonderzoek Nederland, Nijmegen, NL.

Van Dijk, A. J., Noback, M., Troost, G., Vergeer, J.-W., Sierdsema, H. & Van Turnhout, C. A. M. (2013). De introductie van Autocluster in het Broedvogel Monitoring Project. Limosa 86: 94-102.

Vergeer, J.-W., van Dijk, A. J., Boele, A., van Bruggen, J. & Hustings, F. (2016). Handleiding Sovon broedvogelonderzoek: Broedvogel Monitoring Project en Kolonievogels. Sovon Vogelonderzoek Nederland, Nijmegen, NL.

Wickham, H., Çetinkaya-Rundel, M. & Grolemund, G. (2023). R for Data Science (2e). Import, tidy, transform, visualize, and model data, https://r4ds.hadley.nz/.

5 Wintering birds

5.1 AIM

Here we test the effect on overwintering birds of enhanced (winter) habitat provided through agri-environmental measures, in particular PARTRIDGE flower blocks, at our demonstration sites.

5.2 PROTOCOL

5.2.1 METHOD SELECTION

1) Is the abundance of overwintering birds higher in demonstration sites with measures compared to reference sites without measures ("business as usual")?
2) Are birds concentrated on or near the measures in the demonstration sites?
3) Is bird diversity higher on or around the measures?

To monitor the birds overwintering on our sites we used a point counting technique (Buckland 2006). By locating counting points close to and further away from PARTRIDGE measures in a demonstration site, it is not only possible to compare bird densities between demonstration and reference sites, but it is also possible to assess whether the wintering birds tend to cluster around or in the measures within the demonstration sites. In winter most farmland birds are not territorial and become more mobile, with several species moving around the countryside in flocks of varying sizes. This means it is not possible to apply distance sampling techniques to obtain density estimates from counts of birds (Roodbergen et al., 2011). Therefore, we used relative densities, i.e., the number of birds counted within a circle of a radius of 300m around the counting position.

5.2.2 METHOD DESCRIPTION - POINT-COUNTS

The winter bird counts were carried out at six demonstration sites and their respective reference sites (Table 5.4). The reference sites were situated nearby the demonstration sites to make them comparable, but far enough away to be independent. To assess the effects of the measures, we always compared the demonstration site with the adjacent reference site (a paired approach). At most sites, birds were monitored over three winters, except for Rotherfield (England) where birds were only recorded for two winters.

Table 5.4: Overwintering bird monitoring at the PARTRIDGE sites. The three numbers reflect 1) the number of counting points in the demonstration sites with measures, 2) the number of counting points in the demonstration without measures and 3) the number of counting points in the reference sites. For example, on Isabellapolder we counted birds at 7 points with measures and 7 points without measures, while on the reference site at Oudmanspolder we counted birds at 8 points.

Country	Demo site	Reference site	2019-2020	2020-2021	2021-2022	2022-2023
BE	Isabellapolder	Oudmanspolder	7-7-8	7-7-8	7-7-8	-
	Ramskapelle	Middelkerke	7-7-8	7-7-8	7-7-8	-
NL	Burgh-Sluis	Nieuwerkerke	-	9-10-9	9-10-9	9-10-9
	Oude Doorn	Genderen	9-9-9	9-9-9	9-9-9	-
SC	Balgonie	Balbirnie	-	7-8-7	7-8-7	7-8-7
EN	Rotherfield	Cheriton	-	10-10-10	10-10-10	-

Each site was visited once a month from November until February (4 times in total). Birds can be observed at a comparable rate of detection throughout the day (Gutzwiller 1993), which makes it possible to count the demonstration site and the nearby reference site in the same day. Field surveys preferably took place on days with calm, sunny weather.

In Belgium and in The Netherlands, birds were counted in circles with a radius of 300m. Here the landscape is flat and open. In Scotland and England, the radius of the counting circles was 100m due to the hilly landscape and the presence of hedges hampering reliable observations over a longer distance.
At the demonstration sites, we randomly selected both counting circles that overlapped measures, and circles situated in-between the measures. Care was taken that circles did not overlap. At the reference sites, where no or very few habitat measures were present, the birds were counted in non-overlapping, randomly selected circles. The number of counting points differed slightly between sites due to local habitat configuration. However, this did not affect the results of the analysis as the number of birds observed in an individual counting circle was the unit used for analysis.

Fieldworkers stood in the centre of each circle and noted down, on a map, all the birds they saw within a 10-minute observation period. This was repeated for all circles on the same day on each site. Each month, the counting order of the circles was changed sequentially. To simplify the fieldwork we used the AVIMAP app for entering the observations in the field (SOVON 2015). The app runs on a smartphone/tablet with a GPS (see also Chapter 4, Breeding birds). At the end of each survey session, the data were uploaded to a server.

5.2.3 SELECTED BIRDS

Overall, we analysed the data obtained for 29 species in two groups (Table 5.5). The first group of 10 species commonly occur on farmland and largely depend on seeds as a source of food in winter (Dochy and Hens, 2005; Gillings et al., 2005; Hammers et al., 2015; Broughton et al., 2020). Farmland birds from this group have undergone the greatest decline across Europe, with these declines considered to be the result agricultural intensification (Rigal et al., 2023). The other 19 species are also commonly encountered in a farmland environment, but they do not rely primarily on seeds as food over the winter. Bird abundance and species richness were calculated for both groups in each counting circle for each site visit.

Table 5.5: Bird species included in each group.

Declining farmland seed-eaters	Brambling *Fringilla montifringilla,* Chaffinch *Fringilla coelebs*, Linnet *Carduelis cannabina*, Goldfinch *Carduelis carduelis*, Greenfinch *Carduelis chloris*, Grey Partridge *Perdix perdix*, Reed Bunting *Emberiza schoeniclus*, Skylark *Alauda arvensis*, Yellowhammer *Emberiza citrinella*.
Other birds	Blue Tit *Cyanistes caeruleus,* Blackbird *Turdus merula*, Collared-Dove *Streptopelia decaocto,* Jackdaw *Corvus monedula,* Magpie *Pica pica,* Robin *Erithacus rubecula,* Starling *Sturnus vulgaris,* Fieldfare *Turdus pilaris,* Great Tit *Parus major,* House Sparrow *Passer domesticus,* Meadow Pipit *Anthus pratensis,* Lapwing *Vanellus vanellus,* Redwing *Turdus iliacus,* Ring-necked Pheasant *Phasianus colchicus,* Rook *Corvus frugilegus,* Song Thrush *Turdus philomelos,* Stock Pigeon *Columba oenas,* Wren *Troglodytes troglodytes*

5.2.4 DATA ANALYSIS

We used generalised mixed model (GLMM) analysis to analyse the abundance data. For each visit, at each observation point, we summed the number of birds of each species group; this was the dependent variable. The three fixed explanatory variables were counting point type, month, and the interaction type x month. Counting point type was a categorical variable reflecting the three types of counting points: “Demo+” - counting points on or near PARTRIDGE measures on demonstration sites, “Demo-“ - counting points without measures on demonstration sites, and “Ref” - counting points on reference sites). Months were the four months the sites were visited (November, December, January, and February).

We analysed the data, both on a local level (demonstration/reference pairs) as well as on the “European” level (all pairs combined). Several counting points were monitored at the same site rendering these points statistically non-independent. Therefore, ‘site’ was added as a random effect to our models. The same applied to sites monitored in the same winter as weather conditions can differ strongly between years. Since not all site pairs (demonstration and reference) were monitored in the same year and winter conditions can differ among sites (e.g., Balgonie is much further north than the sites in Belgium), we added a random ‘site-pair x winter’ (17 units) effect to the overall analysis. At a local level, ‘winter’ was added as a fixed effect since there were not enough years to add them as a random effect. The log(area) of the circle around a counting point (in ha) was added as an offset to account for the differences in the area observed between sites. We used a negative binomial error structure for the count data to account for the observed overdispersion in the count data.

Beside abundance, we also tested whether species richness differed between the “Demo+”, “Demo-“, and “Ref” locations and months. The similar model was used to that above except that a Poisson error distribution was used as the species richness data were not overdispersed.
All statistical analyses were performed in R v.4.3.0 (R Core Team, 2023). The generalised mixed models were run with the glmmTMB function (glmmTMB package, Brooks et al, 2017). Overdispersion and zero inflation were tested with the DHARMa package (Hartig, 2021). Model estimates were obtained with the ggeffects (ggeffects package, Lüdecke, 2018) and graphically displayed with the ggplot function (tidyverse package, Wickham et al, 2023) and the patchwork package (Pedersen, 2023) or tabulated with the flextable package (Gohel, 2023).

5.3 RESULTS

Over the three winter field seasons, the highest abundance of species that depend on seeds (9 out of 10 species) was found at the Belgian sites and in Scotland (Appendix 1.3.1). At the sites in The Netherlands and England, 7 species were encountered. Eighteen of the other 19 species were observed at the sites in The Netherlands and Belgium, 16 at the English sites and 13 at the Scottish site.

5.3.1 ABUNDANCE

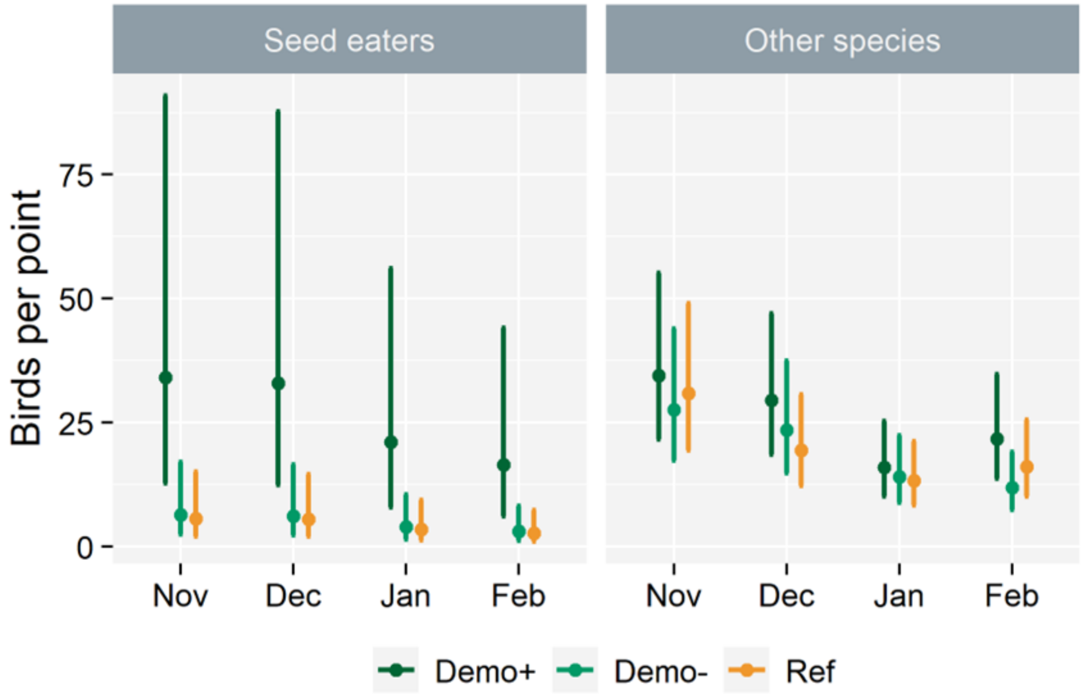


Figure 5.1. Abundance - Average number of birds observed per count point during winter at our demonstration and reference sites. 'Demo+' = - point counts, with measures, on demonstration sites, 'Demo-' = point counts, without measures, on demonstration sites, Ref = reference site point counts, all without measures. The vertical lines show the variation between counts.

For all sites combined, the number of birds from the declining farmland seed-eater group observed in counting circles with measures at the demonstration sites (Demo+) was, on average, over six times higher than in counting circles on the reference sites (Figure 5.1). On a local scale, the effect was even higher at some sites. In Isabellapolder (Belgium) for instance, the number of birds seen in the circles with measures was 42-times higher than in circles without measures on its reference site Oudmanspolder (Appendix 1.3.2). For the point count circles at the demonstration sites which contained no measures ("Demo-"), the number of birds was, on average, 13% higher than at the reference sites. Again, this was even higher on some sites, including at the demonstration site Isabellapolder (Belgium). Here, the number of birds in the circles without measures was nearly 9-times higher than at its reference site.

A similar picture was obtained for the other birds, but the differences were smaller. For these species, the average number of birds observed in counting circles with measures on demonstration sites (Demo+) was on average 29% higher than on the reference sites, for all sites combined. For circles without measures on the demonstration sites (Demo-), there was no difference in the average number of other birds compared to the average number of birds in the reference site circles "Ref". The largest effect was observed on Rotherfield (England) where the number of other birds was twice as high in the demonstration site (with or without measures) than in the reference site (Appendix 1.3.2).

For both groups of species the number of birds was highest at the beginning of the winter and then decreased towards the end of the winter.

5.3.2 DIVERSITY

The effect on the number of bird species visiting our areas in winter was more subtle. Overall, the number of species per year, was slightly higher on the demonstration sites than on the reference sites for the declining farmland seed-eaters (Figure). On average, 7 species were observed in the circles with measures on demonstration sites, 6 in circles without measures on demonstration sites, and 5 on the reference sites. There was no difference between the three treatments for the other bird group, with 14-15 species per year.

Figure 5.2. Diversity - Average number of birds species observed per year in our demo and reference areas. 'Demo+' = - point counts, with measures, on demonstration sites, 'Demo-' = point counts, without measures, on demonstration sites, Ref = reference site point counts, all without measures. The vertical lines show the variation between counts. The maximum recorded number of species per year was 10 for 'the declining farmland seed eaters' and 19 for 'other birds'.

When looking at the number of species seen simultaneously in a single counting circle, the difference was greater (Figure). In this case, on average for all sites combined, there were nearly three times as many declining farmland seed-eating species in the counting circles with measures on demonstration sites than at the reference sites. For the counting circles without measures on demonstration sites, there were 21% more. The effect for the seed-eaters was again highest for the Isabellapolder (Belgium) demonstration site, with respectively 8-times more birds than on the reference site (on circles with measures) and 4-times more than on the reference site (on circles without measures). For the other species, species richness was 40% higher on demonstration sites (on circles with measures) and 10% higher (on circles without measures) than at reference sites.

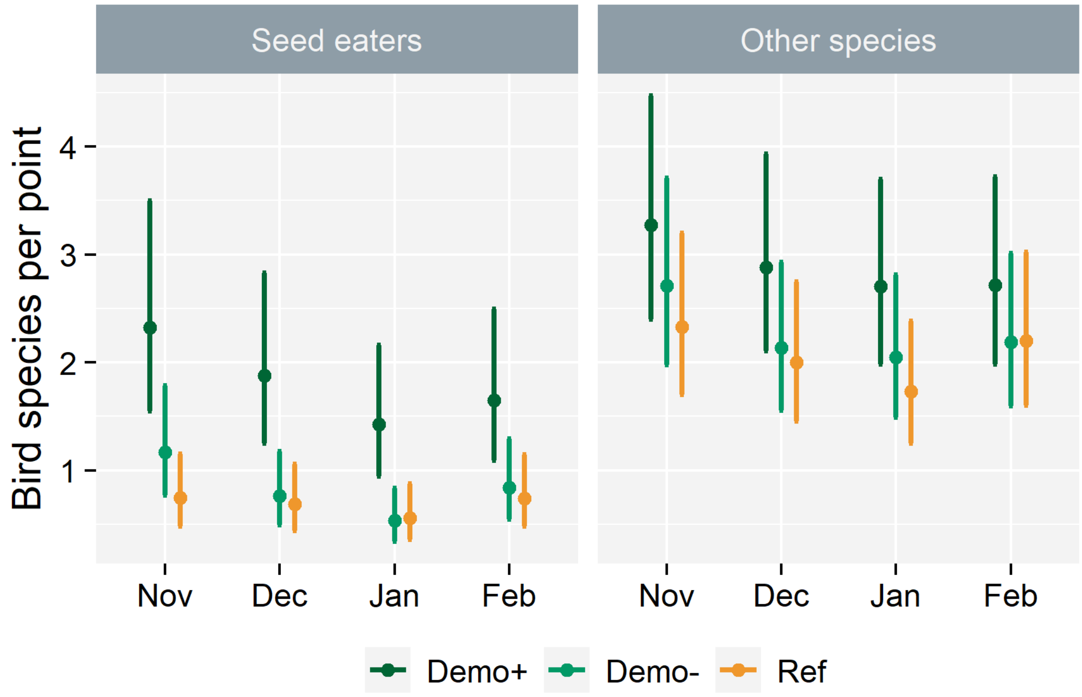


Figure 5.3. Diversity - Average number of birds species observed per count point during winter in our demonstration and reference sites. 'Demo+' = - point counts, with measures, on demonstration sites, 'Demo-' = point counts, without measures, on demonstration sites, Ref = reference site point counts, all without measures. The vertical lines show the variation between counts.

5.4 CONCLUSION

Our study demonstrated that both the number of birds (abundance) and the number of species (diversity) are higher when the farmland habitat is enhanced with beneficial wildlife habitats such as our project's PARTRIDGE flower blocks and beetle banks. It is clear, from our results, that birds that rely heavily on seeds during winter benefit the most. The PARTRIDGE mix contains several plant species that produce seeds that are available in winter. During our winter counts, large bird flocks were regularly seen diving into the measures, searching for food. Interestingly, the other species that do not seek seeds were also found in greater numbers on or near the measures. They were most likely looking for shelter and/or food. Although we did not examine the amount of food produced in these measures in winter, we were able to show that the PARTRIDGE mix produced more insect-food in summer compared to the surrounding cereal crops.

5.5 REFERENCES

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Maechler, M. & Bolker, B. (2017). glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. The R Journal 9(2): 378-400.

Broughton, R. K., Kettlewell, M. G. W., Maziarz, M., Vickers, S. H., Larkman, A. & Wilkinson, I. (2020). Intensive supplementary feeding improves the performance of wild bird seed plots in provisioning farmland birds throughout the winter: a case study in lowland England. Bird Study 67:409-419.

Buckland, S. T. (2006). Point-Transect Surveys for Songbirds: Robust Methodologies. The Auk 123:345-357.

Dochy, O., & Hens, M. (2005). *Van de stakkers van de akkers naar de helden van de velden: beschermingsmaatregelen voor akkervogels*. Rapporten van het instituut voor natuurbehoud IN.R.2005.01, Brussel, Belgium.

Gillings, S., Newson, S. E., Noble, D. G. & Vickery, J. A. (2005). Winter availability of cereal stubbles attracts declining farmland birds and positively influences breeding population trends. Proceedings of the Royal Society B: Biological Sciences 272:733-739.

Gohel, D. (2023). flextable: functions for tabular reporting. https://ardata-fr.github.io/flextable-book/, https://davidgohel.github.io/flextable/.

Gutzwiller, K. J. (1993). Refining the Use of Point Counts for Winter Studies of Individual Species. The Wilson Bulletin 105:612-627.

Hammers, M., Müskens, G. J. D. M., van Kats, R. J. M., Teunissen, W. A. & Kleijn, D. (2015). Ecological contrasts drive responses of wintering farmland birds to conservation management. Ecography 38:813-821.

Hartig, F. (2021). DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. https://cran.r-project.org/web/packages/DHARMa/vignettes/DHARMa.html

Lüdecke, D. (2018). ggeffects: Tidy Data Frames of Marginal Effects from Regression Models. Journal of Open Source Software 3:1-5.

Pedersen, T. (2023). patchwork: The Composer of Plots. https://patchwork.data-imaginist.com, https://github.com/thomasp85/patchwork.

R Core Team. (2023). R: A language and environment for statistical computing. ISBN 3-900051-07-0, R Foundation for Statistical Computing, Vienna, Austria, URL https://www.R-project.org/.

Rigal, S., Dakos, V., Alonso, H., Auniņš, A., Benkő, Z., Brotons, L., Chodkiewicz, T., Chylarecki, P., de Carli, E. , del Moral, J. C., Domşa, C., Escandell, V., Fontaine, B., Foppen, R., Gregory, R., Harris, S., Herrando, S., Husby, M., Ieronymidou, C., Jiguet, F., Kennedy, J., Klvaňová, A., Kmecl, P., Kuczyński, L., Kurlavičius, P., Kålås, J. A., Lehikoinen, A., Lindström, Å., Lorrillière, R., Moshøj, C., Nellis, R., Noble, D., Eskildsen, D. P., Paquet, J.-Y., Pélissié, M., Pladevall, C. , Portolou, D., Reif, J., Schmid, H., Seaman, B., Szabo, Z. D., Szép, T., Florenzano, G. T., Teufelbauer, N., Trautmann, S., van Turnhout, C., Vermouzek, Z., Vikstrøm, T., Voříšek, P. Weiserbs, A. & Devictor, V. (2023). "Farmland practices are driving bird population decline across Europe." Proceedings of the National Academy of Sciences 120(21): e2216573120.

Roodbergen, M., van Scharenburg, K., Soldaat, L., Teunissen, W., Koks, B. & van Leeuwen, M. (2011). Achtergronddocument Meetnet Agrarische Soorten (MAS). SOVON-onderzoeksrapport 2011/08, Nijmegen, Nederland.

SOVON. (2015). Handleiding SOVON broedvogelonderzoek. PDF 4: AVIMAP handleiding. Sovon Vogelonderzoek Nederland, Nijmegen, NL.

Wickham, H., Çetinkaya-Rundel, , M. & Grolemund, G. (2023). R for Data Science (2e). Import, tidy, transform, visualize, and model data, https://r4ds.hadley.nz/.

6 Brown hare (*Lepus europaeus*)

6.1 AIM

The aim of the brown hare (hereafter referred to as hare) monitoring that we did in PARTRIDGE was to understand whether the grey partridge-tailored management measures established at our demonstration sites influenced local hare numbers compared to the situation at our reference sites, where no or very few measures were present (i.e. "business as usual").

More specifically, data on hare numbers were gathered to address the following research questions:

1) Is the trend in the number of counted hares more positive in the demonstration sites compared to the reference sites?
2) Is the number of counted hares higher in the demonstration sites compared to the reference sites at the end of the project?

6.2 METHOD

6.2.1 METHOD SELECTION

Over the years, numerous methods have been developed and evaluated for the purpose of monitoring brown hare populations in the field (Langbein et al., 1999). Among these methods, total counts, flush counts, capture-mark-recapture methods, as well as point and line-transect counts are the most commonly used.

Both, total counts and flush counts rely on the observation of hares as they are flushed by a line of walking beaters and their dogs. For total counts, the aim is to detect all hares present within an area by flushing them out of cover. Although this provides a near-absolute number of hares, this method is extremely labour-intensive, causes much disturbance to wildlife and is typically restricted to smaller, open areas (Pielowski, 1969). To increase the survey area, the total hare flush count technique can be applied to transects, ranging from 50 to 150 meters in width, spread across the area of interest. Flushed hares are subsequently counted within each of these transects. While this method increases the sampled area, it is equally labour-intensive and may lead to significant overestimations of the local population (Pielowski, 1969; Rajska, 1968). Capture-mark-recapture is another widely applied and reliable technique for monitoring brown hare populations. However, these require a lot of preparation, manpower, time, and money, rendering this method unsuitable for large-scale projects (Abildgärd et al., 1972; Andrzejewski & Jezierski, 1966).

Thankfully, point and line-transect counts serve as viable alternatives to the more labour-intensive methods described above (ONCFS, 2015). In this method, hares are counted from predetermined observation points or along driven transects distributed throughout the area of interest (Barnes & Tapper, 1985; Frylestam, 1979, 1981; Huysentruyt et al., 2018; Sliwinski et al., 2021). These counts require fewer personnel and preparation than flush counts and are thus frequently applied in large-scale hare monitoring projects. Both day- and night-time surveys can be conducted, with nocturnal surveys being the more commonly applied option due to the brown hare's night-time activity pattern (Schai-Braun et al., 2012). Spotlights or night vision goggles are utilized in such cases (Sliwinski et al., 2021). While point counting and line-transect counting are similar, the presence of vegetation, such as hedgerows, obstructing the view along transects may render line-transect counting impractical in certain habitats (Péroux et al., 1997). In such instances, point counting serves as a viable alternative.

In the PARTRIDGE project, line-transect spotlight counting was employed as the standard monitoring method across all but one project sites. Only at the Horninghold reference site (UK), the dense concentration of hedgerows along field boundaries combined with a lack of suitable tracks to drive on, made line-transect counting unfeasible. Instead, point counting with spotlights was utilized for monitoring at Horninghold and its paired demonstration site Loddington.

6.2.2 METHOD DESCRIPTION – LINE-TRANSECT SPOTLIGHT METHOD

See PARTRIDGE monitoring factsheet 'Best practice guidelines for successful brown hare monitoring on farmland' on our Webpage: https://northsearegion.eu/partridge/output-library/.

6.2.3 METHOD DESCRIPTION – POINT-COUNT SPOTLIGHT METHOD

The point-count spotlight method is very similar to the line-transect spotlight method. However, instead of driving along transects, hares are counted from fixed points spread as evenly as possible and practical across the area. The area visible with the spotlight is used as the viewshed in which the hares are counted (ONCFS, 2019; Verheyden, 1991).

6.2.4 DATA PROCESSING

All statistical analyses were performed in R v.4.3.0 (R Core Team, 2023).

6.2.4.1 Data preparation

Both, the hare count and viewshed data underwent visual inspection in ArcMap (application in ArcGIS Desktop version 10.8.1) to correct any potential map coordinate errors, and to remove observations that accidentally fell outside the viewshed areas (Figure 6.1). Map coordinate errors were fixed manually, and observations outside of the viewshed were excluded from further analysis.

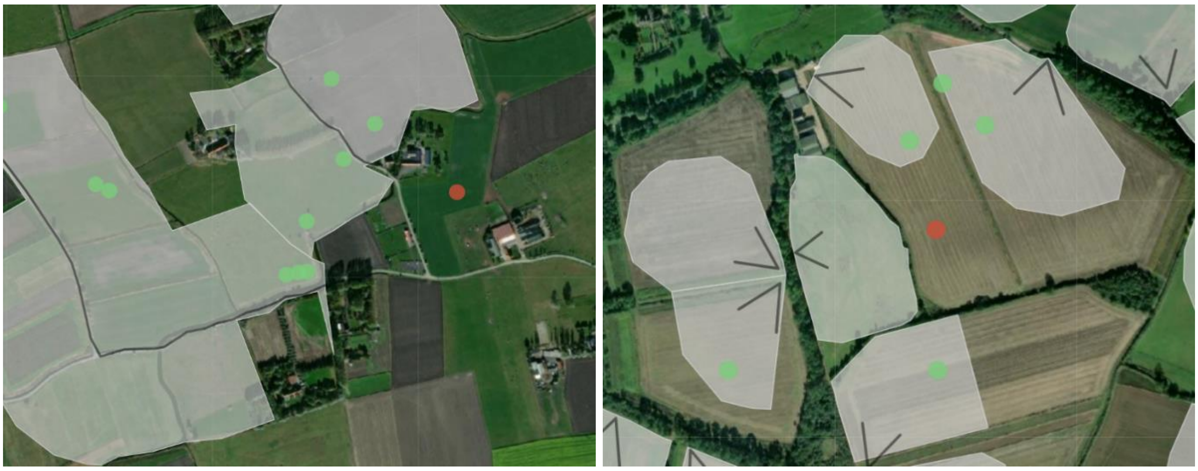


Figure 6.1. Example of viewshed filtering for line-transect counts at the Middelkerke reference site (left) and point-counts at the Loddington demonstration site (right); light grey area: viewshed; green dots: observations inside viewshed; red dots: observations outside viewshed; triangles in the point-counts viewshed indicate the location observers viewed the field from, i.e. the viewpoint, and the directionality of the spotlight.

6.2.4.2 Trend analysis

The model set-up and parameter values for analysing the hare monitoring trend were the same as for those used for the partridge spring monitoring (Section 2.2.3.2). However, for the hare monitoring trend analysis the number of counted hares was used as the dependent variable and the natural logarithm of the viewshed area (in km^2) was used as the offset, instead of the total transect length (in km).

6.2.4.3 Abundance

The model set-up and parameter values for analysing the difference in hare numbers between the demonstration and reference sites by the end of the project period (2021-2023) were the same as the ones described for the partridge spring monitoring (Section 2.2.3.3). However, for the hare monitoring trend analysis the number of counted hares was used as the dependent variable and the natural logarithm of the viewshed area (in km^2) was used as the offset instead of the total transect length (in km).

6.3 RESULTS

6.3.1 RAW DATA

For most sites, there were at least 3 separate counting sessions held annually, except in a few cases where a shortage of volunteers or a later start to the monitoring period resulted in fewer counting sessions (for example in Germany in 2017 and Scotland in 2017 & 2018). Due to challenges outside our control imposed by the Covid-19 restrictions, no surveys could be undertaken at the Whitburgh demonstration site in 2021.

Additionally, our analysis exclusively incorporated point count data from the English Loddington and Horninghold project sites to ensure comparability between both sites. While line-transect surveys were also conducted at the Loddington demonstration site, they were excluded from the analysis, resulting in 1-2 counting sessions annually for both sites. Given that monitoring was still in its testing phase at the Dutch Burghsluis site pair in 2017, the resultant data was deemed unreliable and thus left out of the analysis.

Both German demonstration sites Diemarden and Nesselröden, exceeded the originally intended 500-hectare project area at the start of the project and consequently underwent resizing after the project's initiation. This adjustment led to some transects extending beyond the final project boundaries, specifically transect 5 in Diemarden and transects 6 and 7 in Nesselröden. The counts from all three transects were excluded from any further analysis.

In summary, the raw hare monitoring dataset covers a total of 453 separate counting sessions. Throughout these sessions, a combined count of 33,972 hares was recorded across all project sites and years.

6.3.2 TREND ANALYSIS

Figure 6.2 shows the fit of our model to the hare monitoring raw data per site pair. For all analyses, we used the number of hares counted per 100ha as an index to account for the viewshed area differences across the project sites and years.

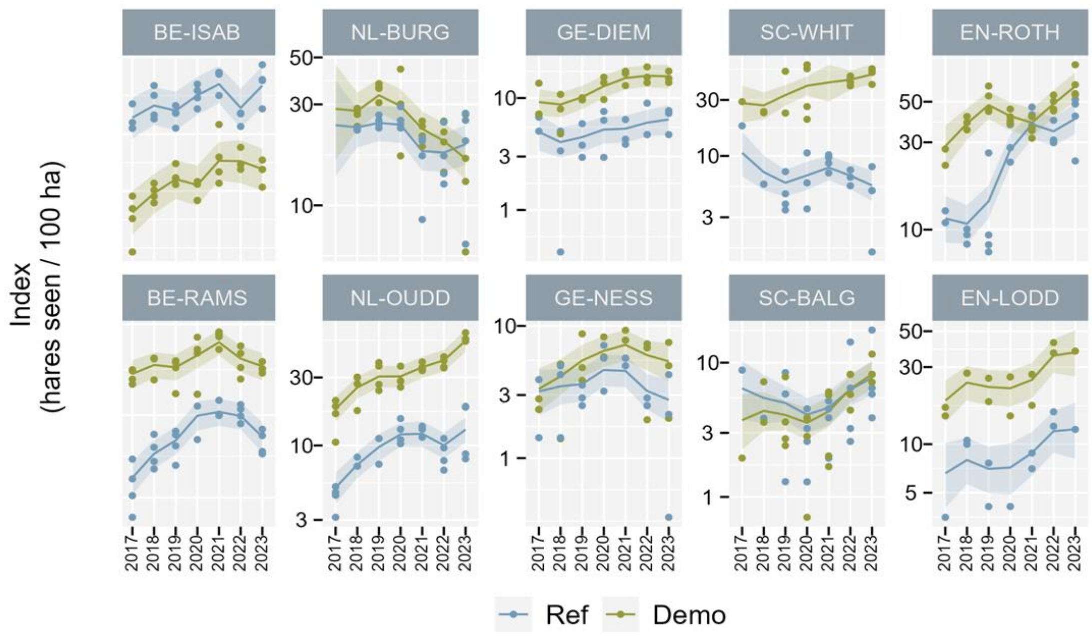


Figure 6.2. Hare count data per site pair: All dots represent the raw count data, while the lines and the shaded areas represent the median and 95% interval of model fit respectively. The y-axis is presented on a log scale. BE-ISAB = Belgian Isabellapolder demonstration (demo) and reference (ref) site, BE-RAMS = Belgian Ramskapelle demo and ref site, NL-BURG = Dutch BughSluis demo and ref site, NL-OUDD = Dutch Oude Doorn demo and ref site, GE-DIEM = German Diemarden demo and ref site, GE-NESS = German Nesselröden demo and ref site, SC-WHIT = Scottish Whitburgh demo and ref site, SC-BALG = Scottish Balgonie demo and ref site, EN-ROTH = English Rotherfield demo and ref site, EN-LODD = English Loddington demo and ref site. Note that the y-values for the Belgian sites are not shown in the figure due to the confidentiality of the data.

Figure 6.3 shows the difference in trends between the demonstration and reference sites for each site pair and for all sites combined (overall), expressed as a percentage. A 0% difference indicates that the trend in hare numbers is equal in the demonstration and reference sites (no difference). Differences were considered significant if the 95% credibility interval did not include the 0% reference, or non-significant if it did. Positive percentages indicate that the trend in the demonstration site was either more positive or less negative than at the reference sites, while negative percentages suggest the opposite. The 30% difference indicated the project's target, which was to reach at least a 30% increase at the demonstration sites compared to reference sites.

The overall trend difference between demonstration and reference site was not significant. Although the trend is leaning slightly towards the positive side, the wide interval across all sites includes some extremely negative values. This suggests that overall, the trend in the number of hares counted per 100ha was not significantly different between demonstration and reference sites and that it ranged from being highly negative to highly positive.

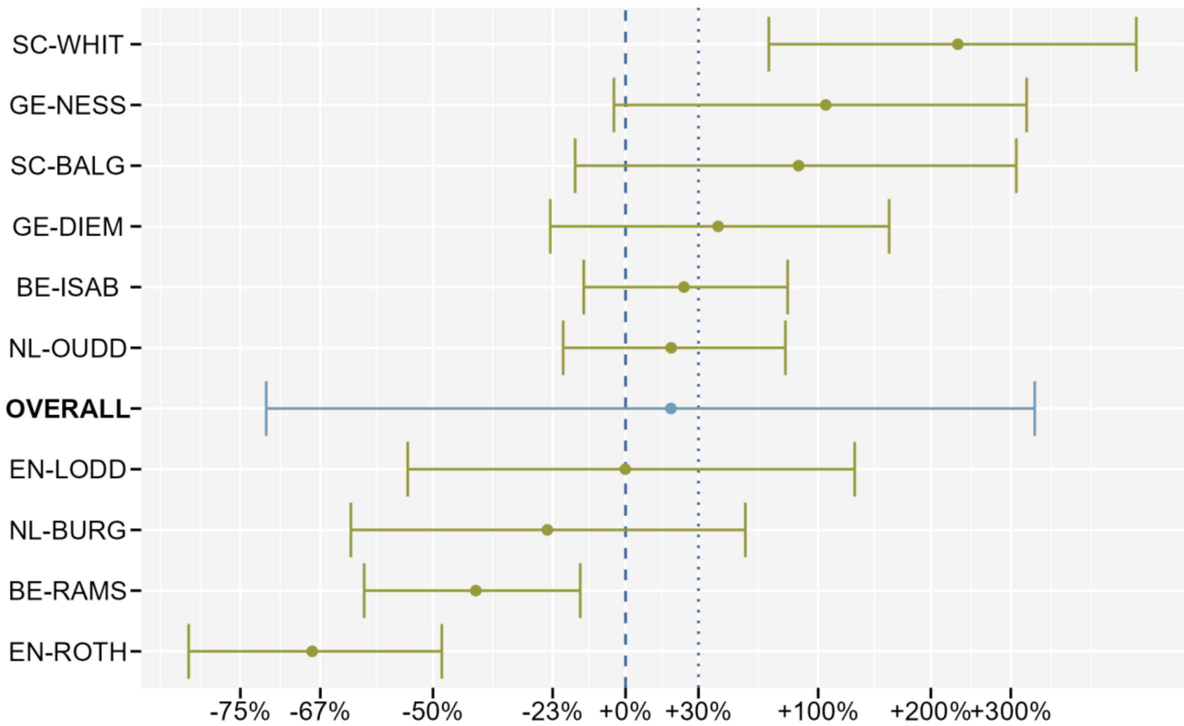


Figure 6.3. Difference in hare monitoring trends (%) between demonstration and reference site pairs (green) and overall (blue) where the dots show the median value and the error bars the 95% intervals. The x-axis is presented on a log scale. The dashed line at 0% indicates no difference; the dotted line at 30% indicates the project's target. For explanation of site abbreviations please see Figure 6.2.

At the site pair level, the difference in the trend of hares counted also varied widely. Only the Whitburgh demonstration site in Scotland showed a significant increase (exceeding the 30% project target) in hare numbers compared to its reference site (Lennoxlove). For the Nesselröden demonstration site and its reference site the trend difference is positive and almost significant. For most other sites the difference was not significant, except for the Ramskapelle and Rotherfield demonstration sites, where the trend difference was significantly negative, suggesting hare numbers either decreased or increased slower on the demonstration sites compared to the paired reference sites. However, at least for the English Rotherfield site pair this reflects a confounding of two effects; increased levels of legal hare shooting on the demonstration site mid-project – possible due to the high numbers of hare present – and, at the reference site at the same time, new, effective measures to stop hare poaching that had taken place early in the project.

6.3.3 ABUNDANCE

Figure 6.4 shows the mean number of hares at both the demonstration and reference sites for all sites combined. **By the end of the project period, the number of hares counted differed significantly between the demonstration and reference sites. Overall, almost twice as many hares were observed at the demonstration sites.**

At the site pair level, the hare numbers were higher at all demonstration sites, except for Isabellapolder (Belgium), where numbers were higher at the reference site, and Balgonie (Scotland), where no difference between the demo and reference site was observed. The difference between demonstration and reference site was highest at Whitburgh (Scotland) and Oude Doorn (The Netherlands), with respectively 4 and 7 times more hares recorded at the demonstration sites (see also Appendix I.5).

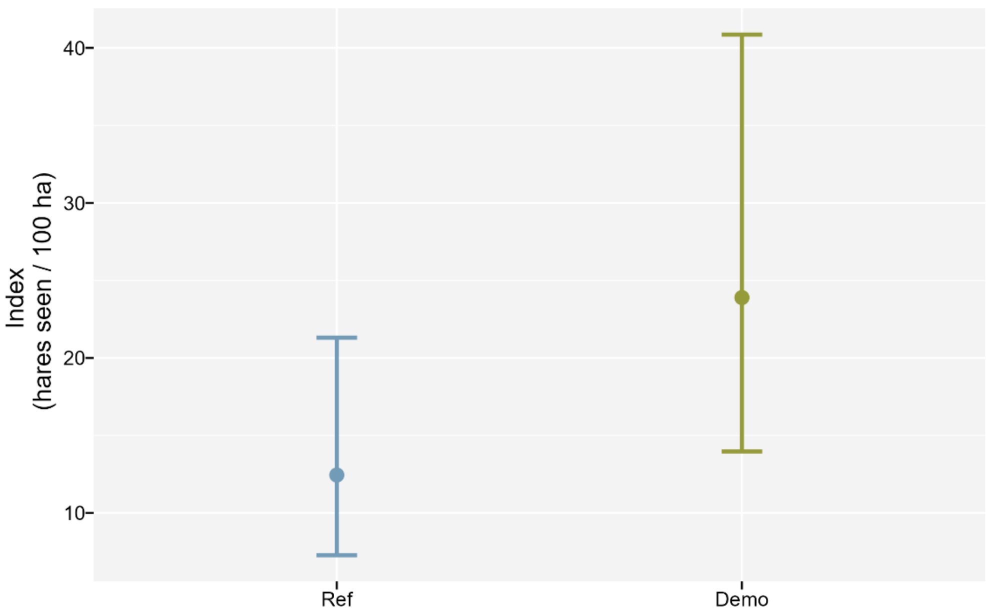


Figure 6.4. The number of hares counted per 100ha at the demonstration and reference sites for all sites combined (2021-2023). Error bars represent 95% confidence intervals.

6.4 DISCUSSION

By the end of our project, we counted noticeably more hares at the managed demonstration sites than at the paired reference sites. This finding underscores the positive impact of increasing the wildlife habitat area and quality on local farmland biodiversity, including the brown hare. Moreover, detailed habitat mapping demonstrated that the wildlife-friendly habitats at our demonstration sites resulted in a significantly higher coverage of both beneficial summer (12.5%) and winter (12.3%) habitat for hares by the end of the project period (Hubbard et al., 2023). **This, together with a steady increase in hare numbers throughout the project period at most of our demonstration sites (Fig. 6.2.), indicates that the habitat improvements, tailored to the grey partridge, equally benefit local hare populations**.

However, as was the case with our grey partridge spring monitoring results, we were unable to identify a substantial trend difference between the demonstration and reference sites. Again, it is important to consider the influence of our project setup and the selection of demonstration sites when examining the apparent lack of impact of our management measures on the trend in hare numbers at our demonstration sites. Specifically for the brown hare, our habitat mapping revealed that while we succeeded in adding on average 3.3 % more beneficial summer habitat for hares during the project period, beneficial winter habitat remained mainly unchanged. Additionally, most demonstration sites started already in a favourable condition with close to or even exceeding the targeted 7% of beneficial habitat coverage in 2017 (Hubbard et al., 2023). Although our habitat improvements were undoubtedly valuable, it might be that they did not manage to have a substantial enough impact on the local brown hare population trend at our demonstration sites to be detectable by our monitoring efforts. Alternatively, the local hare populations may already have been close to or at carrying capacity due to the ample beneficial habitat present at the demonstration sites from the start of the project, resulting in little response to our additional habitat improvements. Furthermore, longer time series or larger project sites might be needed to accurately detect hare population trends across farmland project sites such as ours.

Establishing a clear cause-and-effect relationship between our habitat enhancements and local hare numbers may have been further complicated by other factors that equally influence hare populations. Beyond habitat quality, local conditions such as weather, high predation levels, dispersal, disease, human-related fatalities (e.g. hunting, poaching or road kills) and methodological errors may equally impact the number of hares counted. As these factors could not be explicitly quantified in our analysis (owing to a lack of data), their influence remains speculative and intertwined with the effects of our management measures.

6.5 CONCLUSION

In conclusion, the results of our brown hare monitoring data provide compelling evidence that enhancing habitat quality beyond the 7% mark, plays a crucial role in supporting local hare populations in farmland settings. Moreover, they demonstrate that habitat improvements, tailored to the grey partridge, also benefit local hare populations. Nevertheless, the challenges posed by trend analysis and the influence of various factors highlight the intricate nature of brown hare dynamics and the complexities involved in evaluating the relationship between habitat enhancement and biodiversity.

6.6 REFERENCES

Abildgärd, F., Andersen, J., & Barndorff-Nielsen, O. (1972). The hare population (*Lepus europaeus* Pallas) of Illumø island, Denmark – A report on the analysis of the data from 1957-1970. Danish Review of Game Biology, 6(5): 1-32.

Andrzejewski, R., & Jezierski, W. (1966). Estimation of population density and attempt to plan the yearly take of hares. *Acta Theriologica*, 11, 443-448.

Barnes, R.F.W., & Tapper S.C. (1985). A method for counting hares by spotlight. Journal of Zoology, 206, 273–276.

Frylestam, B. (1979). Structure, Size, and Dynamics of Three European Hare Populations in Southern Sweden. *Acta Theriologica*, 24, 449–464.

Frylestam, B. (1981). Estimating by spotlight the population density of the European hare. *Acta Theriologica*, 26, 419–427.

Hubbard, C., Ewald, J., Buner, F., van Alebeek, F., Benders, M., Brown, B., Corvin-Czarnodolski, A., De Bruyn, L., Dienst, V., Dumpe, L., van Gernert, B., Gottschalk, E., Kimbrey, H., Mayall, E., Oost, F., Ots, M., Petersen, F., Raynor, E., Robertson, L., Scheppers, T., Sloothaak, J., Spivey, T., van de Straat, S., Torrance, F., Van Colen, W., Vanden Bussche, C., Verslyppe, K., Verzelen, Y., & Vreugdenhill, C. (2023). Landscape change on site in the PARTRIDGE Project. PARTRIDGE North Sea Region Interreg.

Huysentruyt, F., Scheppers, T., Verschelde, P., Onkelinx, T., & Casaer, J. (2018). Analysis of the usefulness of transect counts in monitoring local brown hare populations: Description of monitoring in 12 test areas and detailed analysis of the results from Bertembos. (Rapporten van het Instituut voor Natuur- en Bosonderzoek; Nr. 5).

Langbein, J., Hutchings, M. R., Harris, S., Stoate, C., Tapper, S. C., & Wray, S. (1999). Techniques for assessing the abundance of Brown Hares *Lepus europaeus*. Mammal Review, 29(2), 93–116.

ONCFS. (2019). Protocole de suivi des populations de lapin et lievres par échantillonnage par points avec un projecteur (EPP).

ONCFS. (2015). Rappel des protocols du réseau lièvre. La Lettre Du Réseau Du Lièvre, 1, 6–7.

Onkelinx, T., Vermeersch, G., & Devos, K. (2023). Trends op basis van de Algemene Broedvogelmonitoring Vlaanderen (ABV). Technisch achtergrondrapport voor de periode 2007- 2022. Rapporten van het Instituut voor Natuur- en Bosonderzoek 2023 (1). Instituut voor Natuur- en Bosonderzoek, Brussel.

Parkes, J. (2001). Methods to monitor the density and impact of hares (*Lepus europaeus*) in grasslands in New Zealand. DOC SCIENCE INTERNAL SERIES 8.

Pegel, M. (1986). Deer Feldhasen in Beziehungsfüge seiner Um- und Mitweltfaktoren. Schriften des Arbeitskreises Wildbiologie und Jagdwissenschaft and der Justus - Liebig Universität Giessen. Heft 16.

Péroux, R., Maury, B., Lartiges, A., Bray, Y., & Marboutin, E. (1997). Point transect sampling: a new approach to estimate densities or abundances of European hare (*Lepus europaeus*) from spotlight counts. Gibier Faune Sauvage 14, 525-529.

Pielowski, Z. (1969). Belt Assessment as a Reliable Method of Determining the Numbers of Hares. *Acta Theriologica*, 14, 133–140.

Rajska, E. (1968). Estimation of European Hare Population Density Depending on the Width of the Assessment Belt. *Acta Theriologica*, 13, 35–53.

R Core Team (2023). R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org.

Rue, H., Martino, S., & Chopin, N. (2009). Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. In J.R. Statist. Soc. B. (Vol. 71, Issue 2).

Schai-Braun, S. C., Rödel, H. G., & Hackländer, K. (2012). The influence of daylight regime on diurnal locomotor activity patterns of the European hare (*Lepus europaeus*) during summer. Mammalian Biology, 77(6), 434–440.

Sliwinski, K., Strauß, E., Jung, K., & Siebert, U. (2021). Comparison of spotlighting monitoring data of European brown hare (Lepus europaeus) relative population densities with infrared thermography in agricultural landscapes in Northern Germany. PLoS ONE, 16(7 July).

Verheyden, C. (1991). A spotlight, circular-plot method for counting Brown hares in the hedgerow system. *Acta Theriologica*, 36(4), 255–265.

WILD. (2001). Erfassung von Feldhasenbesätzen. Scheinwerfertaxation. Kurzanleitung. Institut für Wildtierforschung, Tierärztlichten Hochshule.

7 Supplementary winter feeding

7.1 AIM

Winter weather can pose serious challenges for birds living on modern farmland. Besides an increased lack of habitat cover for protection from harsh weather and hungry predators, scarce seed-food availability, especially during the 'hungry winter gap' in late winter, adds to the serious risk of increased winter mortality. In addition to our habitat measures, which aimed to provide better cover, protection from raptors and a reliable source of seeds into mid-winter, we provided additional supplementary winter food through feeders at our PARTRIDGE demonstration sites, wherever it was feasible, to increase and extend seed-food availability into early spring. The aim was to increase the winter survival-rate of seed-eating, farmland birds and help them improve their body condition, for the next breeding season (Brewin et al., 2020).

Besides partridges, other seed-eating birds can benefit from supplementary food (Brewin et al., 2020). However, supplementary feeding may also attract species regarded as pest species in agricultural areas (e.g., brown rat, common wood pigeon, and corvids), attract ground-nesting predators and facilitate disease transmission. To reduce these side effects, best practices guidelines have been developed to minimise the benefit for pest or 'un-welcome' species and maximise the benefit for gamebirds and songbirds (Sánchez-García & Buner, 2017).

While supplementary winter feeding has become a common management tool on shooting estates across Europe, not all demonstration sites had a recent history of this practice at the start of the project. For these sites we used camera traps set at feeders to obtain a general picture of which species used them, and more specifically, how our target species used them. While we strived to follow the best-practice guidelines as described by Sánchez-García & Buner (2017) as closely as possible, deviations in the field nevertheless occurred. Camera trapping revealed the consequences of these deviations and allowed us to adapt our feeder approach.

To optimise the use of feeders for supplementary winter feeding as part of our PARTRIDGE management toolbox, camera traps were placed at a selection of feeders at several demonstration sites. More specifically the camera trap monitoring allowed us to:

1) provide an insight into the use of the feeders by different categories of species

2) evaluate the impact of the best-practice guidelines

7.2 METHOD

7.2.1 SITES

Monitoring wildlife visiting feeders using camera traps is not a job that should be underestimated. We therefore restricted our monitoring to three of our ten demonstration sites.

We used camera trapping at two sites with no recent history of supplementary feeding, namely Balgonie (Scotland) and Oude Doorn (The Netherlands). Here, we managed the feeders ourselves according to current best-practice guidelines (Sánchez-García & Buner, 2017). Additionally, we monitored feeders in our demonstration site Ramskapelle (Flanders, Belgium), where local hunters already ran their own winter feeder management for many years. At the latter we provided in-depth advice to the hunters on how to use feeders according to the best-practice guidelines mentioned above.

In Belgium, we were also interested in evaluating the impact of the best-practice guidelines since we noted, early on in the project, that despite our advice most feeders were not always managed according to the best-practice guidelines by the local stakeholders. More specifically, the height of the nozzle was not always respected, a rat-proof nozzle was not used, the feeders were not moved frequently, and they were not always placed in the open fields. As our project aimed at demonstrating best examples, we set up a small field trial in Belgium during which we managed four feeders ourselves. We monitored the use of these feeders by camera trapping, while simultaneously monitoring four nearby feeders managed by the local stakeholders.

7.2.2 PERIOD

Across all sites, we used camera trapping in five subsequent winters, from the winter of 2017-2018 until the winter of 2021-2022. At each site, however, the data originates from four different winters. At demonstrations sites in both Scotland and Belgium there was no data collected in the first winter 2017-2018, while the demonstration site in The Netherlands did not collect data in the winter of 2018-2019. The additional field trial in Belgium was restricted to the winters of 2020-2021 and 2021-2022.

Supplementary winter feeding can take place during the whole winter from October-April but is most important from February until the end of April. Camera traps were placed on the 16th of October at the earliest and removed on the 22nd of April at the latest. To assess overall use of the feeders at the three demonstration sites, we placed camera traps at 45 feeders for a total of 1,662 monitoring days, spread roughly equally across the three sites (Table 7.1).

Table 7.1. Overview of the number of feeders, the total number of days that feeders were monitored and the mean number of monitoring days per feeder per demonstration site.

Country (site)	Number of feeders	Number of feeder-monitoring days	Mean number of monitoring days per feeder
Belgium* (Ramskapelle)	16	515	27.1
The Netherlands (Oude Doorn)	11	525	43.8
Scotland (Balgonie)	18	622	22.2

**All managed by local stakeholders.*

Note that the feeders in Belgium (Table 7.1) were all managed by the local stakeholders who were hunters or farmer/hunters. For the field trial evaluating the impact of the best-practice guidelines, we selected a subset of four of these feeders to compare to four additional feeders managed by INAGRO, our project partner, in accordance with the best-practice guidelines developed in England (Sánchez-García & Buner, 2017). This trial was repeated for two winters, resulting in eight feeders of the above dataset being used for the comparison with eight additional best-practice feeders managed by INAGRO. Table 7.2 gives an overview of the dataset resulting from this field trial.

Table 7.2. Overview of the number of feeders, the total number of days that feeders were monitored and the mean number of monitoring days per feeder per management type in Belgium.

Management	Number of feeders	Number of feeder-monitoring days	Mean number of monitoring days per feeder
Traditional (managed by local stakeholders)	8*	378	37.8
Best-practice (managed by INAGRO)	8	251	27.9

**Part of the cohort listed in Table 7.2.*

7.2.3 DATA COLLECTION

Two models of infra-red camera traps were used for monitoring, namely Acorn LTL 5210® in Scotland and The Netherlands, and Dörr Snapshot Black 5.0 mp® in Belgium. As described by Sánchez-García & Buner (2017), the cameras were placed approximately 1.5m from the feeders and put at a height of 25-40 cm above ground. Camera traps worked continuously (day and night), taking one photograph when triggered, with a delay between triggers of approximately 15 second. This could vary slightly depending on the type of camera.

The photographs obtained by the camera traps were uploaded in Agouti (https://agouti.eu/), an online application for handling camera trap data from wildlife surveys. After entering the feeder location and the deployment details, Agouti automatically pulls timestamps and other metadata from the images and groups images in sequences that represent the same event. Each image sequence is then inspected manually and annotated with one or more observations employing an easy-to-use interface. Twenty-eight research assistants and volunteers categorised the observations based on species, number of individuals, sex, and age.

7.2.4 DATA PROCESSING

The data from Agouti was exported as a Camera Trap Data Package (Camtrap DP), a community developed data exchange format for camera trap data. All subsequent analyses were performed in R v.4.3.0 (R Core Team, 2023).

7.2.4.1 Data preparation

Since Agouti pulls the timestamps from the images directly, it is important that the time and date were set correctly on the camera traps in the field. Deployments with incorrect settings were therefore excluded from the analyses.

Manually inspecting and identifying the image sequences obtained through camera trapping is a time-consuming process. Despite the effort of 28 research-assistants and volunteers, not all image sequences uploaded to Agouti could be identified with the available resources. We excluded deployments in those cases where less than 75% of the image sequences was identified.

Image sequences were identified at the species level whenever possible. Where this was not possible, the observations were identified at the genus or order level. We excluded observations of humans and domestic dogs, and a single observation of a wild boar (*Sus scrofa*). For the ease of interpretation, we grouped the resulting identifications into 10 categories, namely pheasant, partridge, songbirds, corvids, pigeons, rodents, Lagomorphs (hares and rabbits), predators, waterbirds, and roe deer (Table 7.3).

Analysing the photographs from camera traps can be challenging. When looking at the different species visiting our feeders, it became clear that their feeding behaviour had an impact on the number of photographs taken and the interpretation of a single visit. For example, a species can visit the feeder only once but for a long time, or frequently for short times during a single day. This complicates the comparison of feeder use between different species. To circumvent these issues, we recorded whether a species visited the feeder during a specific monitoring day. The first day of deployment and the day that camera traps were picked up were excluded from this dataset as they did not cover a full 24 hours.

Since we evaluated the impact of the best-practice guidelines at the level of the species or category, the issues mentioned above did not arise. For this analysis we recorded the number of visits to the feeders per 15-minute interval. This allowed more detailed analyses.

Table 7.3. Categorization of the observations based on species, genus, or order.

Category	Species, genus, or order
pheasant	*Phasianus colchicus*
partridge	*Perdix perdix*
songbirds	*Chloris chloris, Emberiza citrinella, Emberiza schoeniclus, Erithacus rubecula, Fringilla coelebs, Passer domesticus, Passer montanus, Passeridae, Passeriformes, Prunella modularis, Turdus merula*
corvids	*Corvus corone, Corvus frugilegus, Corvus sp., Pica pica, Garrulus glandarius, Corvidae, Coloeus monedula*
pigeons	*Columba oenas, Columba palumbus, Streptopelia decaocto, Columbidae, Columba livia*
rodents	*Rattus sp., Rodentia, Apodemus sylvaticus, Rattus norvegicus*
Lagomorphs	*Lepus europaeus, Oryctolagus cuniculus*
predators	*Accipitriformes, Buteo buteo, Felis catus, Felis sp., Martes foina, Meles meles, Tyto alba, Vulpes vulpes, Falco tinnunculus, Strigiformes, Mustela erminea*
waterbirds	*Anas platyrhynchos, Ardea cinerea, Gallinula chloropus, Rallus aquaticus, Tadorna tadorna, Chroicocephalus ridibundus, Alopochen aegyptiaca*
roe deer	*Capreolus capreolus*

7.2.4.2 Analysis

We used a logistic regression model to calculate the daily observation probability to assess overall use of our feeders by animals in the different species categories. In this model the response variable was whether or not there was an observation of an individual within a category. We used the ‘country of the demonstration site’ as a fixed effect, and, as random variables, added the ‘feeder individual id code’ (to account for effects related to the feeder itself), the ‘days since the beginning of winter’ (to account for differences within the season) and ‘year’ - coded 1-5 (to account for differences between the five winters). The model was run for each species category separately.

The INLA package (Rue et al., 2009) was used to specify and fit a Bayesian logistic regression model. The feeder effect and the winter effect were modelled using an independent and identically distributed (iid) random effect, while the day of the season effect was modelled as a second-order random walk (rw2). We applied a binomial distribution.

In summary, this logistic regression model was used to calculate the daily observation probability of a category of species per country, considering effects related to the feeder, changes through the season, and across the different winters.

A different model was used to assess the impact of the best-practice guidelines in Belgium. For this analysis, we used a Bayesian generalised linear mixed regression model to calculate the number of observations during a 15-minute interval. We used this value as the response variable. We used 'winter – i.e., year' and the 'management type' (traditional or best-practice) as fixed, categorical effects. We added the 'geographic location' of the feeders (to account for spatial autocorrelation), the 'days since the beginning of winter' and the 'time of the day' as random effects. The 'geographic location' was modelled as a Gaussian field with Matérn correlation function, while the 'days since the beginning of winter' and the 'time of the day' were modelled as a second-order random walk (rw2). The model utilised a Poisson distribution.

This allowed us to isolate the effect of management from the other effects. The model was run for each category of species separately.

7.3 RESULTS

7.3.1 OVERALL USE OF THE FEEDERS

Figure 7.1 illustrates the results of the overall use of the feeders for the three demonstration sites. The significance of the cross-country comparisons is given in Table 7.4.

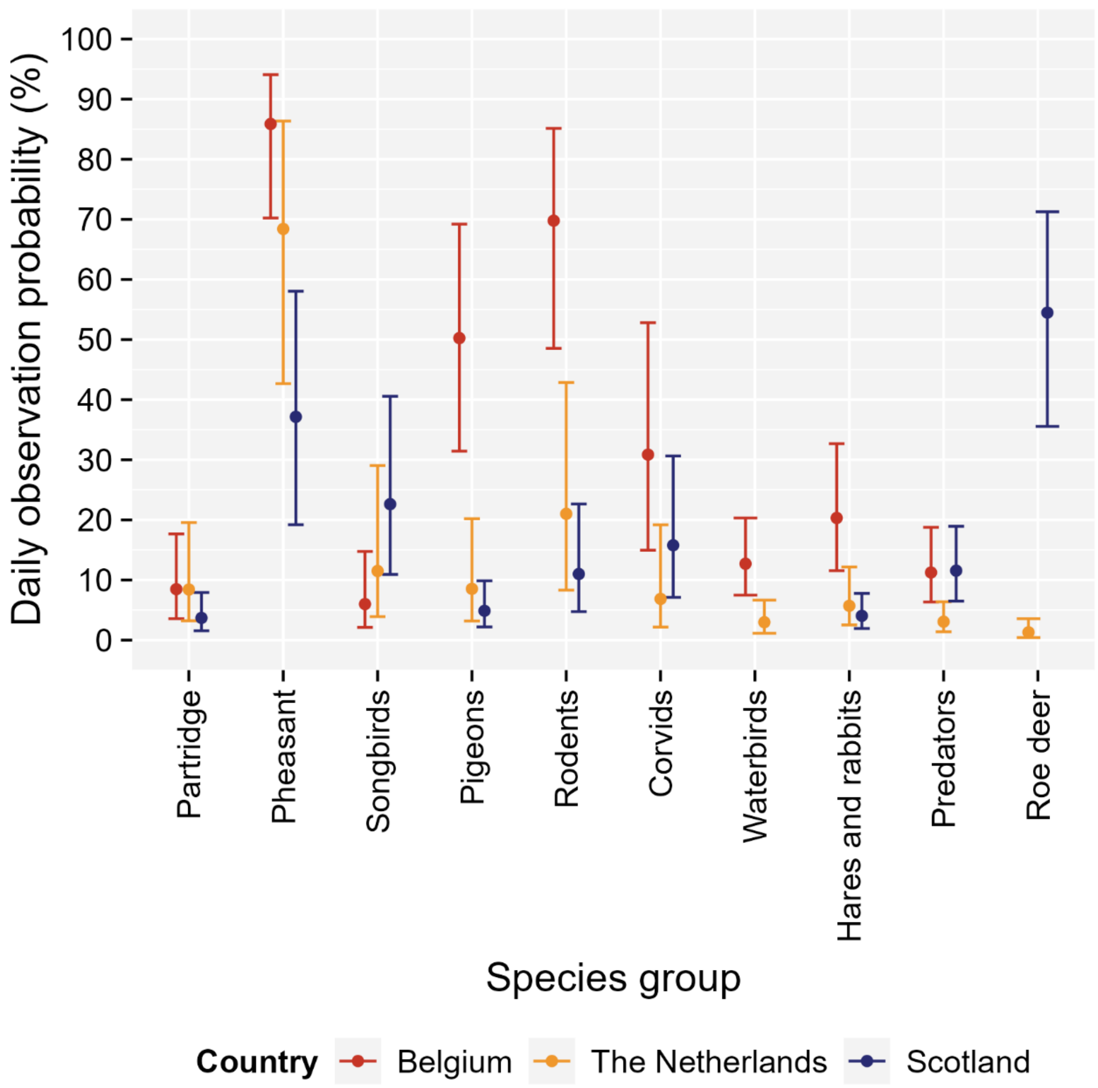


Figure 7.1. Daily observation probability per species category and country: point estimate and 95% credible interval. During the monitoring period, there was only one observation of a roe deer in Belgium and one observation of a waterbird in Scotland. No results are presented for that category/country combination.

Table 7.4. Comparisons between demonstration sites in daily observation probability for each species category (BE: Belgium, NL: The Netherlands, SC: Scotland).

Category	**BE - NL**	**NL - SC**	**BE - SC**
Partridge	-	-	-
Pheasant	-	*	*
Songbirds	-	-	*
Pigeons	*	-	*
Rodents	*	-	*
Corvids	*	-	-
Waterbirds	*	*NA*	*NA*
Lagomorphs	*	-	*

Predators	*	*	-
Roe deer	*NA*	*	*NA*

** P < 0.05.*

Considering our target species (grey partridge, pheasant, and songbirds) pheasants were visiting our feeders most frequently, especially our demonstration sites in Belgium and The Netherlands. In demonstrations sites in both countries, the pheasant was also the most frequent visitor across all categories, while in Scotland, only roe deer had a higher probability of visiting the feeders. Songbirds, on the other hand, were using the feeders relatively frequently in Scotland, but to a lesser extent in The Netherlands and even significantly less in Belgium. This effect was driven by Yellowhammer (*Emberiza citrinella*), which were recorded in high numbers at our Scottish demonstration site, while at our Belgian and Dutch demonstration sites yellowhammer did not occur. The grey partridge did not visit the feeders very often; this was consistent across all sites.

When considering pest or 'un-welcome' species, namely pigeons, rodents and corvids, there was a clear significant difference between demonstration sites in Belgium and the other sites (except for the difference of corvids in Scotland, which was not significant). There was no significant difference between Scotland and The Netherlands for these categories. These species occurred more often at the feeders in Belgium, especially rodents and pigeons.

Waterbirds were also visiting the feeders in Belgium, but significantly less so in The Netherlands. Only one observation of one waterbird was recorded in Scotland. Hares and rabbits were observed significantly more frequent at the demonstration site in Belgium, compared to the demonstration sites in the other two countries, where their visiting rate was low. Regarding predators, these visited the feeders significantly more in Belgium and Scotland (no significant difference between demonstration sites in these countries) as compared to The Netherlands. While this category contains a broad range of species, the main species recorded where the red fox and domestic cat.

As mentioned earlier, in Scotland roe deer was the species that visited the feeders the most. They were rarely observed at the demonstration site in The Netherlands, and in Belgium only one observation was made.

In addition to calculating the overall daily observation probability itself, the model also allowed us to look at the effect of the different winters and the use throughout the season. For five categories of observations (partridge, songbirds, pigeons, waterbirds, hares and rabbits) there was no difference between the winters. For the other five categories (pheasant, rodents, corvids, predators, and roe deer), there were differences between years, but there was no clear overall pattern. For roe deer, hares and rabbits there was no change in visiting rate over the winter season. For the other categories we noted a trend during the season (Figure 7.2 and 7.3). Rodents was the only category where the daily observation probability decreased as the season progressed. For the other species (partridge, pheasant, songbirds, pigeons, corvids, waterbirds, and predators), the use of the feeders increases as the winter proceeded, reaching its maximum by the end of the feeding period at the end of April.

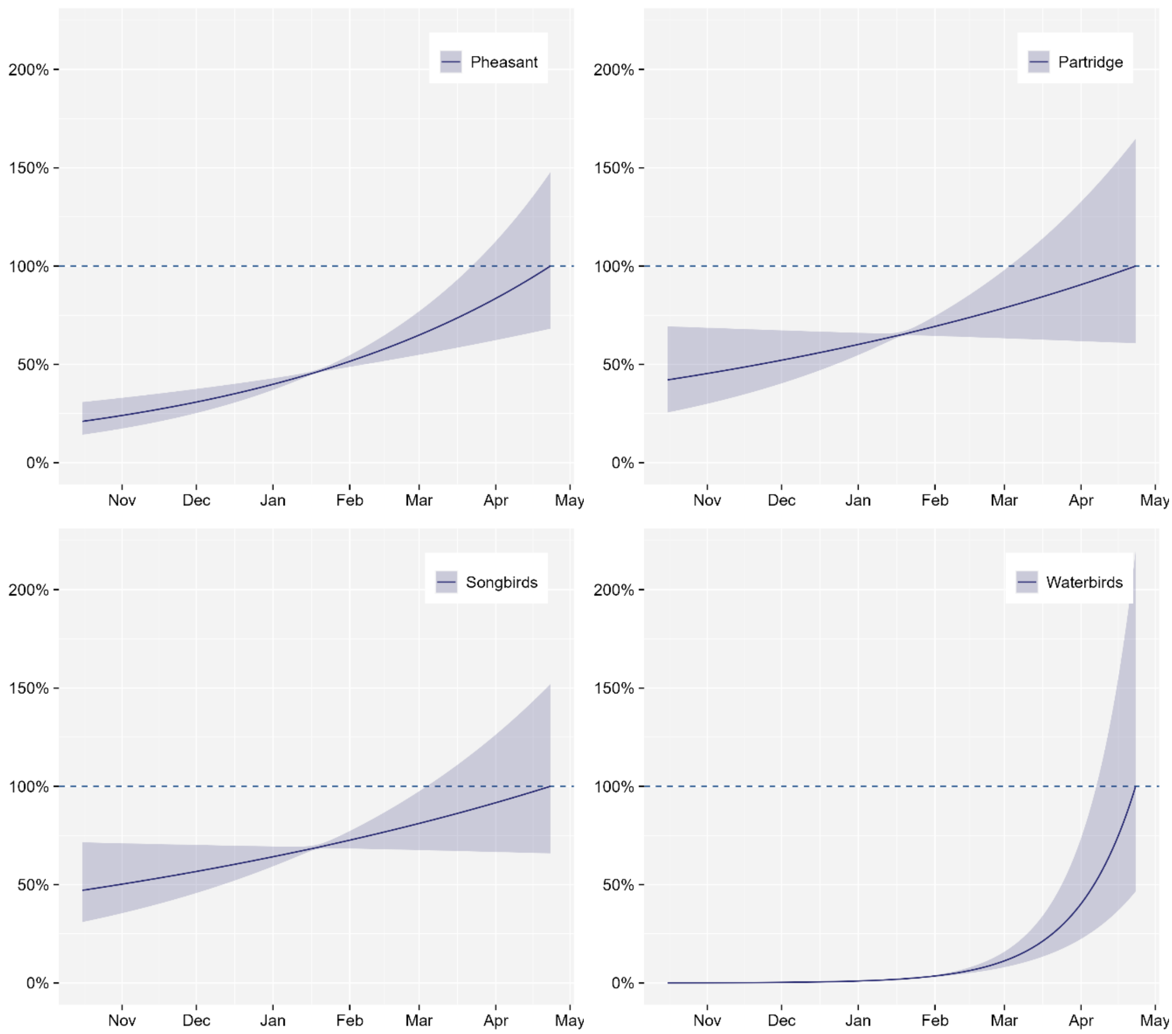


Figure 7.2. Relative effect (% of the maximum) of the day in the season on the daily observation probability for pheasant, partridge, songbirds, and waterbirds.

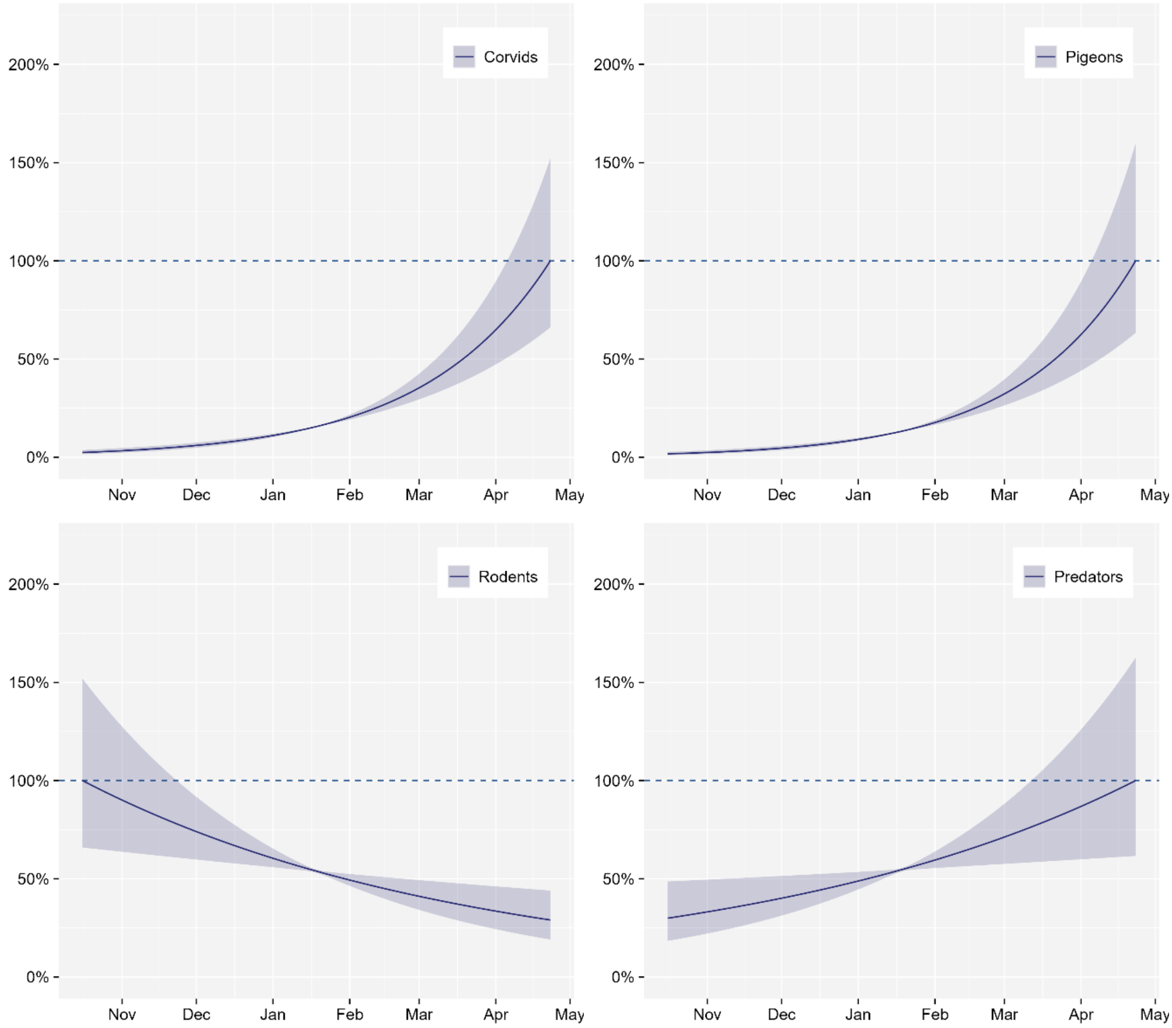


Figure 7.3. Relative effect (% of the maximum) of the day in the season on the daily observation probability for corvids, pigeons, rodents, and predators.

7.3.2 IMPACT OF THE BEST-PRACTICE GUIDELINES

Given the smaller dataset of the field trial, there were not enough observations to assess the effect of the best-practice guidelines for all categories of species. Hence the assessment could only be made for the categories that visited the feeders frequently in Belgium (see also Figure 7.1), namely pheasant, rodents, pigeons, and corvids. The model allowed us to assess the difference of the management type on the number of observations per 15-minute intervals. For ease of interpretation, we transformed the number of observations per 15-minute interval to the number of days required for one observation (Figure 7.4). This means that the more days that are required for one observation, the less frequently members of this category were visiting the feeders.

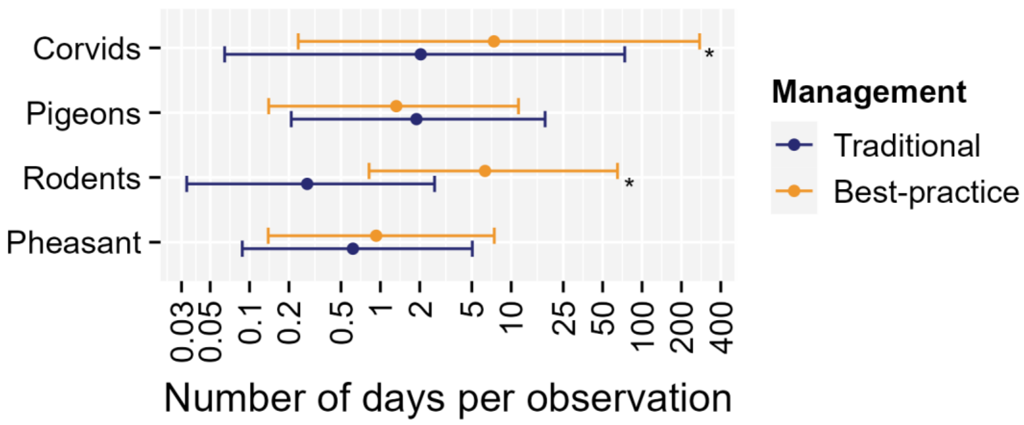


*Figure 7.4. The number of days per observation for each species category for each management type in Belgium (site Ramskapelle): point estimate and 95% credible interval. Significant differences are marked with an *.*

Figure 7.4 shows a clear reduction in the visits of the feeders by rodents and corvids, both considered pest and 'un-welcome' species, at the feeders managed in line with best-practice guidelines. For the other 'un-welcome' species, namely pigeons, no difference could be detected. There was also no difference in the number of visits for pheasant between the two types of feeder management.

7.4 DISCUSSION

Providing supplementary winter food through feeders is part of our PARTRIDGE management toolbox. Despite being a time-consuming monitoring method, camera trapping gave us an insight as to which species were visiting our feeders and how frequently they visited.

The pheasant was the most frequent visitor on demonstration sites in Belgium and The Netherlands, and the second most frequent in Scotland. While pheasants were released on hunting grounds bordering our demonstration site in Scotland, this practice was not allowed at the other sites. Although there was no recent history of feeders at the Scottish site, the presence of pen-reared pheasants near the borders, which were habituated to feed hoppers, might have contributed to their high use of the feeders there. Since the local stakeholders in Belgium already managed feeders at the two Flemish demonstration sites, the pheasants might also have been habituated to the feeders. Habituation, however, cannot explain the high use of the feeders in The Netherlands, as there was no history of feeders and no release of pheasants.

The other target species, namely the grey partridge, did not visit the feeders very often, with daily observation probabilities below 10% in all countries. This further supports our hypothesis that supplementary winter feeding may not be strictly necessary for this species during mild winters. Practical experience by hunters across Europe indicate, that supplementary winter feeding can be an important measure to get partridges through freezing and snowy winter periods. However, such harsh conditions did not occur during our project (except a short-lived 3-week period with snow cover in 2021). Unsurprisingly, we were unable to detect any winter effect on their feeder use. Supplementary winter feeding has been shown to improve body condition prior to egg laying in pheasants (Draycott et al., 1998) and Brewin et al. (2020) therefore suggest this effect may also occur in partridges. Winter feeding might also reduce post-winter dispersal although this has not been scientifically tested. However, neither of these aspects were assessed in this project.

Songbirds, as a target group, were visiting the feeders mostly at the demonstration site in Scotland, but were not observed that often at the demonstration sites in the other countries. One species had a large effect on these differences, namely Yellowhammer, which were observed in high numbers in Scotland, but were absent in the sites in Belgium and The Netherlands. The absence or lower abundance of songbirds eating larger seeds, such as wheat, might explain the lower observation probability of this group in the latter countries. In addition, the use of a special rat-proof cylinder instead of a spiral to distribute the food might have reduced the use of the feeders by songbirds in The Netherlands, since less food was spoiled on to the ground and therefore available for small birds.

The pest or 'un-welcome' species, pigeons, rodents, and corvids, visited the feeders more frequently in the demonstration site in Belgium compared to demonstration sites in the other countries, where the levels of visitation for these categories were comparable. The field trial in Belgium may indicate that this was at least partially due to not following all the best-practice guidelines for the management of the feeders. Best-practice feeder management had a high impact, especially on the visits of rodents. In Scotland and The Netherlands, the feeder management strategy was in line with these guidelines. Our experimental results underline the fact that the best-practice guidelines can reduce the negative side effect of feeding pest species, not only in the UK, but also in Belgium, and the lower level of pest visits with best-practice management in The Netherlands suggests that this will hold across Western Europe.

In Scotland, roe deer were the most frequent visitors to the feeders. As local roe deer abundance was low at the other sites, they were rarely observed at the feeders. Roe deer can knock over the feeders. In these cases, the use of well-framed feeders with excluders may be considered. However, frames and wire mesh can be used by rats, climbing to better access food. We therefore opted for solid tripod feeders which can cope with some interference from roe deer.

Another potential negative side effect of the use of feeders is the attraction of predators. Predators visited the feeders more often at demonstration sites in Belgium and Scotland (around 11%) as compared to the Netherlands (3%). Although this group contains a broad range of species (both mammals and raptors), the main species where the red fox and domestic cat.

The daily observation probabilities of hares and rabbits reflect our hare monitoring results (see chapter 6); significantly higher at the demonstration site in Belgium compared to the other countries. Hence, this difference between countries might be explained by a difference in local abundance.

The last group to consider were the waterbirds. Only one observation was made in Scotland (Balgonie does not have any ditches or other open water features) and visits to the feeders by waterbirds in The Netherlands were also rare (3%). In Belgium the observation probability was nearly 13%, almost certainly reflecting higher waterbird numbers at our Flemish sites (despite an extensive network of ditches and canals at both the Flemish and the Dutch demonstration sites), although we do not have abundance data for comparisons as waterbirds were not specifically monitored during bird surveys.

For most species we detected a difference in the use of feeders through the season. While for rodents there was a decline in their visits to the feeders, the use of the feeders by many other species increased as the winter proceeded. This might be explained by an increase in daylight during our monitoring period, namely from October until April. The difference between the shortest day on 21/22 December and the longest day at the end of April is nearly 7 hours. Diurnal animals therefore had more time to visit the feeders at the end of the monitoring period, while nocturnal animals, such as rodents, had less time. Another hypothesis is that, as the availability of seeds in the field shrinks, the feeders become more important for these species as an alternative food source. This agrees with the results of wintering bird monitoring, which shows a decline in the use of the habitat measures providing seed resources towards the end of the winter season, as those seed-resources are apparently depleted (see Chapter 5).

7.5 CONCLUSION

In conclusion, our camera trapping data provides further insights into the use of feeders for target and non-target species. Our results further support the findings of Sánchez-García et al. (2015) on which the best-practice guidelines on how to manage feeders are based. We confirmed the significant effect of these guidelines to reduce the use of 'un-welcome' species, in particular rodents and corvids. The data also validates our recommendation that the usefulness of supplementary winter feeding by feed hoppers is most important from February until the end of April. Rodents benefit the most from feeding early in the autumn/winter and target species the most towards the end of the winter period. Overall, our results highlight the need for further adoption of the best-practice feeder guidelines, especially by hunters, who tend to favour traditional management practices over new best-practice guidelines. This underlines the need for good advice or improved legislation to bring about behavioural change.

7.6 REFERENCES

Brewin, J., Buner, F. & Ewald, J. (2020*). Farming with nature – promoting biodiversity across Europe through partridge conservation*. The Game & Wildlife Conservation Trust, Fordingbridge, UK.

Draycott, R.A.H., Hoodless, A.N., Ludiman, M.N. & Robertson, P.A. (1998) Effects of spring feeding on body condition of captive-reared ring-necked pheasants in Great Britain. Journal of Wildlife Management, 51, 446-452.

R Core Team (2023). _R: A Language and Environment for Statistical Computing_. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org.

Rue, H., Martino, S. & Chopin, N. (2009). Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. In J.R. Statist. Soc. B. (Vol. 71, Issue 2).

Sánchez-García, C. & Buner, F.D. (2017). Guidelines for successful gamebird and songbird. Game Wildl. Conserv. Trust, 19.

Sánchez-García, C., Buner, F.D. & Aebischer, N.J. (2015). Supplementary winter food for gamebirds through feeders: Which species actually benefit? J. Wildl. Manage., 79, 832–845.

Acknowledgements

First and foremost, we want to thank the more than 70 local farmers who actively participated in the project, implementing and enhancing habitats based on our guidance. Their commitment has played a pivotal role in accomplishing the project objectives, underscoring the effectiveness of collaborative conservation efforts.

Additionally, we extend our gratitude to the dedicated hunters, farmers, volunteers from the public, students, and project partners who invested countless hours in the field, year after year, meticulously collecting extensive monitoring data from our diverse project sites. There were more than 500 of them and hence, regrettably too many to be mentioned by name here. Without their tireless efforts, this project would not have been possible. Thank you all for your amazing contribution.

Furthermore, a special thank you to all who have helped setting up the cameras and identifying the animals on the numerous photographs taken. We thank Bastiaan Deketelaere, Emily Laenen, and Maxime Bourdeaud'hui for helping with the data cleaning of the camera trapping and writing preliminary analysis scripts in R. We also thank the hunters, game keepers, project partners, students, and other volunteers for managing the feeders in the field.

Our appreciation also extends to SOVON (Vogelonderzoek Nederland) for generously granting us access to the AVIMAP application, which significantly facilitated the breeding and wintering monitoring.

PARTRIDGE was 50% funded through the North Sea Region Interreg Programme – we are grateful for their support that has extended way beyond the merely financial. Match funding was provided by all project partners and their supporters.

Imprint

Reference recommendation

Petersen, F., De Bruyn, L, Scheppers, T., Buner, F., Dumpe, L., Ewald, J., Gottschalk, E., Hubbard, C., Cnuts, M., Devisscher, S., Devos, K., Dhaluin, P., Gelaude, E., Mistiaen, R., Neukermans, A., Onkelinx, T., Oost, F., Oostinga, N., Parish, D., Pijcke, J., Sloothaak, J., T' Jollyn, F., Torrance, F., Van Colen, W., van de Straat, S., Van De Walle, M., Vanhuyse, K., Vercammen, J., Verstraete, H., Verzelen, Y., Vreugdenhill, C., Wackenier, M., & Wieland, A. (2023). PARTRIDGE monitoring: Results from the monitoring programme of the Interreg North Sea Region PARTRIDGE project. Institute of Nature and Forest (INBO). https://doi.org/10.21436/inbor.98449677.

DOI: 10.21436/inbor.98449677

Affiliations

1. Institute of Nature and Forest (INBO), Belgium
2. The Game & Wildlife Conservation Trust (GWCT), UK
3. University of Göttingen, Germany
4. Hubertus Vereniging Vlaanderen (HVV), Belgium
5. Inagro, Belgium
6. Brabants Landschap, The Netherlands
7. Het Zeeuwse Landschap, The Netherlands
8. Vlaamse Landmaatschappij (VLM), Belgium
9. Vogelbescherming Nederland (VBN), The Netherlands
10. The Danish Hunters' Association (Danmarks Jægerforbund), Denmark

Illustrations and graphic design

Anne-Lieke Struijk-Faber, BirdLife, Netherlands

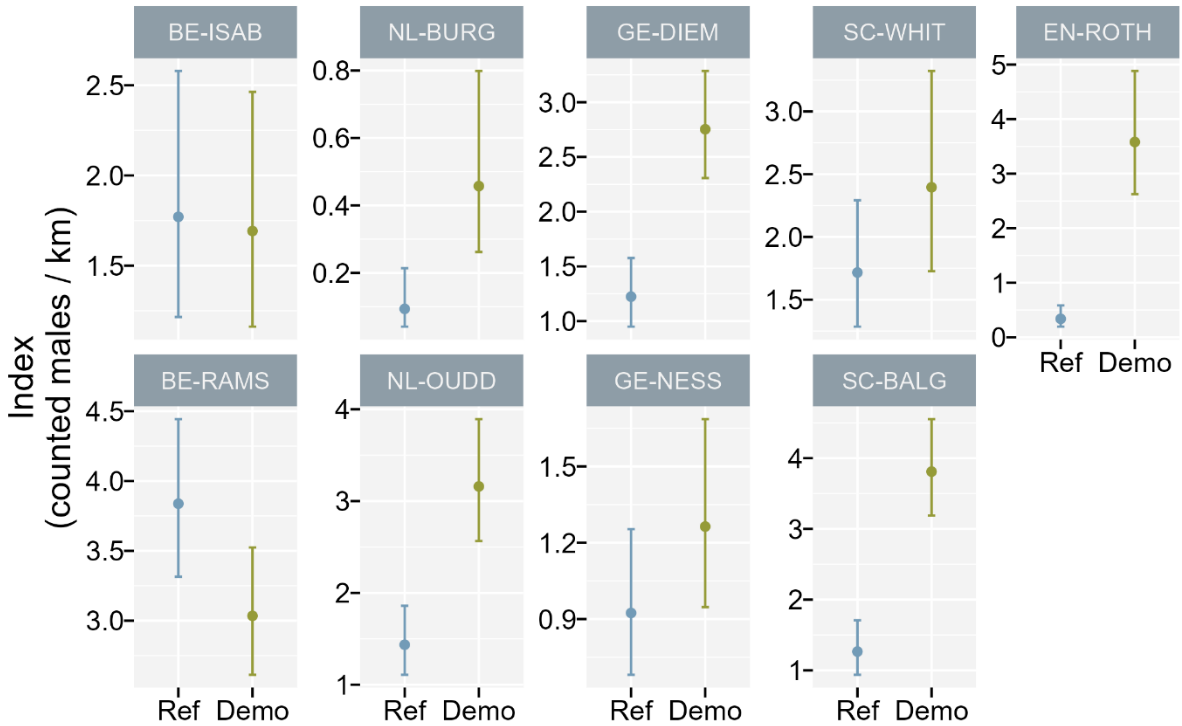
Photography

Jochem Sloothaak, Brabants Landschap, the Netherlands (page 9)
Rollin Verlinde, Vilda (page 21)
Jannie Timmer (page 24, 35)
Fien Oost, Brabants Landschap, the Netherlands (page 44)
Chris Knights (page 54)

Appendix I – Site specific results

APPENDIX I.1 – GREY PARTRIDGE

APPENDIX I.1.1: ABUNDANCE – MEAN NUMBER OF COUNTED PARTRIDGES PER SITE-PAIR. Note different y-axis.



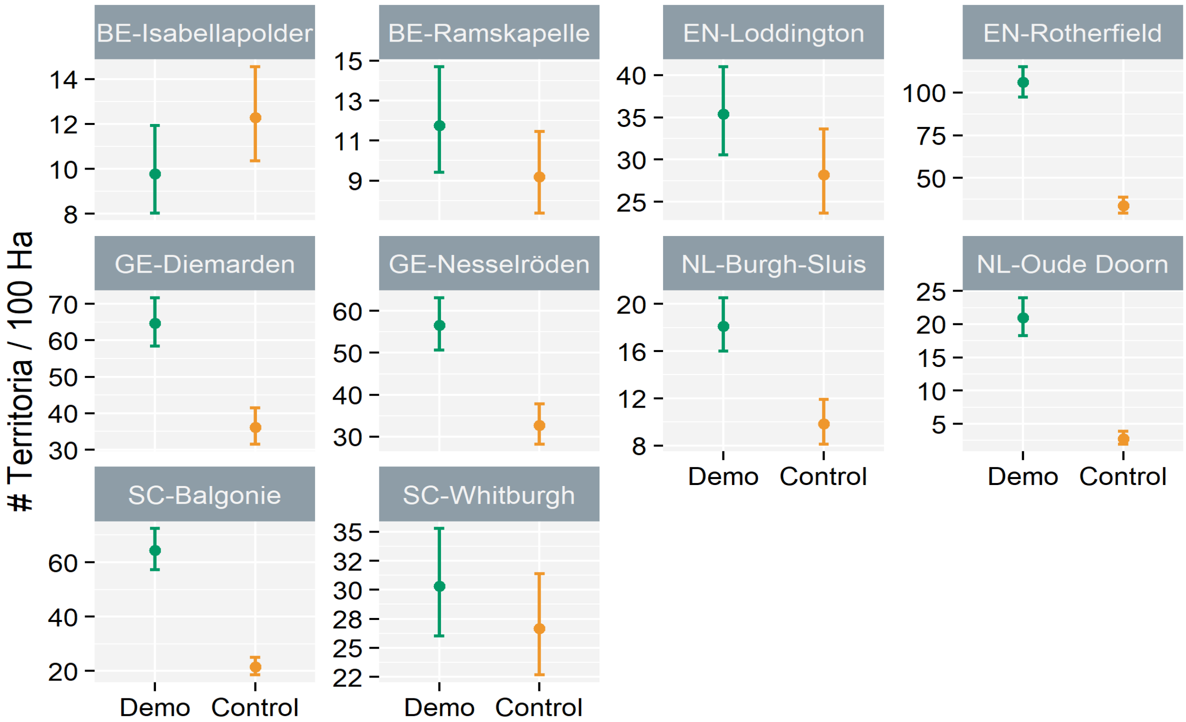
APPENDIX I.2 – BREEDING BIRDS

APPENDIX I.2.1: BREEDING BIRD SPECIES PRESENT AT THE DIFFERENT SITE PAIRS

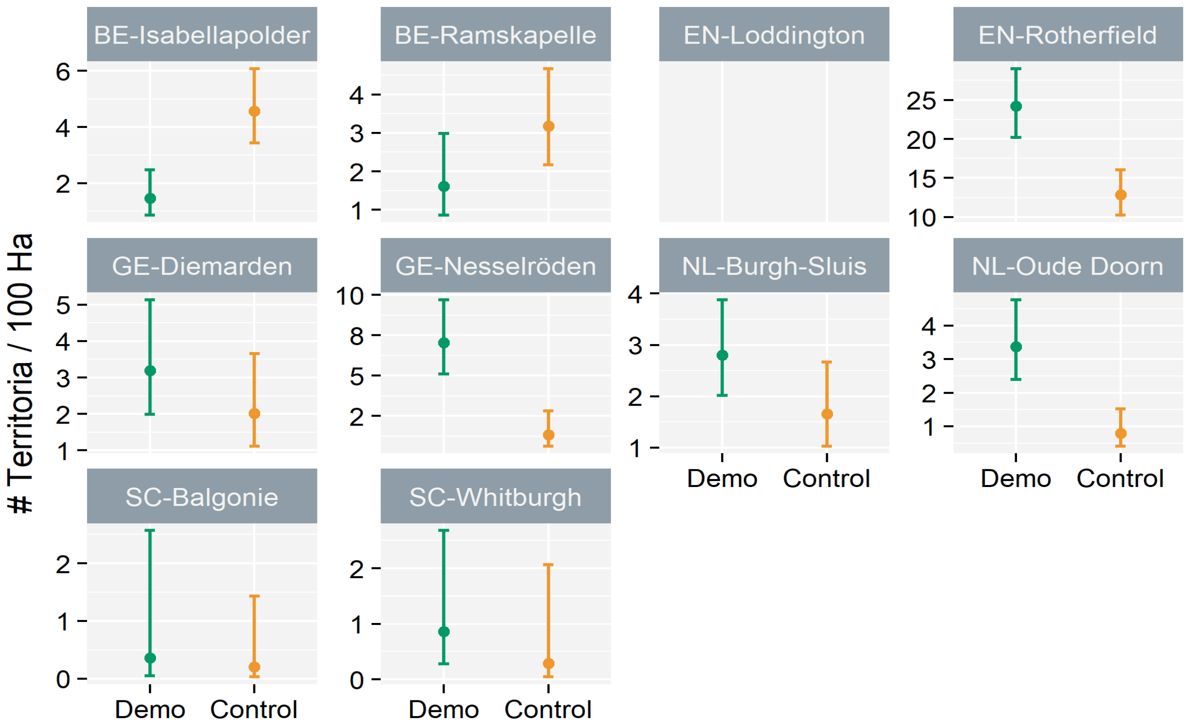
Landscape	Species	Belgium	England	Germany	Scotland	The Netherlands
Small-field	Linnet	X	X	X	X	X
	Tree Sparrow	X	X	X	X	X
	Turtle-Dove	X				
	Goldfinch	X	X	X	X	X
	Whitethroat	X	X	X	X	X
	Grey Partridge	X	X	X	X	X
	Lesser Whitethroat	X	X	X		X
	Red-backed Shrike			X		
	Yellowhammer		X	X	X	
Semi-open	Kestrel	X	X	X		X
	Stonechat	X	X	X		X
	Rook		X		X	X
	White Wagtail	X	X	X	X	X
Open	Corn Bunting		X			
	Meadow Pipit	X	X	X	X	X
	Northern Lapwing	X	X		X	X
	Sky Lark	X	X	X	X	X
	Yellow Wagtail	X	X	X		X

APPENDIX I.2.2: ABUNDANCE – MEAN ANNUAL NUMBER OF BREEDING TERRITORIES AT THE DIFFERENT SITE PAIRS. Note different y-axis.

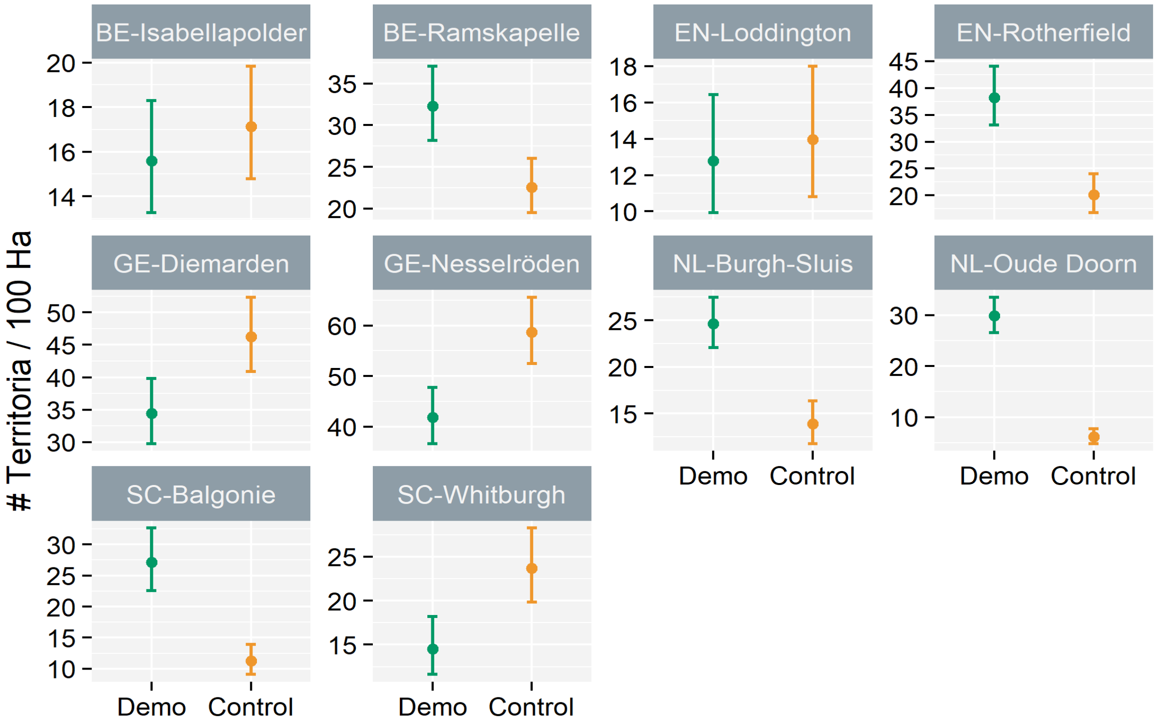
Small-field bird species



Semi-open landscape bird species. Note different y-axis.

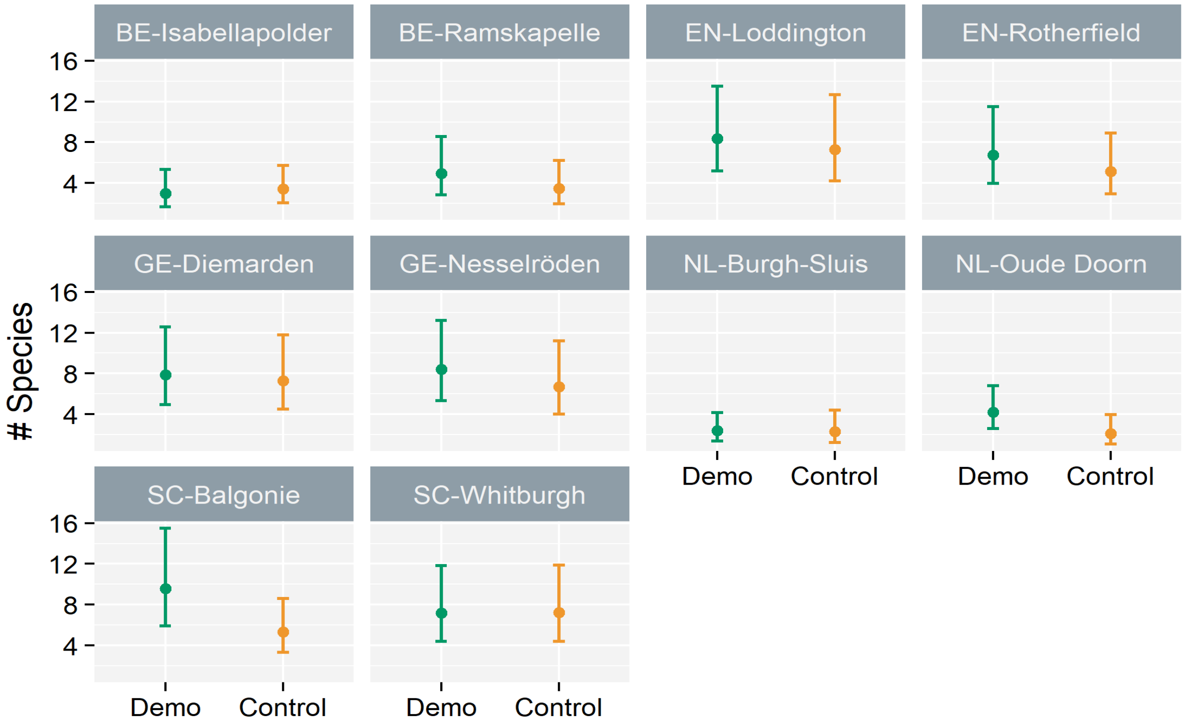


Open landscape bird species. Note different y-axis.



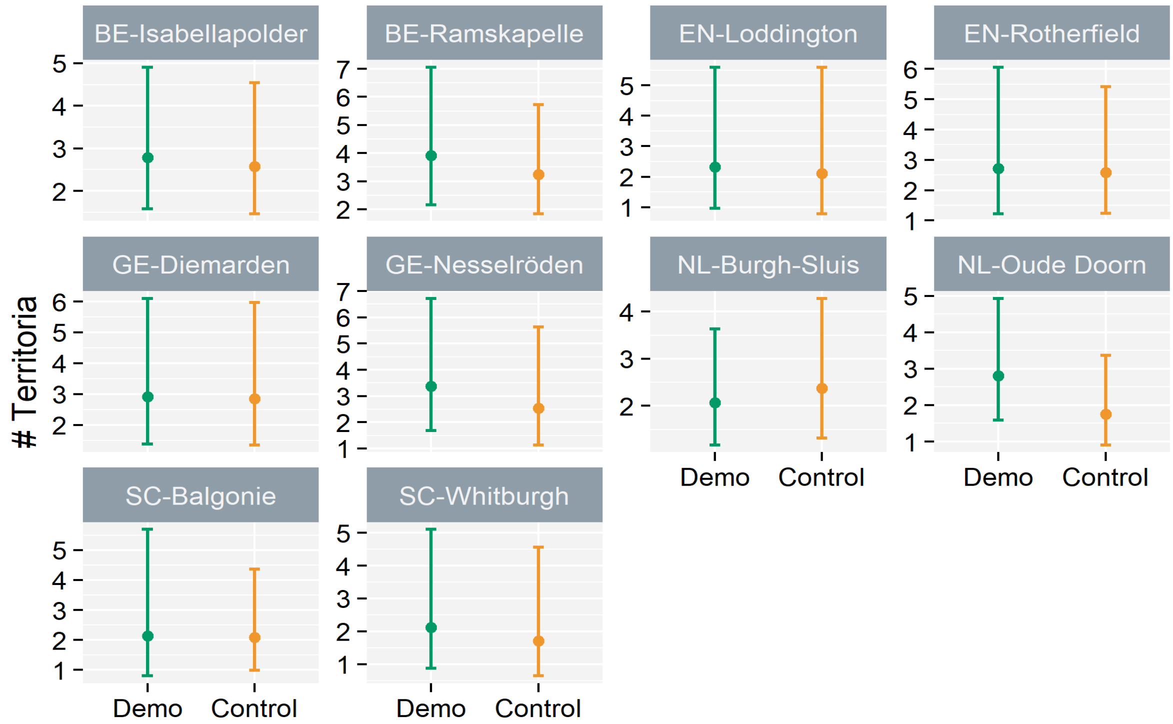
APPENDIX I.2.3: DIVERSITY – MEAN ANNUAL NUMBER SPECIES WITH BREEDING TERRITORIES AT THE DIFFERENT SITE PAIRS

Small-field bird species



Semi-open landscape bird species. Note different y-axis.

Open landscape bird species. Note different y-axis.



APPENDIX I.3 – OVERWINTERING BIRDS

APPENDIX I.3.1: OVERWINTERING BIRD SPECIES PRESENT AT THE DIFFERENT SITE PAIRS

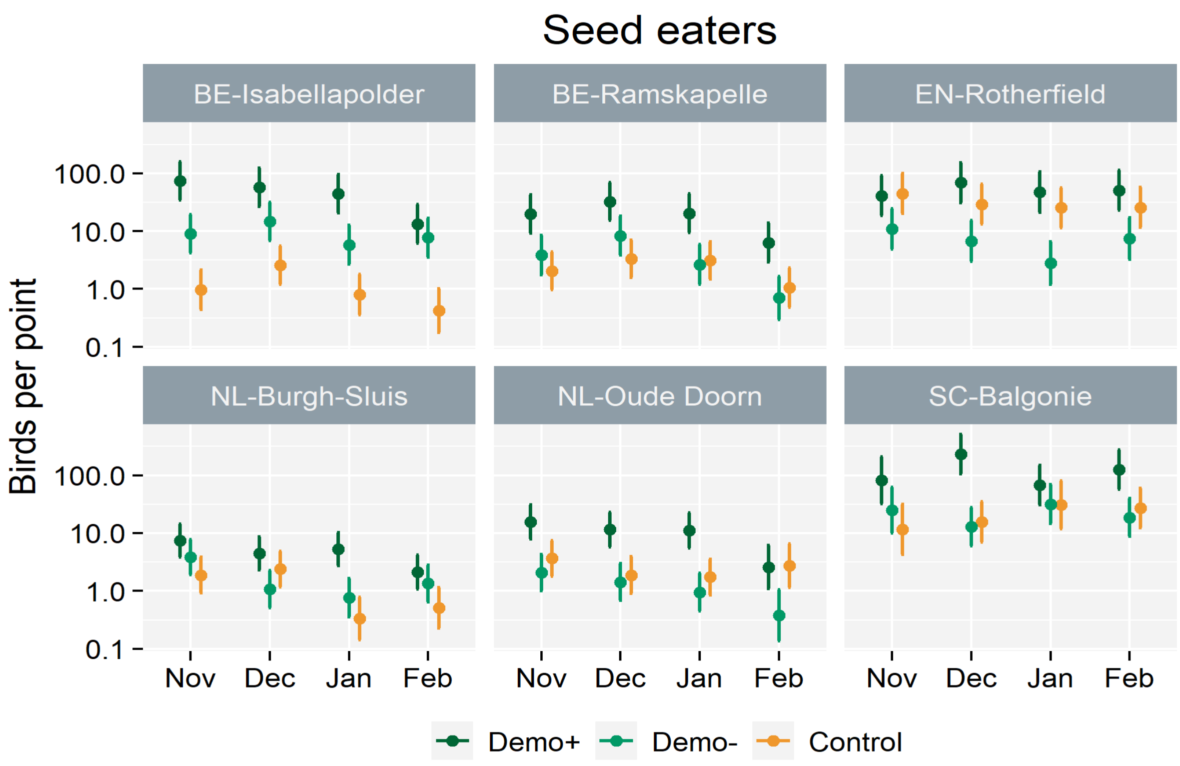
Seed eaters

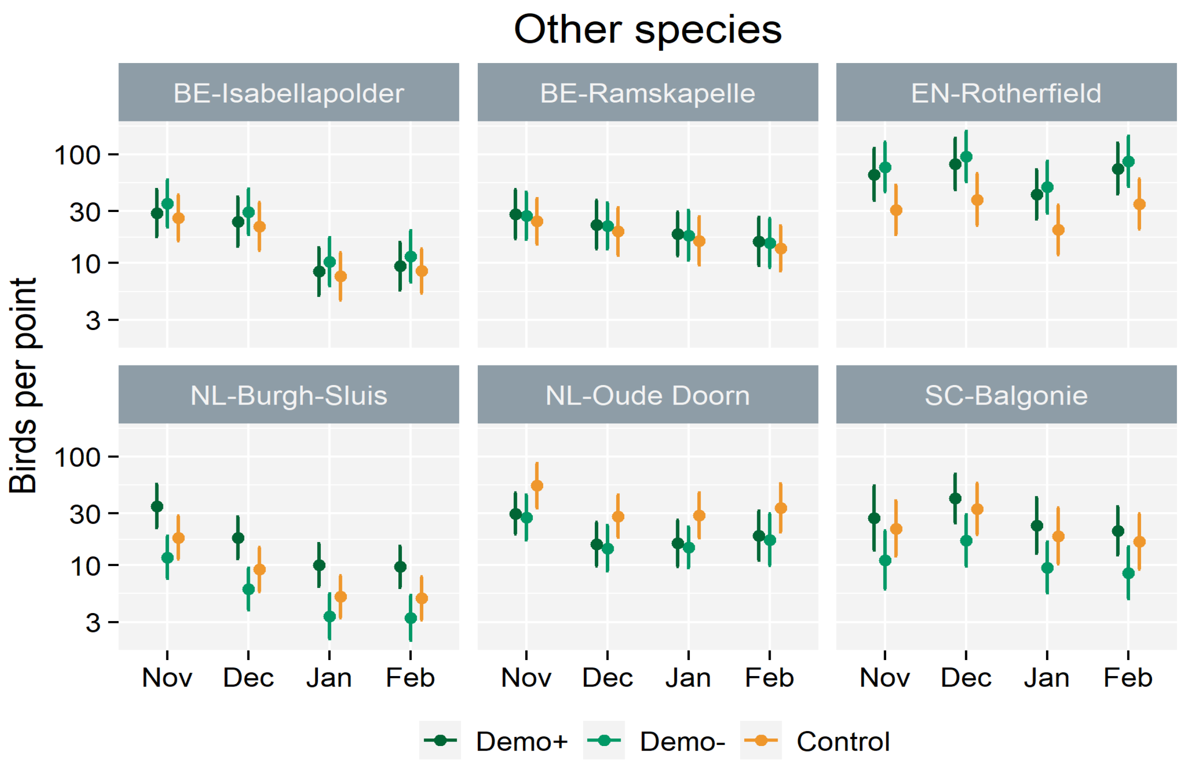
Species	BE Isabellapolder	BE Ramskapelle	NL Burgh-Sluis	NL Oude Doorn	EN Rotherfield	SC Balgonie
Brambling	X	X	X	X		
Chaffinch	X	X	X	X	X	X
Linnet	X	X	X	X	X	X
Tree Sparrow	X	X				X
Goldfinch	X	X	X	X	X	X
Greenfinch	X	X	X	X	X	X
Gray Partridge	X	X	X	X	X	X
Reed Bunting	X	X				X
Sky Lark	X	X	X	X	X	X
Yellowhammer					X	X

Other birds

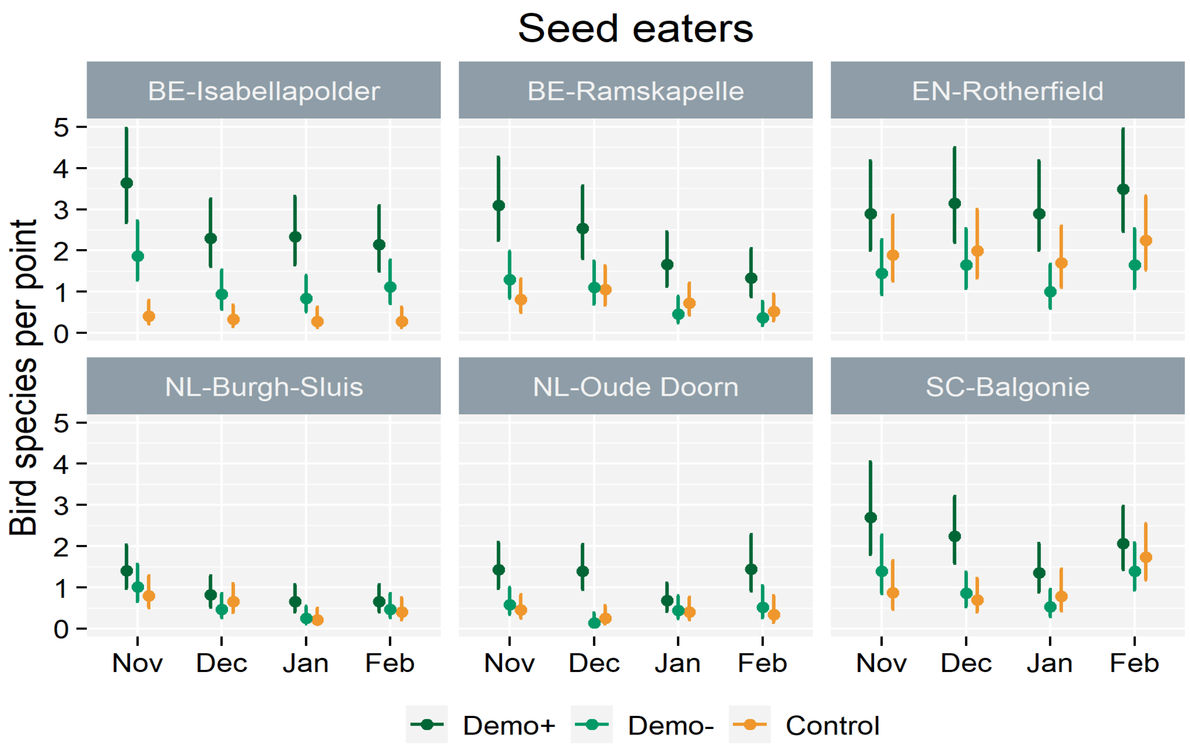
Species	BE Isabellapolder	BE Ramskapelle	NL Burghsluis	NL Oude Doorn	EN Rotherfield	SC Balgonie
Blue Tit	X	X	X	X	X	X
Common Wood-Pigeon	X	X	X	X	X	X
Blackbird	X	X	X	X	X	X
Collared-Dove	X	X	X	X		
Jackdaw	X	X	X	X	X	X
Magpie	X	X	X	X	X	X
Robin	X	X	X	X	X	X
Starling	X	X	X	X	X	X
Fieldfare	X	X	X	X	X	X
Great Tit	X	X	X	X	X	X
House Sparrow	X	X	X	X		X
Meadow Pipit	X	X	X	X	X	
Northern Lapwing	X	X	X	X		
Redwing	X	X	X	X	X	X
Ring-necked Pheasant	X	X	X	X	X	X
Rook				X	X	
Song Thrush	X	X	X		X	
Stock Pigeon	X	X	X	X	X	
Wren	X	X	X	X	X	X

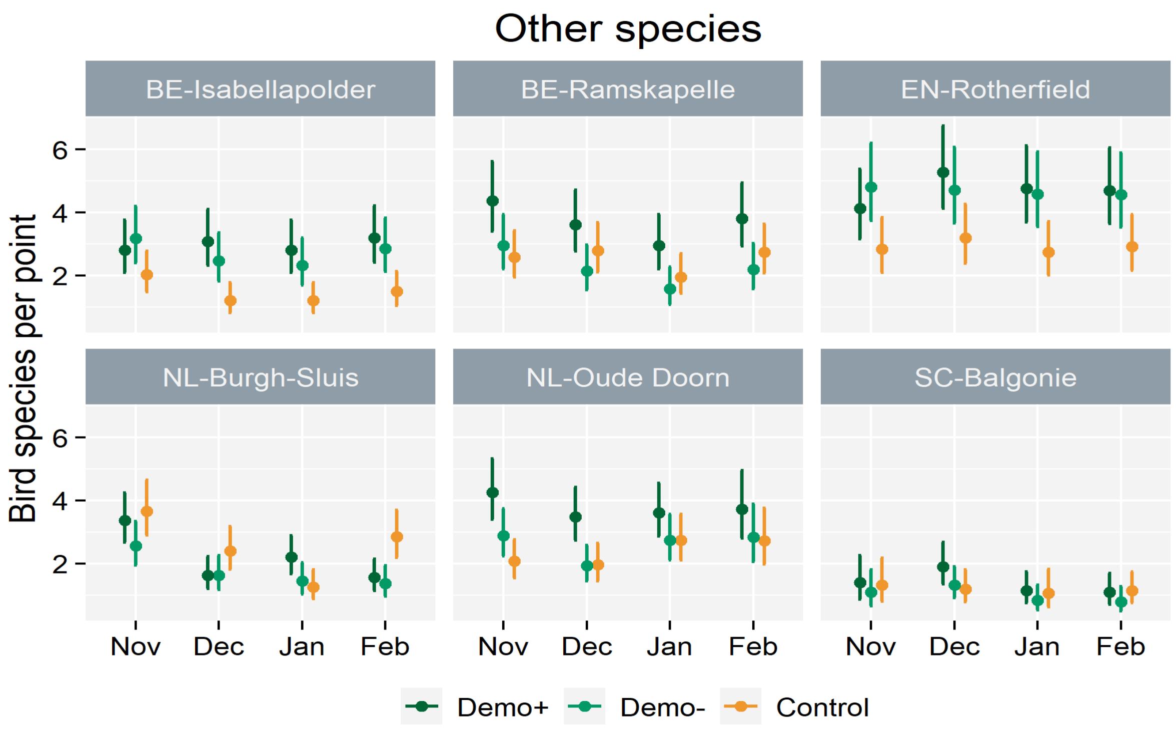
APPENDIX I.3.2: ABUNDANCE – MEAN NUMBER OF BIRDS OBSERVED PER COUNTING CIRCLE AT THE DIFFERENT SITES. DEMO+ WITH MEASURES, DEMO WITHOUT MEASURES. Note logged y-axis.



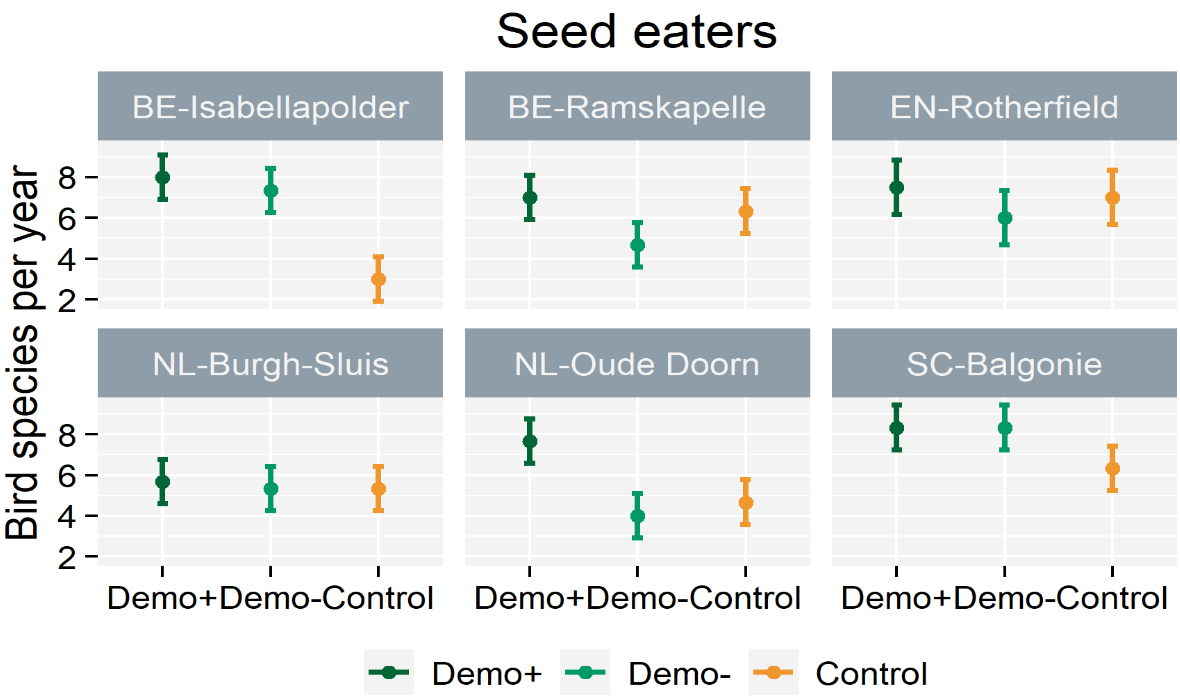


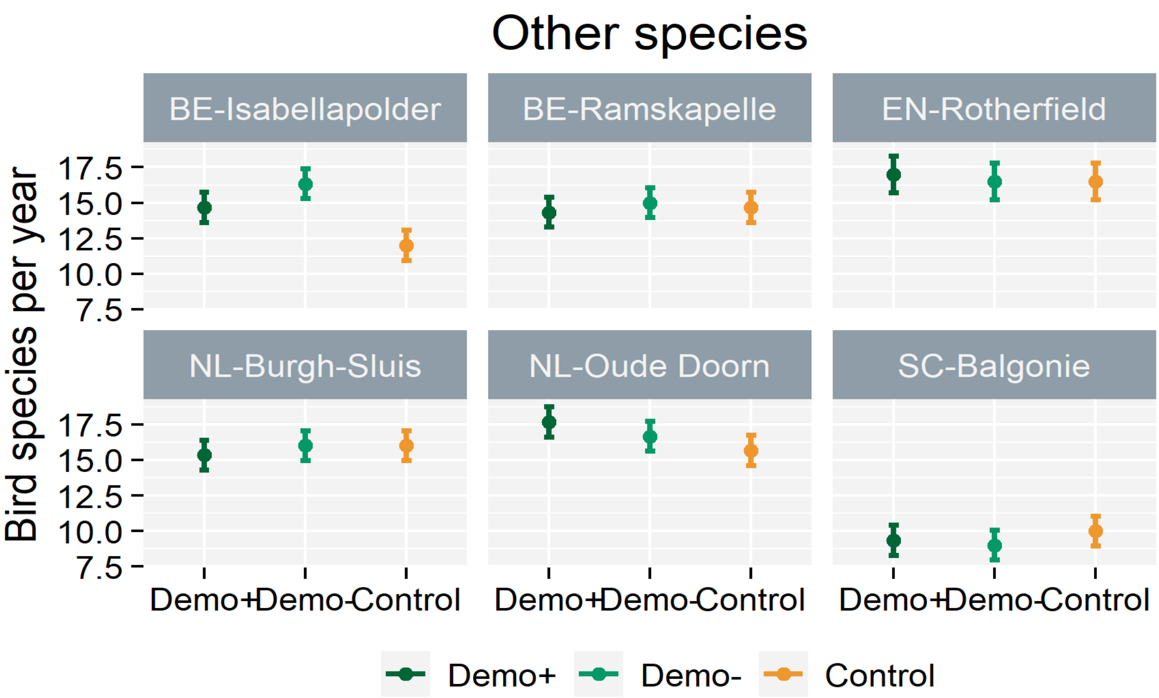
APPENDIX I.3.3: POINT DIVERSITY – MEAN NUMBER OF BIRD SPECIES OBSERVED PER COUNTING CIRCLE AT THE DIFFERENT SITES. DEMO+ WITH MEASURES, DEMO WITHOUT MEASURES.





APPENDIX I.4.4: YEAR DIVERSITY – MEAN NUMBER OF BIRD SPECIES OBSERVED PER YEAR AT THE DIFFERENT SITES. DEMO+ WITH MEASURES, DEMO WITHOUT MEASURES.

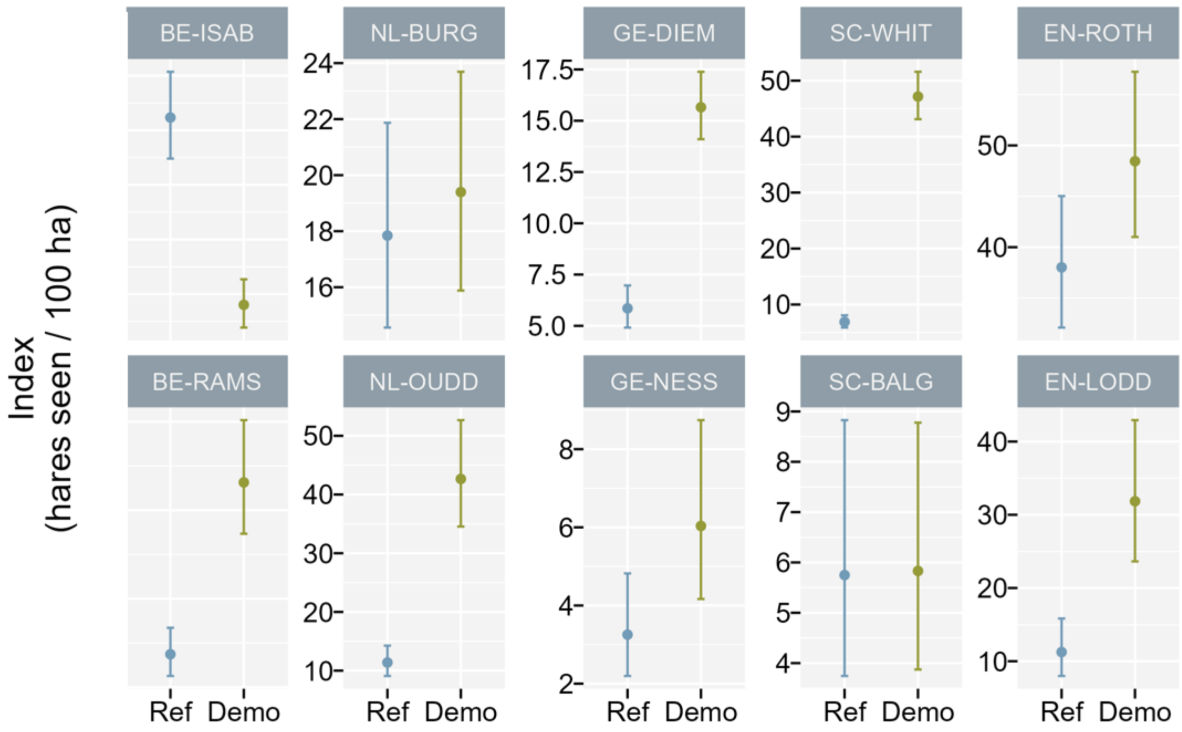




APPENDIX I.4 – BROWN HARE

APPENDIX I.4.1: ABUNDANCE – MEAN NUMBER OF COUNTED HARES PER SITE-PAIR.

Note different y-axis and lack of numbers on the y-axis for the Belgian sites.



Appendix II – Counting forms

A counting form must always contain the following information:

- Date
- Start time and stop time
- Names of participants
- Weather condition (especially fog, snowfall, stormy rain, strong wind, full moon) and temperature

All observations and their exact location should be recorded on a detailed map of the area. It is recommended that the map contains field edges, site boundaries and the predetermined transects. Observations are numbered consecutively. Note that multiple observations can be made from the same transect. A group of animals is noted as one observation. The exact observation time and special remarks can be noted on a separate counting form (provided below).

Based on the species-specific counting method, the following counting instructions are recommended:

Brown hare (*Lepus europaeus*)

A complete log of the observations should contain the following information:

- Transect number
- Observation time
- Animal species (for the various observed species a specific code can be used, e.g.: H = hare, R = rabbit, F = fox, C = cat, ? = unknown)
- Number of animals

When entering the observations on the map, the following code is proposed:

Number of the observation – species code – number of animals

For example, the code 5H4 corresponds to the 5th observation of that night which is a group of 4 hares. On the back of the map, more details regarding this observations can be written (especially the number of the transect from which this observation was made and the time of the observation!).

Grey partridge (*Perdix perdix*)

The line-transect playback method used for partridge spring counting, provides a clear and standardized way of gathering field data to avoid mistakes in the interpretation of the field data at a later stage.

A complete log of the observations should contain the following information:

- Transect number
- Observation time
- Total number of partridges heard or seen
- Type of observation: solitary (one individual), pair (two individuals: male and female) or a covey (two males or more than two individuals)
- Number of calling individuals (number heard)
- Number of individuals seen (number seen)

Examples of counting forms for both species (brown hare and grey partridge) are provided below:

Hare count

Area: ___________________________________ Date: ___ / ___ /_______

Names of counter(s):

1. ____
2. ____
3. ____

Wind: Temperature: _____ °C

calm(0 - 1 Bf)	weak (2 - 3 Bf)	moderate (4 - 6 Bf)

Rain: Remarks (fog, snow, …):

None	drizzle	showers

Clouds:

0 - 33%	33 - 66%	66 - 100%

Start: ___ h ___ Stop: ___ h ___

Observation n° (same as map)	Transect	Time	Species Number of individuals	Remarks
1	3	20:35	1F1	
2	6	21:05	3H2	
3	7	21:50	6?1	Dog?
4				
5				
6				
7				

Figure II.1.2 Counting form hare monitoring

Partridge spring count

Area: ___________________________________ Date: ___ / ___ /_______

Names of counter(s):

1. ____
2. ____
3. ____
4. ____
5. ____

Wind:

calm(0 - 1 Bf)	weak (2 - 3 Bf)	moderate (4 - 6 Bf)

Temperature: _____ °C

Rain:

none	drizzle	showers

Remarks (fog, snow, …):

Clouds:

0 - 33%	33 - 66%	66 - 100%

Start: ___ h ___ Stop: ___ h ___ morning / evening count

Observation n° (same as map)	Transect	Time	Total N° of partridges	Type of observation (SINGLE, PAIR, COVEY)	N° Seen	N° Heard	Remarks
1	1	18h35	1	SINGLE	1	1	Calling loudly
2	3	19h25	5	COVEY	5	2	
3							

Figure II.2.3 Counting form partridge spring monitoring

Appendix III – Model specifications

APPENDIX III.1 – GREY PARTRIDGE AND BROWN HARE

APPENDIX III.1.1 – TREND ANALYSIS

This section provides more detailed information on the generalised mixed-effects model described in Section 2.2.3.2.

```
library(INLA)

model <- inla(
  Count ~
    f(
      Site, model = "iid",
      hyper = list(theta = list(prior = "pc.prec", param = c(0.2, 0.05)))
    ) +
    f(
      cYear, model = "rw1", replicate = iSite,
      hyper = list(theta = list(prior = "pc.prec", param = c(0.1, 0.05)))
    ),
  offset = log_km2/log_km, family = "nbinomial", data = dataset,
  control.compute = list(waic = TRUE, config = TRUE),
  control.predictor = list(link = 1)
)
```

The offset term depends on the monitoring data: the viewshed area (log_km^2) was used for the hare count data, while the total transect length (log_km) was used for the partridge spring data.

The inla.posterior.sample() function was used to generate 1000 posterior samples from the Bayesian model specified above.

```
n_sim <- 1000

inla.posterior.sample(n = n_sim, model)
```

APPENDIX III.1.2 – ABUNDANCE

This section provides more detailed information on the generalised mixed-effects model described in Section 1.2.3.3.

```
library(lme4)

model <- glmer.nb(Count ~ Type + (1 | Group/cYear) + (1 | Site) +
       offset(log_km2/log_km), data = dataset)
```

The offset term depends on the monitoring data: the viewshed area (log_km^2) was used for the hare count data, while the total transect length (log_km) was used for the partridge spring data.

The drop1() function was used to assess the significance of our type variable (demonstration vs. reference) based on a chi-squared test.

```
drop1(model2, test = "Chisq")
```

The ggpredict() function from the ggeffects package was used to calculate predicted values (including lower and upper confidence levels) for both types of sites.

APPENDIX III.2 – SUPPLEMENTARY WINTER FEEDING

This section provides the R code with the specific settings for the analysis. For a description of the model and the variables please refer to Chapter 7.

APPENDIX III.2.1 – OVERALL USE OF THE FEEDERS

```
library(INLA)

model <- inla(
  Observation ~ country
    f(
      feeder_ID, model = "iid",
      hyper = list(theta = list(prior = "pc.prec", param = c(0.2, 0.05)))
    ) +
    f(
      day_of_the_season, model = "rw2", cyclic = FALSE, scale.model = TRUE,
      hyper = list(theta = list(prior = "pc.prec", param = c(0.01, 0.05)))
    ) +
    f(
      winter, model = "iid", cyclic = TRUE, scale.model = TRUE,
      hyper = list(theta = list(prior = "pc.prec", param = c(0.2, 0.05)))
    ),
  family = "binomial",
  data = dataset,
  control.compute = list(waic = TRUE, config = TRUE),
  control.predictor = list(link = 1)
)
```

APPENDIX III.2.1 – IMPACT OF BEST-PRACTICE GUIDELINES

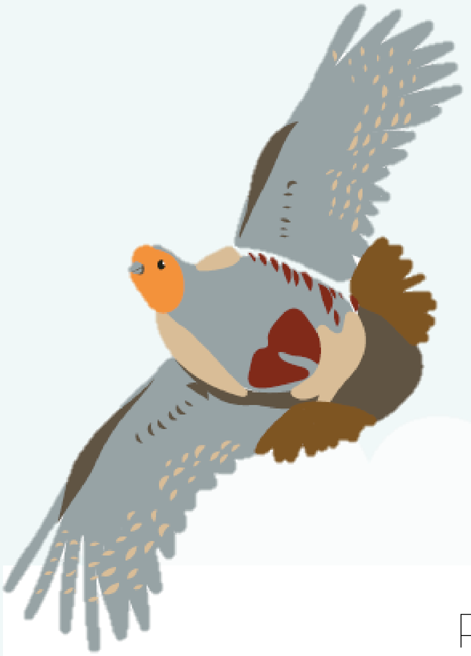
To take spatial autocorrelation into account, geographic location (Belgian Lambert 72 coordinates, EPSG:31370) was modelled as a Gaussian field with Matérn correlation function.

```
matern <- inla.spde2.pcmatern(
             mesh = mesh, prior.range = c(500, 0.01), prior.sigma = c(0.5, 0.5)
             )
```

A range0 in the prior.range of 500 was used for all species groups, except for rodents for which a smaller range0 was chosen, namely 200.

```
library(INLA)
```

```
model <- inla(
  Observations_per_15min_interval ~ 0 + intercept + winter + management +
    f(
      site, model = matern,
    ) +
    f(
      day_of_the_season, model = "rw2", cyclic = FALSE, scale.model = TRUE,
      hyper = list(theta = list(prior = "pc.prec", param = c(0.01, 0.05)))
    ) +
    f(
      time_of_day, model = "rw2", cyclic = FALSE, scale.model = TRUE,
      hyper = list(theta = list(prior = "pc.prec", param = c(0.001, 0.05)))
    ),
  family = " poisson",
  data = inla.stack.data(dataset_stack),,
  control.compute = list(waic = TRUE, config = TRUE),
  control.predictor = list(A = inla.stack.A(dataset_stack))
)
```



PROJECT PARTNERS

BOEREN NATUUR VLAANDEREN

HUBERTUS VERENIGING VLAANDEREN

natuur dichtbij huis
Brabants Landschap
Coördinatiepunt Landschapsbeheer

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Vogelbescherming NEDERLAND

VLAAMSE LAND MAATSCHAPPIJ

inagro

Game & Wildlife CONSERVATION TRUST

HET ZEEUWSE LANDSCHAP

INSTITUUT NATUUR- EN BOSONDERZOEK

DANMARKS JÆGERFORBUND