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Master 2 Internship Report – Master Thesis

Impact of forest roads and paths on bird communities in the Black Forest

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1 Introduction

1.1 The effect of roads

The effect of roads has been studied in the last decades, highlighting both positive and negative effects on bird communities, especially on diversity and abundances, through various mechanisms (Kociolek et al., 2011; Morelli et al., 2014).

Roads contribute to habitat loss, degradation, and fragmentation, which impact biodiversity (Bekker and Iuell, 2003). Birds are not the exception as they are directly or indirectly impacted by roads. The main negative disturbing effects identified on birds are noise, visual stimuli, pollution, collisions, and the spreading of materials such as dust and sand. The effects of roads increase with growing traffic densities and extend outward for more than 1000 m for busy highways. It results in population losses from 30% to almost 100% for busy roads, probably due to noise as a traffic-related causal factor (Reijnen and Foppen, 2006). Bird populations are most notably affected at short distances from infrastructures (Benítez-López et al., 2010). This effect on bird is particularly important for high-traffic paved roads, mainly due to mortality and traffic noise relative to others effects and other taxonomic groups (Kociolek et al., 2011). It is the consequences of impacts on physiology through stress (Campo et al., 2005), on breeding cycles (Francis et al., 2009; Habib et al., 2006), on foraging behaviours (Leonard and Horn, 2005), and on communication especially for species vocalizing in low-frequencies (Goodwin and Shriver, 2010; Polak et al., 2013).

The negative effects are also mixed with positive ones. Roads can increase heterogeneity, which provides habitats and resources for some species, especially due to a more diverse vegetation (Helldin and Seiler, 2003; Palomino and Carrascal, 2007). Road infrastructures also bring refugees, perches, and nesting sites (Morelli et al., 2014). In addition, some species can benefit from roads due to reduced predation (Yamac and Kirazli, 2012). Roads are also positive for scavengers through increased mortality due to road kills (Dean and Milton, 2003). Finally, these infrastructures facilitate energy budget regulation, especially during migrations, through heat released by the road (Yosef, 2009) and can prolong diurnal activity (Byrkjedal et al., 2012).

1.2 Unpaved roads

Although the negative effect of roads on bird communities is predominant for paved roads, especially highways, it is less clear for unpaved and low-traffic roads. These types of roads are also less studied compared to paved and high-traffic roads. The length of unpaved roads, at a landscape scale, is associated with a lower bird richness (Mammides et al., 2016). However, at a local scale and in the context of a secondary production forest in central Europe, it has been observed that low-traffic forest roads increase the bird richness compared to the forest interior. Unpaved forest roads also slightly increase the bird richness (Šálek et al., 2010). This could be due to an increase in habitat heterogeneity, especially in the context of structurally poor forests. Furthermore, communities along unpaved roads were more similar to forest edges than forest interiors. Species richness was lower along roads than in forest edges (Šálek et al., 2010). The pattern of bird communities near unpaved forest roads could be linked with the edge effect as forest roads may almost be seen as “mini” edges, resulting in a similar but less pronounced effect.

1.3 Edge effect

Edges are generally associated with higher vegetative complexity, which can provide resources for diverse taxa, especially birds (Yahner, 1988). A second effect of edges is that they enable spillovers by being an interface between habitats. Thus, increasing edge density could increase spillover and result in more resources and connectivity (Boesing et al., 2018). The spillover may lead to a positive effect on ecosystem functioning (Scherer-Lorenzen et al., 2022). In this manner, edges have been found to support more bird abundance and diversity in Germany’s deciduous forest (Batáry et al., 2014). Nevertheless, nest predation could be a slightly negative effect of edges on bird communities (Cox et al., 2012). The edge effect may also mainly benefit on generalist species (Hofmeister et al., 2017).

1.4 Specificities of the effect and challenges

1.4.1 A context-specific effect

The effect of roads is context-dependent (Kroeger et al., 2022). It has been observed that unpaved low-traffic roads increase species richness compared to forest interior in the context of a secondary production forest (Šálek et al., 2010). It should be noted, that 75% of Europe's forest area is available for wood supply (*FOREST EUROPE, 2020: State of Europe’s Forests 2020*, 2020), hence the interest in studying this type of system. Nevertheless, this result may differ in other forest systems. On the landscape context, urbanization is also likely to make the effect of roads more negative (Ouédraogo et al., 2020). Finally, areas with denser tree cover tend to show a negative effect (Kroeger et al., 2022).

1.4.2 A species-specific effect

Studies often focus on global biodiversity indices, but this aggregated information may omit part of the effect of roads (Kroeger et al., 2022). For instance, omnivorous birds are less impacted by roads mainly because they have a greater diet capacity adaptation (Kroeger et al., 2022). Inversely, specific diet guilds like insectivore species and species that use grassland were found to be less abundant close to roads (da Silva et al., 2017). Vulnerable species such as species with decreasing population status are more affected by unpaved roads (Mammides et al., 2016). Small birds were less likely to cross roads, probably because of changes in vegetation structure and complexity, competition, and predation (Johnson et al., 2017). This species-specific effect results in dissimilarities between bird communities in intact areas and areas with high road density, mostly due to species turnover (Ascensão et al., 2022).

1.4.3 Cofounding factors

In addition to the two previous challenges, the effect of roads involves different drivers, and studies have difficulties untangling the confounding factors such as noise, vegetation, and edge effect (Johnson et al., 2022). The noise has been studied correlatively and couldn't identify it precisely as the main driver (Summers et al., 2011). However, an experiment simulating a phantom road with speakers revealed a negative effect of noise on birds during migratory stopover by observing a lower body condition index around the phantom road. Therefore, noise degrades suitable habitats for migratory birds (Ware et al., 2015). This driver of noise is not fully solved for all birds, as it is also unclear for vegetation and edge effects, hence the interest in studying the underlying mechanisms of the effect of roads on birds.

1.5 Roads in conservation and forest management context

A better understanding of the effect of roads may inform conservation and management practices. Road networks are widely developed. For instance, 63% of Swedish Special Protection Areas are, to some extent, found within the 1 km road/railway effect zone (Helldin, 2019). Nevertheless, roadless and low-traffic areas are useful for preserving biodiversity ecosystem services (Selva et al., 2015). This raises interest for more precise studies on the effect of roads on bird communities, through the remaining gaps in the understanding of road effect on bird communities, especially in a variety of contexts, through a species-specific analysis and focusing on mechanisms such as vegetation and edge effect.

1.6 Questions and hypotheses

This study will try to prolong the one realised on unpaved low-traffic roads in Central Europe, focusing on the local effect on the habitat (Šálek et al., 2010). The present study aims to assess the effect of unpaved low-traffic roads by characterizing the mechanisms and the differentiated effect on bird species. The following questions are addressed, along with their associated hypotheses:

1) How does the vegetation structure explain the effect of low-traffic unpaved roads on bird communities? It may be hypothesized that the main mechanism involved in low-traffic unpaved roads is comparable to an edge effect: roads and paths may lie in a forest-edge gradient, with an increased bird diversity compared to forest interior and with communities similar to those in forest edges.
2) Why are species differently affected? The effect of low-traffic unpaved roads on bird communities is expected to be species-specific. Functional traits are expected to explain part of the differentiated effect of this type of roads: roads and paths may host species with functional traits between those found in forests and in edges, with species more mobile and heavier in forest edges than in roads and paths, themselves more mobile and heavier than in forest interiors.

Through synergies with projects in the same system on different taxonomic groups (see Marta Cardini's Master Thesis, Freiburg University – ConFoBi, 2023) this thesis aims to give a more complete picture of the cascading effects of roads on different species.

2 Material and Methods

2.1 Study area

The study took place in the southern Black Forest in Germany (47.66-48.17°N, 7.72-8.64°E). It is a forest-dominated and low mountain region in the Central Europe with an altitude between 516-1120 m. The Black Forest is predominantly a production forest but has become more mixed and structurally diverse in the recent decades. This project is related to the ConFoBi project which aims to understand the effect of deadwood, habitat trees and forested area in proximity ("retention forestry") on biodiversity, wood production, and its social perception (Storch et al., 2020). Thus, for logistical reasons and synergies with other projects, it was convenient to use selected sites from the original 135 plots for this study (Figure 2).

2.2 Plot selection

To study the effect of unpaved roads as a local habitat on bird communities and to understand the nature of this effect, it is important to compare these habitats to other forest-related habitats: forest interiors (later designated "forest") and forest edges (later designated "edge"). Furthermore, unpaved forest roads and paths can represent a variety of structures. Thus, the two types of structures in this study are defined as follows (these terms will refer to these definitions throughout this manuscript):

- Path: linear structure in a forest habitat, with a width of less than 3 m, that does not open the canopy but without tree or shrub layer directly on it. The soil should be as intact as possible. These structures are typically the result of large harvesting machines or constructed as wide pedestrian trails.
- Road: linear structure in a forest habitat, with a width of at least 5 m, that cuts the canopy, without vegetation on the ground, and with gravels embedded in the soil. These structures are typically suited for standard cars.

These definitions of road types cannot distinguish the effect of the soil (gravel or unmodified) and the canopy's opening. However, this reflects the realities within the Black Forest. These definitions could be seen as a gradient of openness: forest, path, road, edge. And one of the purposes of this report is to assess if paths and roads fit in this gradient or if it lies somewhere else. Pictures of these four habitats are represented in Figure 1.

Figure 1: four types of plots around a ConFoBi area: forest (a), path (b), road (c), and edge (d). Picture taken on 23 March 2023 for path and road, and on 23 May 2023 for forest and edge.

Then, the plot selection was done in QGIS, with spatial data of roads and forest land use, from the study area available in Geofabrik (Geofabrik GmbH, 2023). Copernicus 2018 data with 10 m resolution were used for the canopy cover (Copernicus Service information, 2020). This information was checked on the field during preliminary visits to the plots. The selected plots should fit the following criteria:

- Forest plot (Figure 1 a). They correspond to forest interior, with higher canopy cover, at least 200 m away from paved roads and forest edge, and at least 100 m away from any unpaved roads or trail.
- Path plot (Figure 1 b). They are at least 200 m away from paved roads and forest edges, and at least 100 m away from roads.
- Road plot (Figure 1 c). They are at least 200 m away from paved roads and forest edges.
- Edge plot (Figure 1 d). Edge of the forest, facing meadow, pasture, or cropland. If the location does not offer this possibility, facing an unpaved road (for one edge plot) or a very low traffic paved road (no car seen during each 20 min visit, and defined as “track” or “unknown” in Geofabrik data, for two edge plots).

Finally, the plot selection aimed at grouping four plots of four different types in areas of about 1 km radius (around ConFoBi areas), to make the design logistically accessible while keeping a balanced selection. These four plots had to be at least 300 m apart to consider the bird counts as independent (Bibby et al., 2000; Sutherland et al., 2004). This criterion was set aside only once due to the geography of an area.

With these criteria, 11 areas (Figure 2), each containing four plots (forest, path, road, and edge) were selected. Four plots of one area are shown in Figure 3.

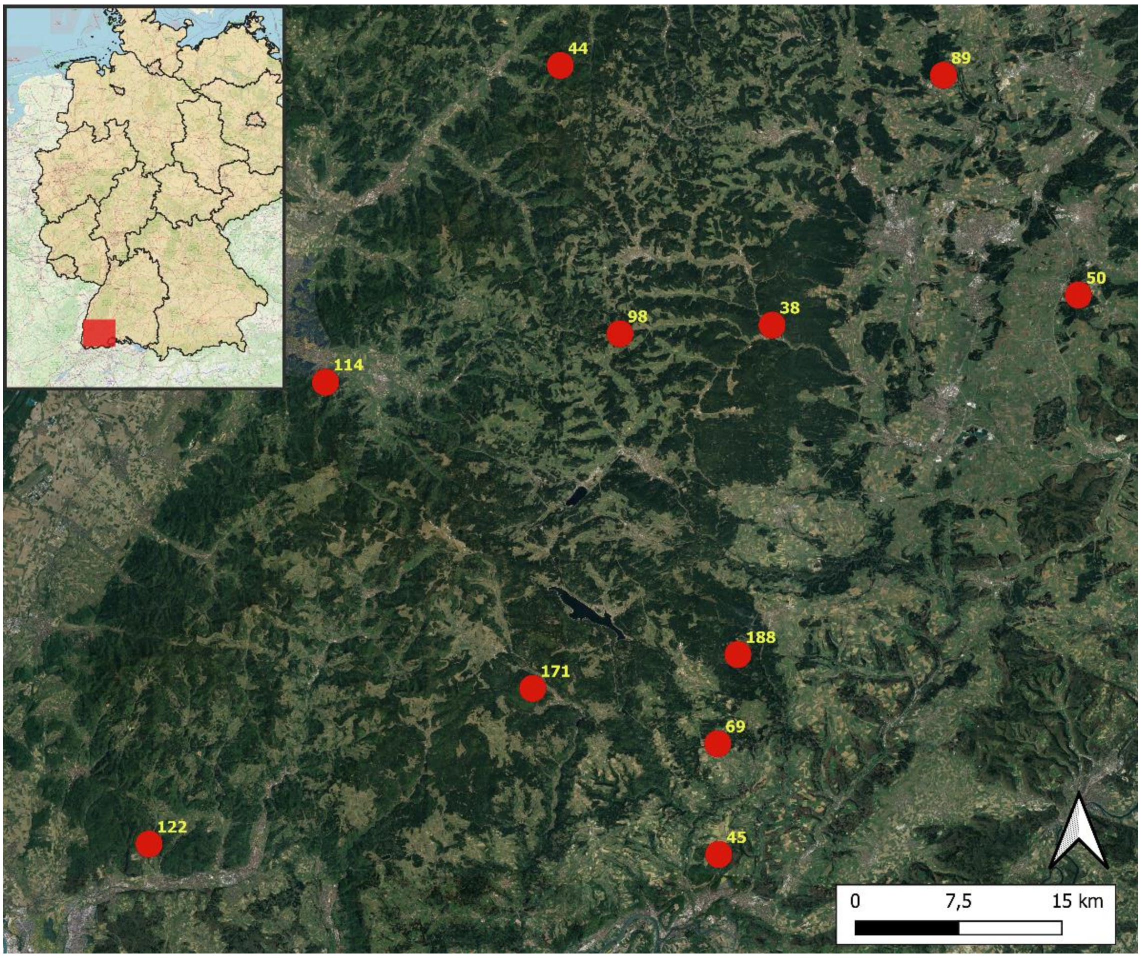

Figure 2: Area selection corresponding to 11 ConFoBi areas. Each of these 11 areas contains 4 plots. The numbers correspond to the ID in the ConFoBi project, and this ID will be used as well in this project.

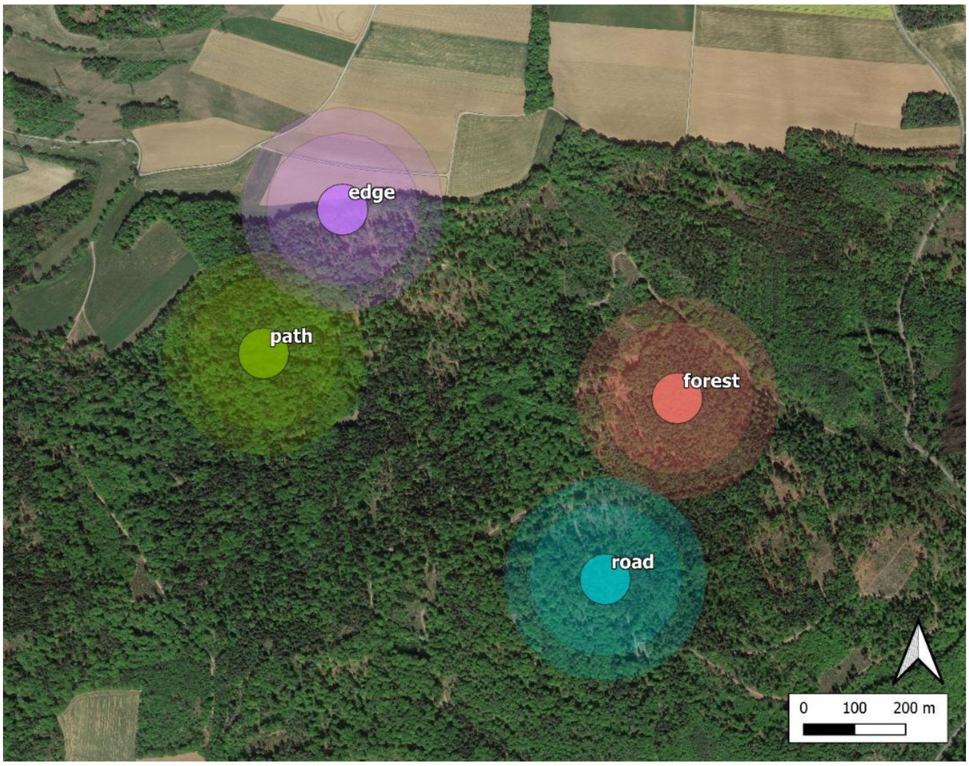

Figure 3: Four plots selected around an area. The points have a 50 m radius as limit for bird observation. The first buffers have a radius of 150 m: these buffers shouldn't overlap to keep 300 m between plots. The largest buffers have a radius of 200 m: path, forest, and road are at least 200 m away from forest edges or roads.

2.3 Bird count

Birds were counted using standardized point count in 50 m radius plots. The observer was located at the centre of the plot and recorded the species of each individual seen or heard in a 50 m radius over four consecutive five-minute intervals (Balestrieri et al., 2017; Bibby et al., 2000; Sutherland et al., 2004). The abundance was assessed by the maximum abundance recorded in five minutes, among the four intervals, for each species. Each plot was visited twice, with at least seven days between the two visits. The order of the visits to the areas and the order of the plots in the area were randomly selected and, in some cases, adapted for logistical reasons. The choice of the observer was randomly chosen when two observers participated in the survey of the four plots for an area. The four plots in each area were always recorded on the same day. The point counts were carried out between sunrise and midday and between 17 April 2023 and 23 May 2023.

The final bird sampling comprises 88 bird samplings: two visits on four plots in 11 areas.

2.4 Data analysis

2.4.1 Overviews and basic analysis

In the analysis, presence/absence data was mainly used, as this data is supposed to be more reliable considering the method of point count used (Haila, 1988). The analysis was conducted on R version 4.2.1 (R Core Team, 2023), with the package `vegan` (version 2.6.2) and `ggplot2` (version 3.4.1) for the graphical visualization.

The Shannon Index (H') was computed using the package `vegan`. Tukey tests were applied to assess differences between groups in models (Zar, 2010). The Tukey tests on species richness and total abundance are based on a Poisson regression model of the species richness and total abundance, respectively, in the visits, depending on the type of plot, using a random effect for the area visited. The same method was applied for the Tukey test on Shannon Index, replacing the Poisson regression with a Gamma regression.

2.4.2 Community analysis

The dissimilarity index used in the community analysis is the Jaccard Index of Dissimilarity from the package `vegan`. It is defined, between two surveys, as the number of species in one survey and not in the other, divided by the total number of species in the two surveys combined. This allows more precise information instead of aggregated indices such as species richness, total abundance, or Shannon Index. The Tukey test on Jaccard dissimilarity Index is based on an ANOVA model of the Jaccard dissimilarity Index between two surveys depending on the pair of type of plots, using a random effect for the pair of area.

A Non-metric MultiDimensional Scaling (NMDS) analysis was applied to visualize the dissimilarities between surveys in a 2-dimension figure (Clarke, 1993), using the package `vegan`, with the function `metaMDS` and `ordiellipse` for confidence ellipses (Faith et al., 1987; Minchin, 1987). In an NMDS representation, the more similar two surveys are for the dissimilarity index, the closer they are in the plane. An ANOSIM (Analysis of similarity) was used, with the function `anosim` from the package `vegan`, to test the differences between groups from distances between individuals (here, dissimilarities between bird communities per survey). It assesses if a significant difference exists between two or more types of plots represented in the NMDS (Clarke, 1993; Warton et al., 2012). This method considers the ranks of surveys, ordered by dissimilarities from each other. Then, it tests whether ranks within groups are lower than average. An Indicator species analysis was conducted, using the function `multipatt` from the package `indicspecies`, to find species that could explain the differences between groups. This method estimates the strength of species associations with some types of plots (Cáceres and Legendre, 2009).

2.4.3 Functional analysis

The traits used in the functional analysis are taken from AVONET database (Tobias et al., 2022). Tukey tests were also applied on different quantitative functional traits, depending on the groups of species. These Tukey tests are based on a Gamma regression model of the species' quantitative functional traits depending on the species' group preference (defined in section 3.5).

Finally, additionally to investigating species level, an analysis of plot's mean traits was conducted. The mean of a quantitative functional trait of species (mass or hand wing index), weighted by the abundance observed for each species, were computed. It provides an average mean of a functional trait for each plot, on which a gamma regression was applied, depending on the type of plot. Then, a Tukey test was applied to compare the types.

All the scripts are available on the following GitLab repository: https://gitlab.com/RaphBnrd/20230412_freiburg_mscthesis_data_analysis.

3 Results

3.1 Overview of the count data

The total number of individual birds recorded within 50 m during the 88 visits was 1388. These observations represent a total number of 46 species. Detailed list and global visualizations of these data can be found in Appendix 1, Appendix 2, and Appendix 3.

The accumulation of the number of species observed varies among plots (Figure 4). The mean rate of increase (species richness for both visits, divided by the species richness for the first round of visits) varies between 1 and 2.4, with a median of 1.374. Reducing this rate would have required additional visits, which was logistically impossible due to the changing of the seasons. However, the accumulation seems similar between types of plots as represented in Figure 4. Furthermore, an ANCOVA was applied to test on the accumulation rate, using final species richness and types of plots as explanatory variables. The accumulation rate does not significantly vary depending on the species richness during the first visit and on the type of plot ($p > 0.05$), as reported in Table 1 (with its visualisation in Appendix 4). The associated R-squared is 0.08561. The p-value of the test of the model using the F-statistic is 0.8416. Finally, the ANOVA type II test reports p-values of 0.6093, 0.9963, and 0.4044 for the effects of species richness, type of plot and the interaction of species richness and type respectively.

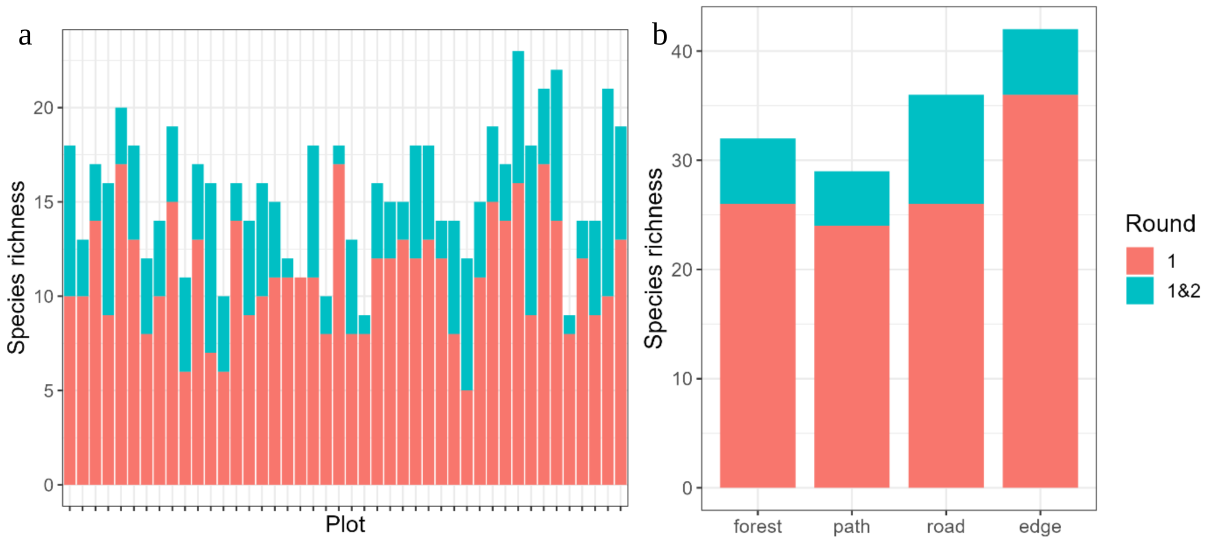

Figure 4: Stacked bars of the species richness recorded during the first and during both two visits, (a) for each plot, and (b) for each type of plot. Red bar represents the species richness during the first round of visits, additional blue bar represents the additional species richness from the second visits (the sum of red and blue bars represents the total species richness, during both two visits).

Table 1: Summary of the ANCOVA model on the accumulation rate using the final species richness and type of plot as explanatory variables (stands for p-values under 0.05, ** under 0.01 and *** under 0.001).*

	Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	1.991	0.578	3.448	0.00146 **
Total species richness (visits 1 and 2)	-0.034	0.036	-0.950	0.34839
Type path	-0.965	0.774	-1.247	0.22031
Type road	-0.234	0.836	-0.280	0.78099
Type edge	-1.082	0.743	-1.456	0.15398
Total species richness per Type path	0.062	0.050	1.228	0.22747
Total species richness per Type road	0.013	0.055	0.245	0.80795
Total species richness per Type edge	0.065	0.044	1.483	0.14676

The surveys show variability in the type and the number of plots of occurrence depending on the species (Figure 5). No species were observed only in forest. Five species were observed only in one type of plot, all of them in edges (Eurasian Skylark, Fieldfare, Yellowhammer, Rook, and Hooded crow). Abundant species were observed in each type of plots, but with a variability of the distribution in occurrences.

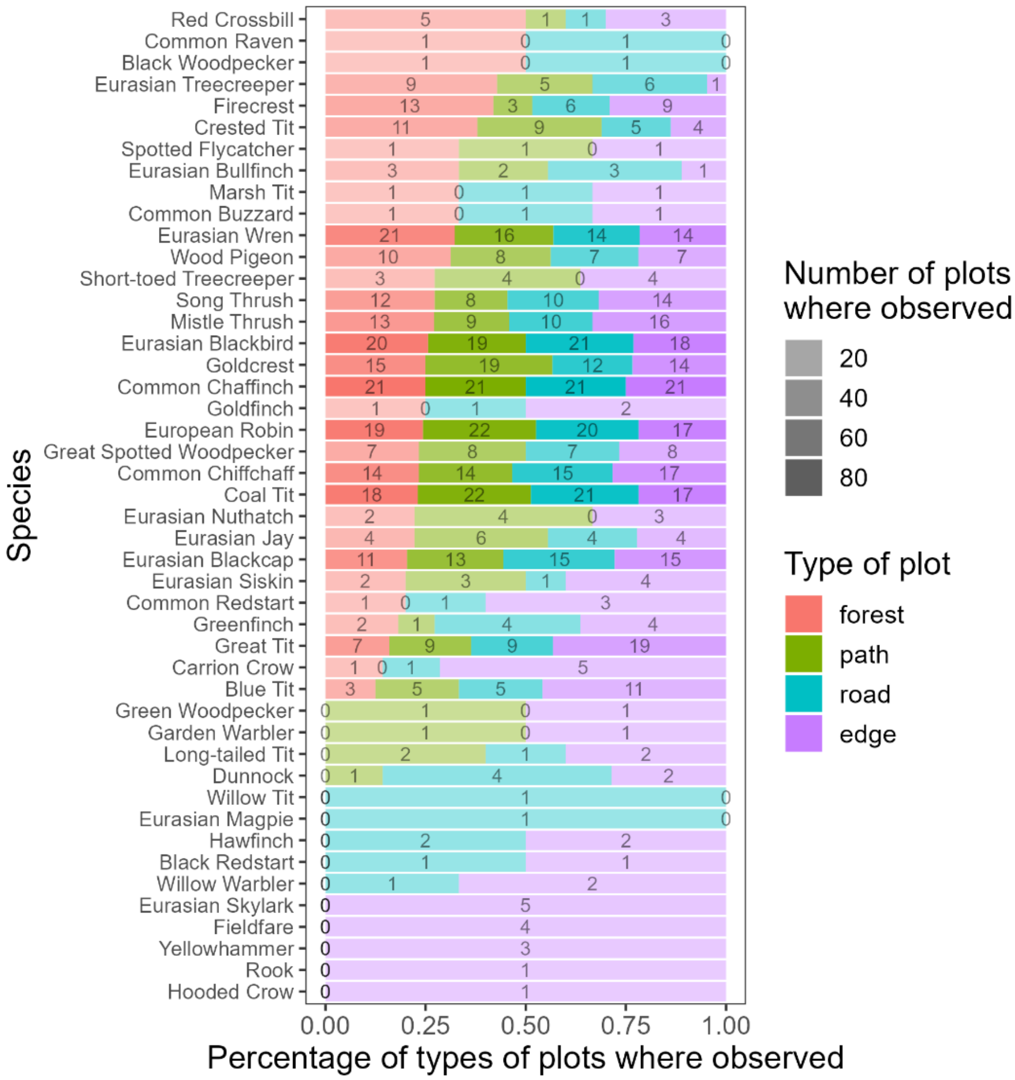

Figure 5: Occurrence of species depending on the type of plot. Colours represent types of plots. Transparency represents the total number of plots where the species was observed.

3.2 Global effect on the community

The Tukey tests report that species richness and total abundances doesn't significantly differ between forest, path, road, and edge (Figure 6 a-b, and Appendix 5 and Appendix 6). However, the Shannon Index value decrease in paths and roads compared to edges. The forest's Shannon Index is somewhere in between (Figure 6 c, and Appendix 7).

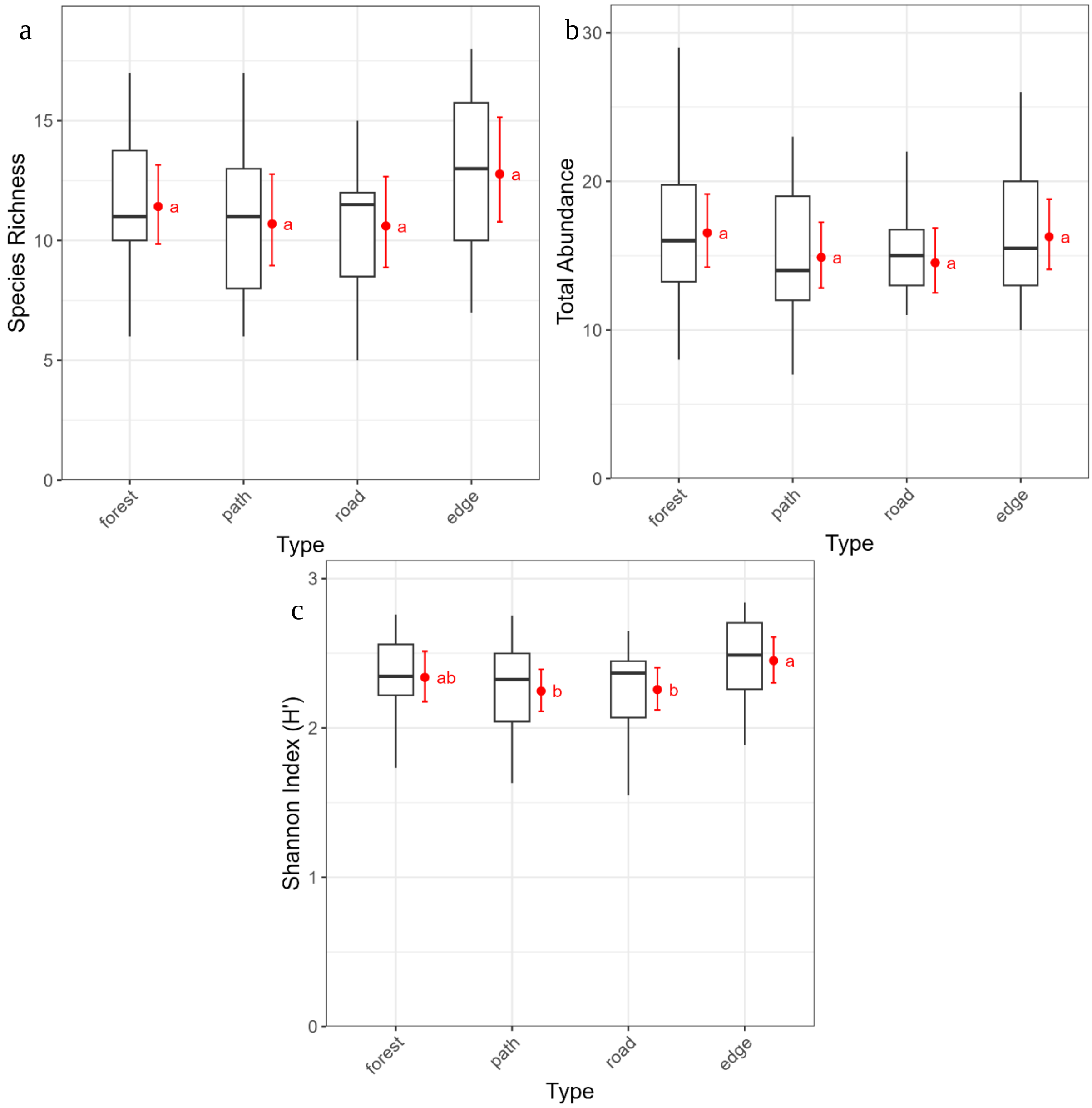

Figure 6: Tukey test on Species richness (a), Total abundance (b), and Shannon Index (b) depending on the type of plot, with the area as a random effect. Boxplots are the observed indices. Red dots and error bars represent (estimated marginal) means with 95% confidence interval per group. The detailed pairwise comparisons of the Tukey test are in Appendix 5, Appendix 6, and Appendix 7.

3.3 Community analysis – dissimilarities

Figure 7, representing the Tukey test on the Jaccard Index of Dissimilarity depending on the pair of types of plots, provides some results:

- Dissimilarities involving edges are significantly higher than others.
- Dissimilarities between road or path and forest are significantly lower than those between edge and forest.
- The lowest dissimilarities concern those between two paths. The three lowest only involves paths and forests.

- Dissimilarities road-forest are not significantly higher than those path-forest. Both are not significantly different from dissimilarities forest-forest.
- Dissimilarities edge-edge and road-road are significantly higher than path-path and forest-forest.

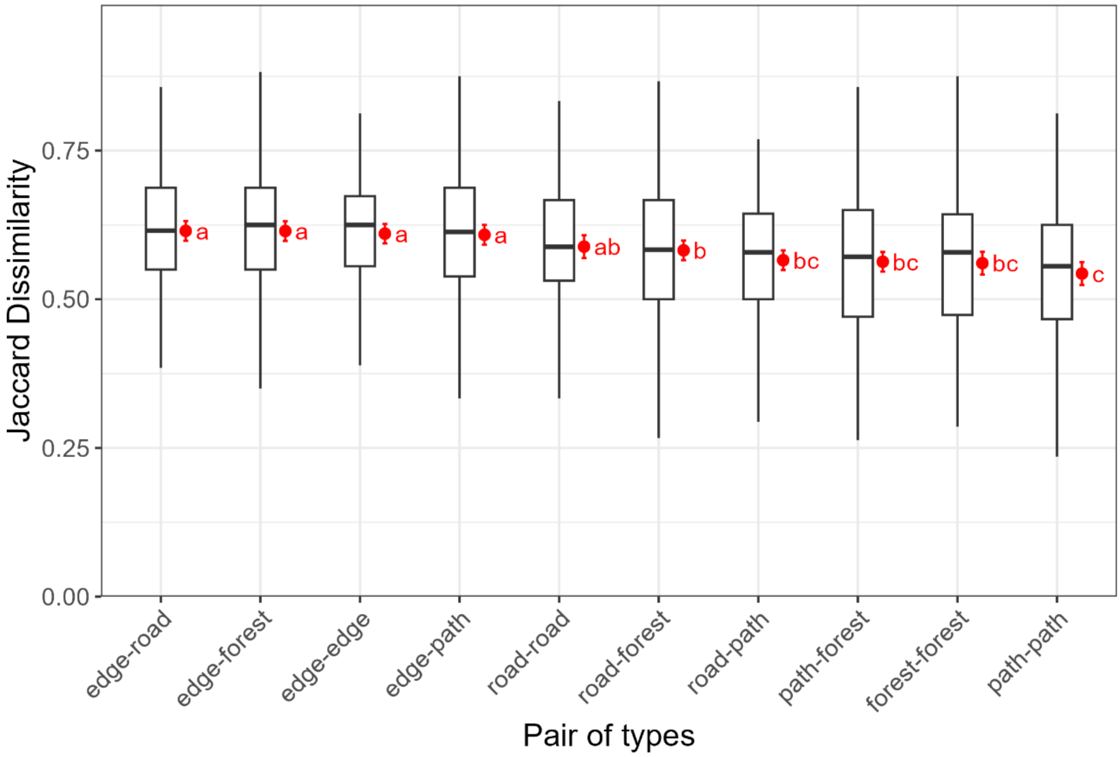

Figure 7: Tukey test on the effects of the pair of types of plots on the dissimilarity with the Jaccard Index of Dissimilarity on presence/absence data, with the pair of areas as a random effect. Boxplots are the observed Jaccard dissimilarities. Red dots and error bars represent (estimated marginal) means with 95% confidence interval per group. The detailed pairwise comparisons of the Tukey test are in Appendix 8.

The NMDS in Figure 8 shows a representation of the similarities between plots. In this visualisation, the confidence ellipses representing forest, path, and road overlap, while the one representing edge is more distinct. It reflects the fact that edges could be dissimilar to other types.

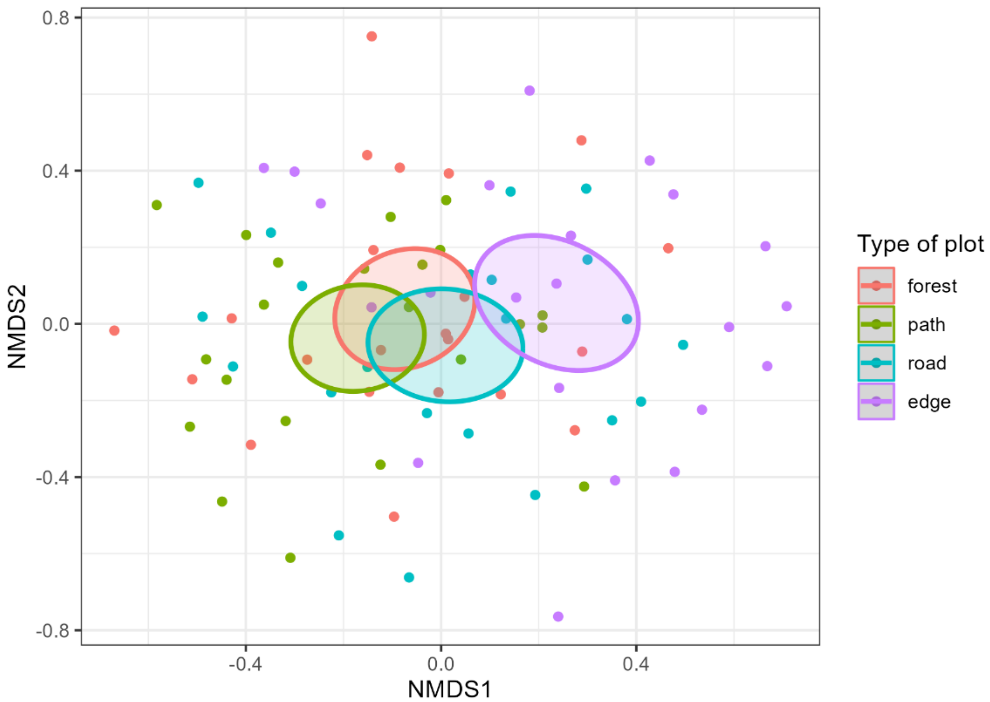

Figure 8: NMDS representation of plot (in 2 dimensions) coloured by type of plot. The ellipses represent the 95% confidence interval around groups. The colours represent the types of plots: red for forest, green for path, blue for road, purple for edge.

Table 2 shows the results of ANOSIM tests for all the plots (first row) and restricting the analysis to some types of plots (other rows). All analyses including edges report a p-value < 0.05, whereas others aren't significant. Hence, edges are significantly different from other communities, while it cannot assert a difference between forest, path, and road communities.

Table 2: ANOSIM models with their associated statistic and p-value. Each row reports a model applied on all the data or only using some types of plots specified in the first column (stands for p-values under 0.05, ** under 0.01 and *** under 0.001).*

Types of plots included	**ANOSIM statistic R** (statistic tested, compared to the null-model with random distribution, to get the significance)	**Significance (p-value)**
Forest – Path – Road – Edge	0.082	0.001 **
Forest – Edge	0.169	0.001 **
Road – Edge	0.078	0.017 *
Path – Edge	0.167	0.002 **
Path – Road	0.024	0.199
Forest – Path	0.038	0.118
Forest – Road	0.020	0.234
Forest – Path – Road	0.027	0.113

3.4 A species-specific effect

With a significance threshold of 0.05, the Indicator Species Analysis reveals nine Indicator Species. For the forest plots, the Eurasian Wren (p-value = 0.008) represents the only indicator species. For forest and path, Goldcrest and Crested Tit (p-values: 0.002, 0.043) are the two indicator species. The indicator species for edges are six: Blue Tit, Eurasian Skylark, Great Tit, Fieldfare, Yellowhammer, and Carrion Crow (p-values: 0.002, 0.002, 0.002, 0.017, 0.047, 0.027 respectively).

To assess what local effect the habitat could have on each species, logistic models were applied to the probability of presence, depending on the type of plot. These models were fitted on all the possible partitions of the set of types, to test all the groups of types (all the 15 possible partitions, from one group “forest-path-road-edge” to four groups “forest”, “path”, “road”, “edge”, and the partitions with two or three groups). Then, for each species, the best model was selected considering the lowest AIC (among all the possible partitions of types). These best models selected from the logistic models on the probability of presence are represented in Figure 9. For 12 species, the best model was the one with only one group (corresponding to the model without an effect of the type of plot). For all the other species, the best model was for two groups. A positive effect of the type of plot is represented in blue, and a negative one is represented in red in Figure 9. The responses to habitats vary among species.

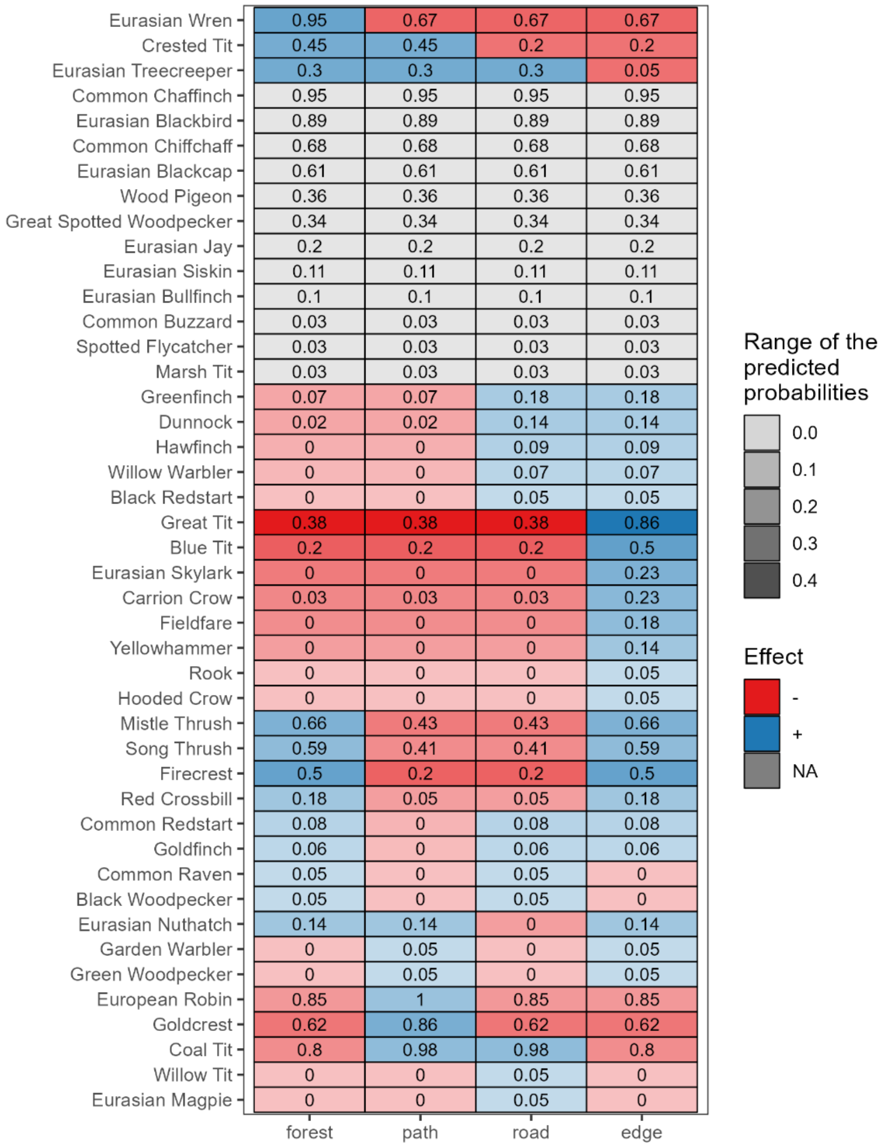

Figure 9: Fitted probability of presence depending on the type of plot, for each species, with the model having the lowest AIC among all the possible partitions in the set of types of plots. Since the maximum number of groups found is two, a red box represents a lower probability for the concerned species, while a blue box represents a higher probability. A grey box represents no effect of the type of plot. The transparency of the box is related to the range of probability.

3.5 A functional understanding of the effect

From the best models selected in section 3.4, five groups were identified to assess the functional trait with an ecological meaning:

- *Forest favouring species*: more probable in forest, forest-path, or forest-path-road compared to others,
- *Edge favouring species*: more probable in edge, road-edge, or path-road-edge compared to others,
- *Road/path favouring species*: more probable in path, road, or path-road,
- *Road/path reluctant species*: less probable in path, road, or path-road,

- *Uninfluenced species*: no effect of the type of plot on the probability of presence.

The tests on the mass shows a significantly higher mass for *edge favouring species* and *uninfluenced species*, compared to *forest favouring species* (p-value < 0.05). *Road/path favouring species* and *road/path reluctant species* lies between these (Figure 10 a). Similar patterns appear for the hand wing index (HWI), except no significant difference between the group of *uninfluenced species*, and the group of *forest favouring species* (Figure 10 b).

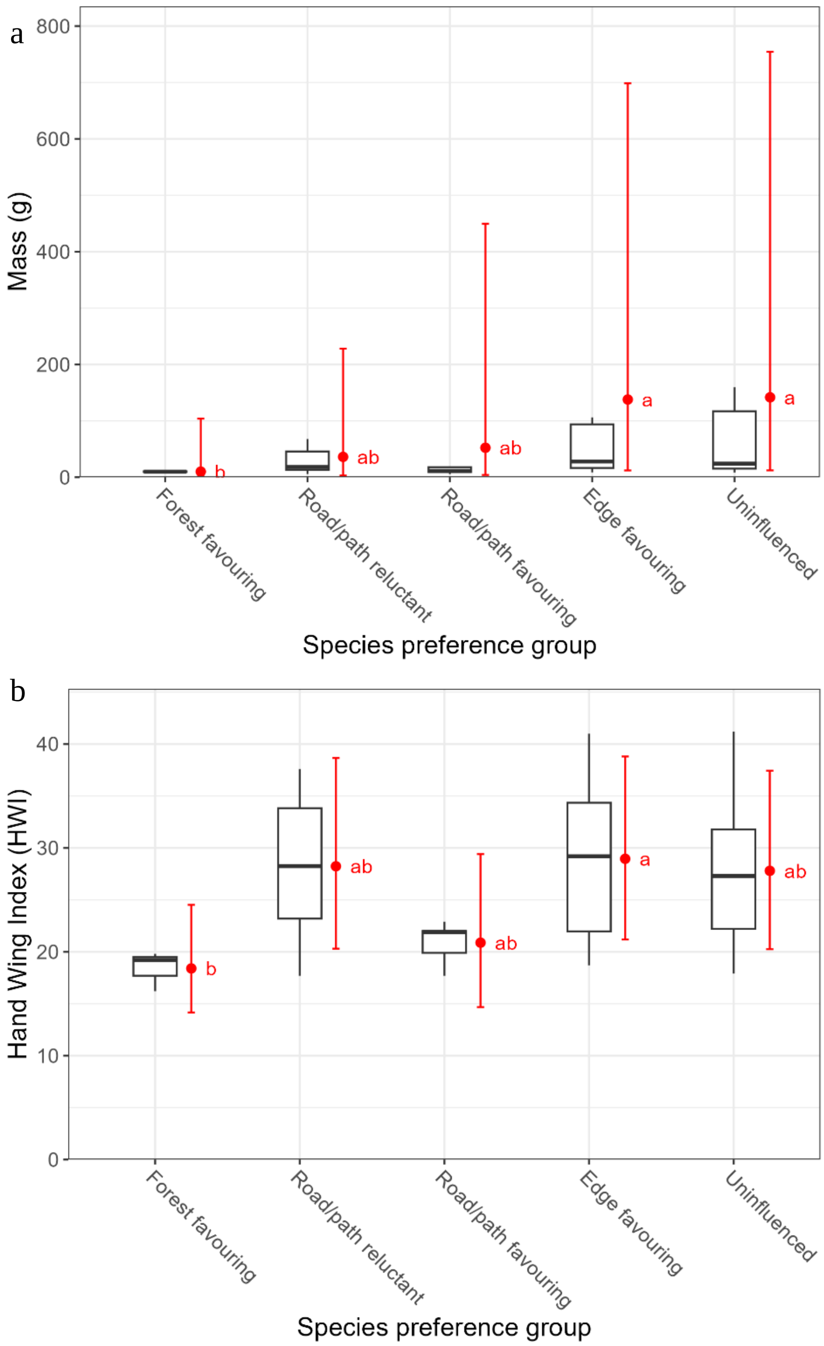

Figure 10: Tukey test on the mass (a) or the hand wing index (b) of species depending on the species preference group. Boxplots are the raw masses (a) and hand wing indices (b). Red dots and error bars represent (estimated marginal) means with 95% confidence interval per group of species. The detailed pairwise comparisons of the Tukey test are in Appendix 9 and Appendix 10.

Finally, focusing on plots' mean functional traits, the mean mass observed is significantly lower in paths compared to edges (Figure 11 a), and the average hand wing index is significantly higher in edges compared to others (Figure 11 b).

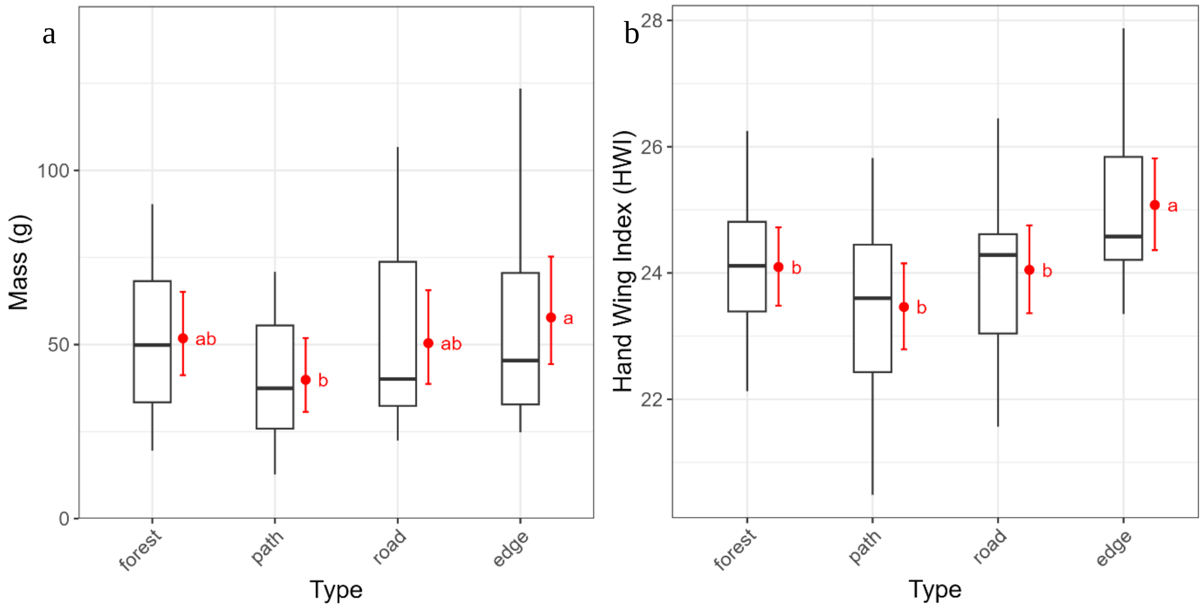

Figure 11: Tukey test on the weighted mean mass (a) and hand wing index (b) on a plot depending on the type of plot. Boxplots are the observed means. Red dots and error bars represent (estimated marginal) means with 95% confidence interval per type of plots. The detailed pairwise comparisons of the Tukey test are in Appendix 11 (mass) and Appendix 12 (hand wing index).

4 Discussions

4.1 Global effect on the community

The results show that bird's species richness and total abundance are not significantly different between forests, paths, roads, and edges. While the literature finds a strong negative effect on these indicators for high-traffic paved roads (Benítez-López et al., 2010; da Silva et al., 2017; Reijnen and Foppen, 2006), it is not surprising that low-traffic unpaved roads and paths considered in this study do not act as strong direct disturbances for birds. The mechanisms behind the effect of high-traffic paved roads is mainly related to noise or mortality (Kociolek et al., 2011), which are not determinant for low-traffic unpaved roads. However, contrary to Šálek et al., 2010, this study did not find a greater species richness in roads and edges compared to forests. Their study was conducted in "compact and structurally poor stands", where the positive effect of habitat supplementation may outweigh the negative effect of fragmentation. The context of the Southern Black Forest may be different, and therefore lead to a neutral trade-off on species richness and total abundance, potentially due to a slightly more diverse vegetation structure than in their study in Doudlebia, Czech Republic. Furthermore, expanding the number of surveys in the coming years may influence the results.

On the other hand, a higher Shannon index in edges compared to roads and paths has been found. Thus, the results highlight the mechanism of an edge effect in edges, as expected. Nevertheless, the hypothesis of a mechanism of an edge effect in roads and paths that would increase bird diversity by an increased heterogeneity compared to forests, is not supported here. As an explanation, paths do not allow light to enter the canopy, and they only present a less dense shrub layer compared to the forest. This may result in a decreased heterogeneity of habitats and resources for birds. Concerning roads, the gap in the canopy influences the herbaceous or shrub layer (see Marta Cardini's Master Thesis, Freiburg University – ConFoBi, 2023), but this effect may be too weak to significantly overcome the negative effect of fragmentation and habitat loss, due to the gravel road and the gap between tree stands (Johnson et al., 2017). In addition, the spillover effect in edges, enabled by the interface between two different habitats, might be the main driver of the edge effect. This spillover is not possible on roads, where there is only one type of habitat (a forest stand facing another forest stand).

4.2 Community analysis and a species-specific effect

Species respond differently to the four habitats assessed (Figure 5), which indicates a species-specific effect of roads. Some species are only found in edges, while other species are generally found in different types of plots. Therefore, this suggests that edges are more different habitats than the three others. Furthermore, the community analysis shows that dissimilarities involving edges are higher than others. Thus, edge communities are more different from other types, and even edges differ among them. In addition, dissimilarities between road or path and forest are significantly lower than those between edge and forest. This outcome does not support a similar modification of forest communities with the presence of a road or a path compared to an edge. Once again, the hypothesis of an edge effect mechanism in roads and paths is not supported, as dissimilarities between edges and roads are high.

The dissimilarities between paths and paths are the lowest. It indicates that communities among different paths are not very different, which could be explained by the fact that paths contain simple vegetation structures (tree canopy with a similar share of coniferous and broadleaves compared to other types of plots, poor herbaceous layer, and no shrub layer). In addition, the lowest dissimilarities are path-forest, forest-forest, and path-path, which means a reasonably small modification of the bird communities with a path in a forest habitat.

The dissimilarities between roads and forests are not significantly higher than those path-forest. Thus, this study cannot notice a different magnitude in the modification of the bird communities between roads and paths compared to forests. This may also reflect a small magnitude of modification, considering that both dissimilarities road-forest and path-forest are not significantly higher than forest-forest. Finally, the dissimilarities edge-edge and road-road are higher than forest-forest and path-path, reflecting the greater variability in communities among edges or roads, compared to forest or path where the communities are more similar.

The NMDS analysis confirms the previous remarks. Edges seem different from the remaining habitats evaluated, and roads and paths are not clearly acting as involving an edge effect from forest structures. Indeed, the ANOSIM reveals different communities between edges and the three other types. It may be interpreted that roads and paths do not behave like edges but mainly as forest-related habitats. Again, these results cannot highlight an edge effect mechanism from the types of roads studied, potentially because the edge effect observed in edges is led by a spillover effect, which cannot occur in roads and paths. The hypotheses of vegetation simplification for paths, and habitat change for roads should be favoured. However, the magnitude of these effects is not significant compared to forest.

Lastly, focusing on indicator species analysis, no indicator species for roads were observed. Thereby, roads may not provide a specific habitat for some species and may not host specific species. Hence, the hypothesis of habitat loss may still be consistent (Fahrig and Rytwinski, 2009). On the other hand, the Eurasian Wren turned out as an indicator species for the forest, which highlights the sensitivity of this species regarding the forest habitat. Goldcrest and Crested Tit are indicator species for forest and path. This supports the idea of similarity between forests and paths, at least for these two species. And finally, six species are indicator species for edges. It also points out the variety of types of edges and how different it could be from other types, at least for these six species. The indicator species found are consistent with their ecology: forest specialist species were found as forest or path indicator species, and open land, opportunistic, or non-human-sensitive species were found as edge indicator species.

4.3 A functional understanding of the effect

The functional analysis using body traits shows *forest favouring species* are lighter and smaller (mass and hand wing index) than *edge favouring species*. Species affected positively or negatively by roads and/or paths lie somewhere in between. A similar result comes with the weighted means of functional traits per visit. These results do not seem conclusive for a road effect on functional traits. These functional traits in roads and paths are similar to those in forests. The difference on the edges could be explained because smaller birds may prefer closed areas, to reduce predation and nest predation, as a trade-off with reduced resource availability

(Robinson et al., 1995; Turney and Godin, 2014). Furthermore, a higher hand wing index is associated with a higher dispersal ability (Sheard et al., 2020). It is consistent with the results, where more mobile species may favour edges, to benefit from the possibility of a spillover.

4.4 Perspectives

This study aimed at understanding the mechanisms behind the effect of roads on bird communities. The results could not support a mechanism such as an edge effect, due to an opening in a forest stand with an unpaved forest road. The effect of roads may be related to habitat loss instead of the creation of heterogeneity and suitable habitats. However, paths did not seem to create disturbances. It slightly reduces the bird diversity, probably by simplifying the vegetation structure, but the resulting habitats remain similar to forest interior. Finally, no clear difference was observed in bird mass and hand wing index between forests, roads and paths, while species in edges were found bigger and heavier, probably related to the openness of the habitat and the spillover in the adjacent habitat.

This study focused on the local effect of roads. However, the question arises as to whether an effect of roads at a landscape scale may impact bird communities. As mentioned in the literature, higher total length of unpaved roads in the landscape could reduce the species richness (Mammides et al., 2016). Further analysis should be conducted in the ConFoBi project, to try to identify a potential effect of unpaved roads in the landscape. Preliminary results have been tested, for example on species richness found in ConFoBi plots, depending on the length of roads in a 1000 m radius around plots (using road data from Geofabrik and analysing in QGIS with statistical analysis in R). A Poisson regression model reported a significant relation between species richness and length of roads in a 1000 m radius (Table 3). However, this effect in the model is very low (-1.95×10^{-6} species per meter of road in the 1000 m buffer).

Table 3: Summary of the Poisson regression model on the species richness depending on the length of roads in a 1000 m radius (stands for p-values under 0.05, ** under 0.01 and *** under 0.001).*

	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	2.191	0.036	60.110	0 ***
Length of roads in a 1000 m radius	-1.948e-06	8.408e-07	-2.316	0.021 *

A deeper analysis may report results, focusing on bird communities, and using different methods to analyse the communities in a gradient of length of roads in the landscape (Anderson et al., 2011).

5 Conclusion

Understanding the effect of unpaved roads could improve the knowledge of bird species responses to habitat changes, also considering functional aspects. While this study tried to identify mechanisms behind a potential road effect, experimental designs such as “before and after control investigation” may better inform on a road effect (Johnson et al., 2022). However, these experiments are more difficult to set up in practice. Furthermore, progress in the study of the effect of roads and paths could inform conservation and forest management strategies, by identifying some habitats as suitable or not for some species and adapting the forest landscape planning.

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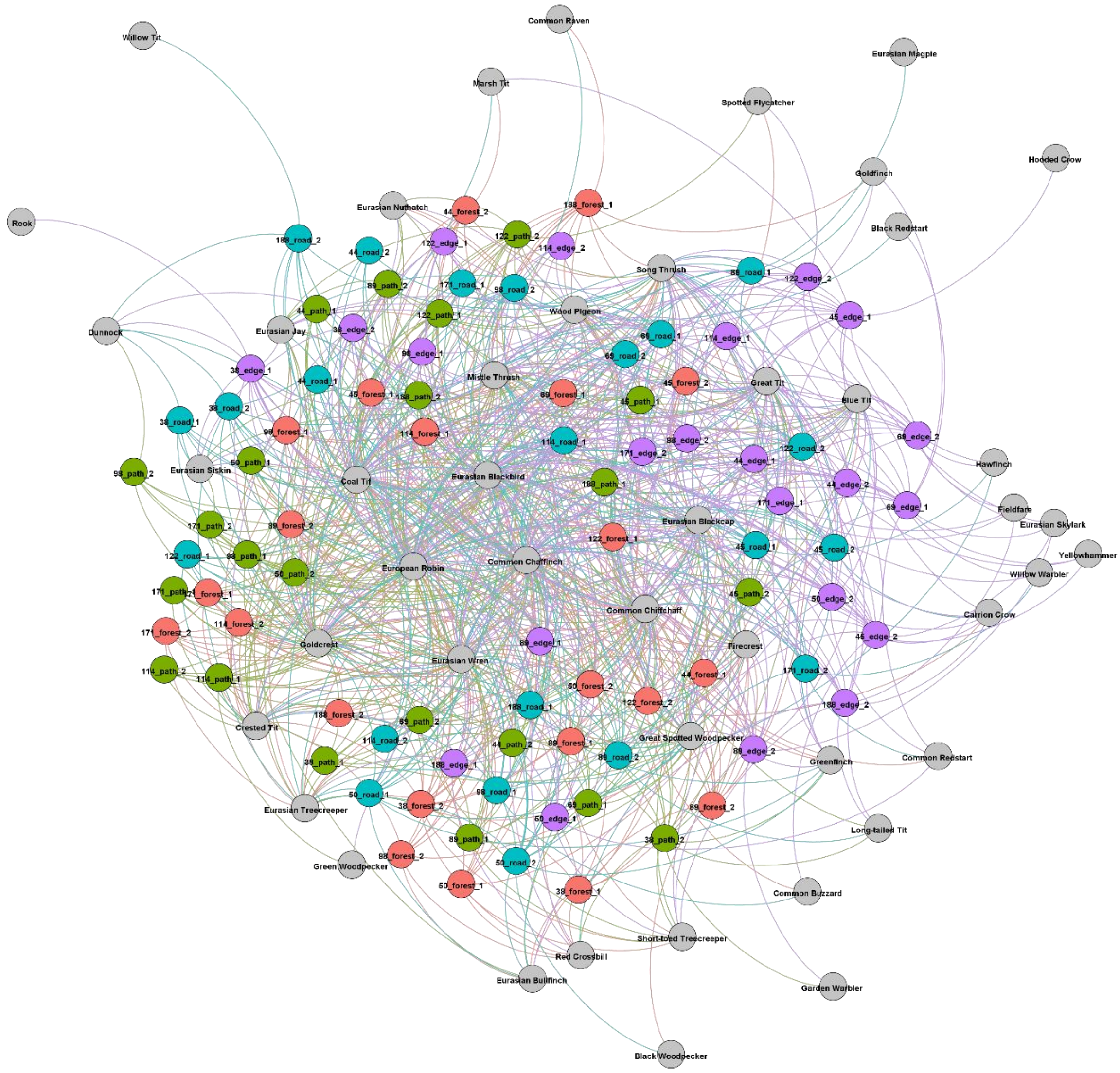
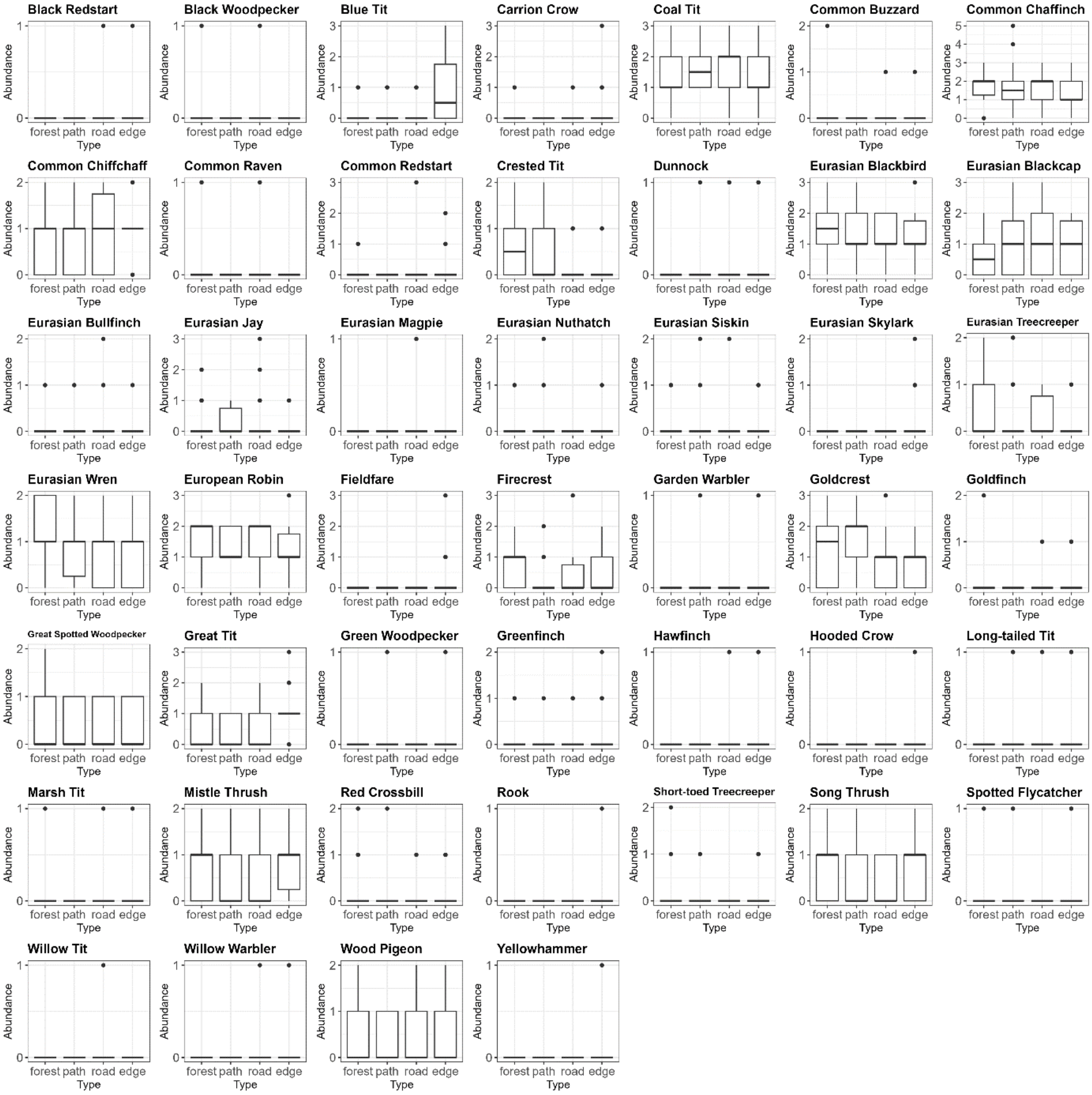
Appendices

Appendix 1: List of species observed

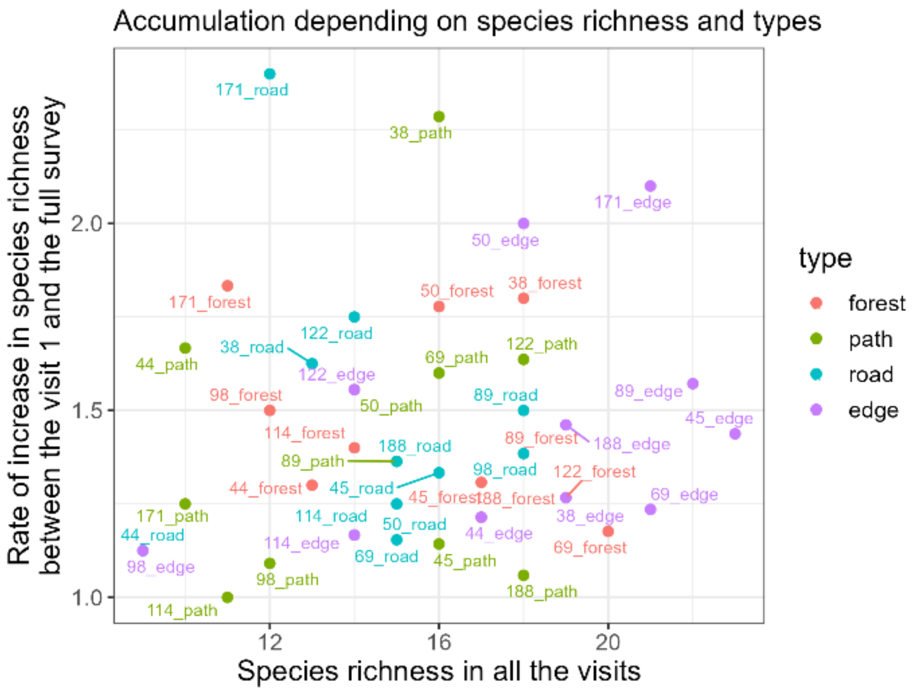
English Name	Scientific Name	Number of observations (total abundance)	Number of plots where observed (total presences)
Black Redstart	Phoenicurus ochruros	2	2
Black Woodpecker	Dryocopus martius	2	2
Blue Tit	Cyanistes caeruleus	31	24
Carrion Crow	Corvus corone	9	7
Coal Tit	Periparus ater	126	78
Common Buzzard	Buteo buteo	4	3
Common Chaffinch	Fringilla coelebs	155	84
Common Chiffchaff	Phylloscopus collybita	79	60
Common Raven	Corvus corax	2	2
Common Redstart	Phoenicurus phoenicurus	8	5
Crested Tit	Lophophanes cristatus	33	29
Dunnock	Prunella modularis	7	7
Eurasian Blackbird	Turdus merula	117	78
Eurasian Blackcap	Sylvia atricapilla	81	54
Eurasian Bullfinch	Pyrrhula pyrrhula	10	9
Eurasian Jay	Garrulus glandarius	22	18
Eurasian Magpie	Pica pica	1	1
Eurasian Nuthatch	Sitta europaea	10	9
Eurasian Siskin	Spinus spinus	13	10
Eurasian Skylark	Alauda arvensis	7	5
Eurasian Treecreeper	Certhia familiaris	24	21
Eurasian Wren	Troglodytes troglodytes	84	65
European Robin	Erithacus rubecula	119	78
Fieldfare	Turdus pilaris	6	4
Firecrest	Regulus ignicapilla	36	31
Garden Warbler	Sylvia borin	2	2
Goldcrest	Regulus regulus	98	60
Goldfinch	Carduelis carduelis	5	4
Great Spotted Woodpecker	Dendrocopos major	32	30
Great Tit	Parus major	54	44
Green Woodpecker	Picus viridis	2	2
Greenfinch	Chloris chloris	12	11
Hawfinch	Coccothraustes coccothraustes	4	4
Hooded Crow	Corvus cornix	1	1
Long-tailed Tit	Aegithalos caudatus	5	5
Marsh Tit	Poecile palustris	3	3
Mistle Thrush	Turdus viscivorus	56	48
Red Crossbill	Loxia curvirostra	13	10
Rook	Corvus frugilegus	1	1
Short-toed Treecreeper	Certhia brachydactyla	12	11
Song Thrush	Turdus philomelos	51	44
Spotted Flycatcher	Muscicapa striata	3	3
Willow Tit	Poecile montanus	1	1
Willow Warbler	Phylloscopus trochilus	3	3
Wood Pigeon	Columba palumbus	39	32
Yellowhammer	Emberiza citrinella	3	3



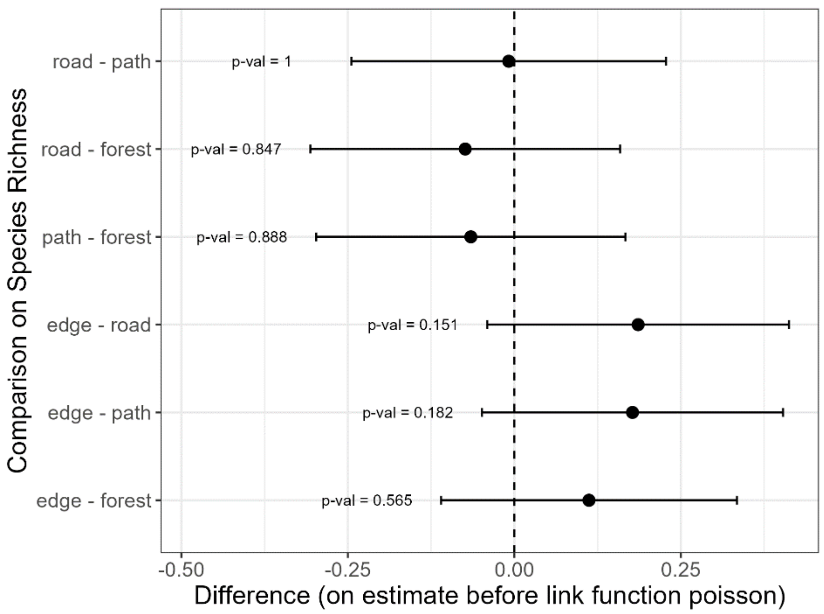
Appendix 2: Network representing the surveys. Grey dots (nodes) represent species. Red, green, blue, and violet nodes represent forest, path, road, and edge plots respectively. A link between a species and a plot represents the presence of this species on this plot. The network is unpacked with Gephi software with the algorithm "ForceAtlas 2" which moves closer the highly connected nodes and moves further away the less connected nodes.



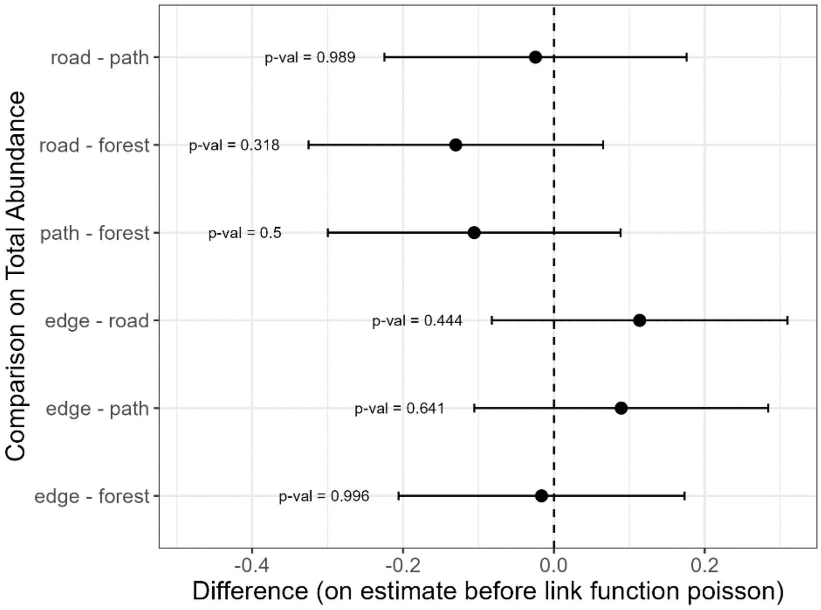
Appendix 3: Boxplot of the abundance observed depending on the type of plot for each of the 46 species observed.



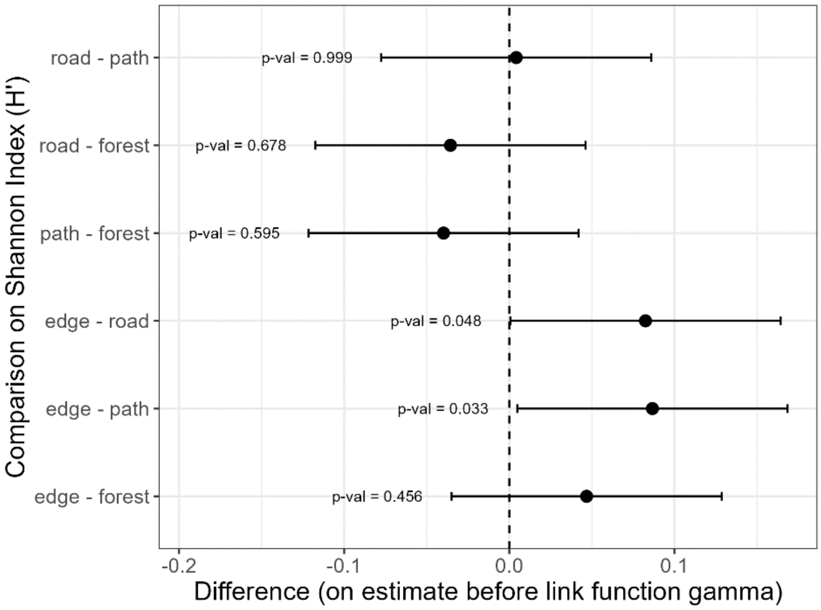
Appendix 4: Rate of increase in the accumulation of species richness, for each plot, coloured by the type of plot. It is the visual representation of the ANCOVA model of the in Table 1.



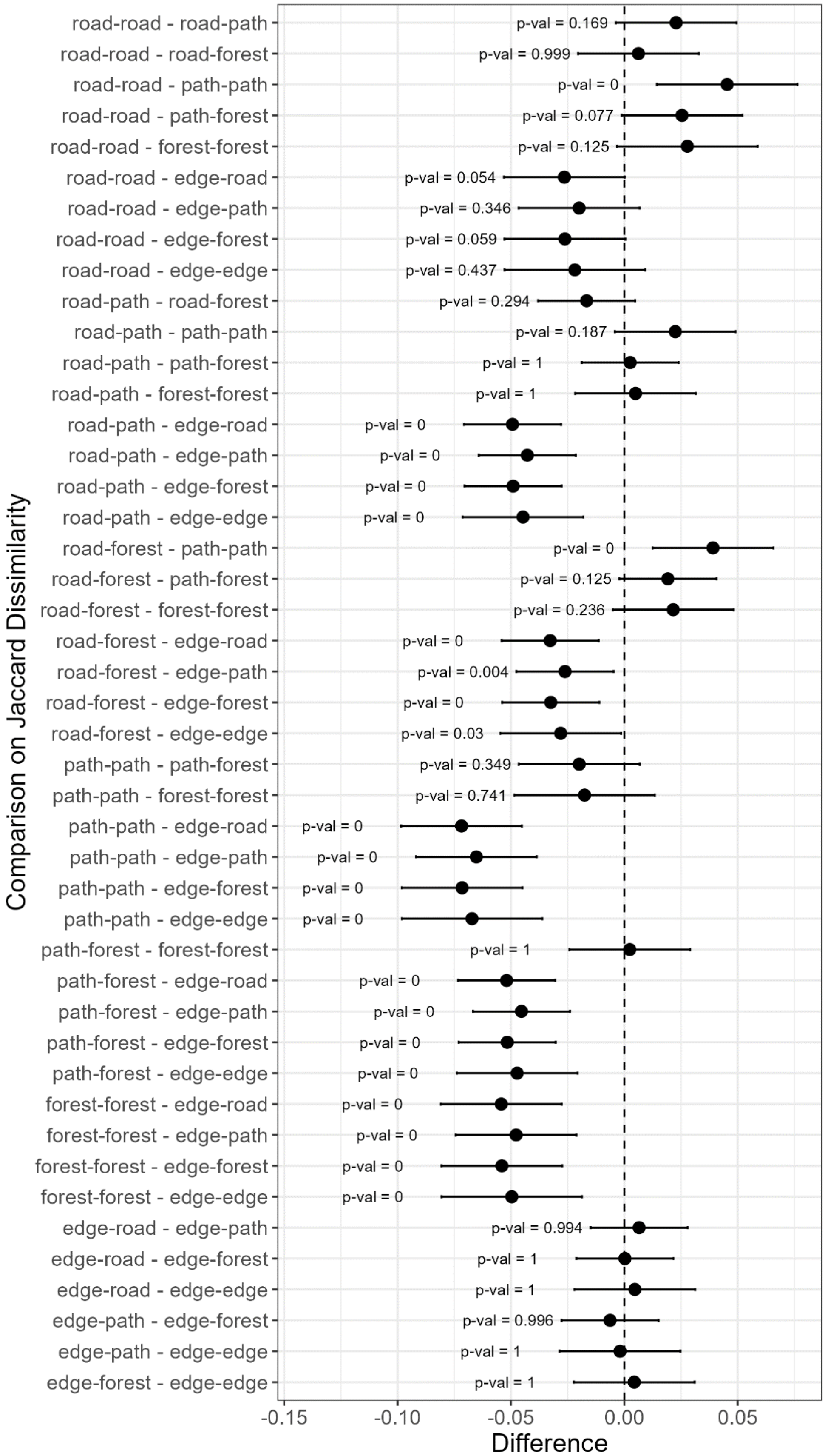
Appendix 5: Pairwise comparisons in the Tukey test of the effects of the type of plot on the species richness (Figure 6 a). The Tukey test is based on a Poisson regression model of the species richness in the visit depending on the type of plot, using a random effect for the area visited. The parameters shown here are the fitted parameters that need to be put in the link function (here exponential) to get the Poisson parameter used to assess the species richness.



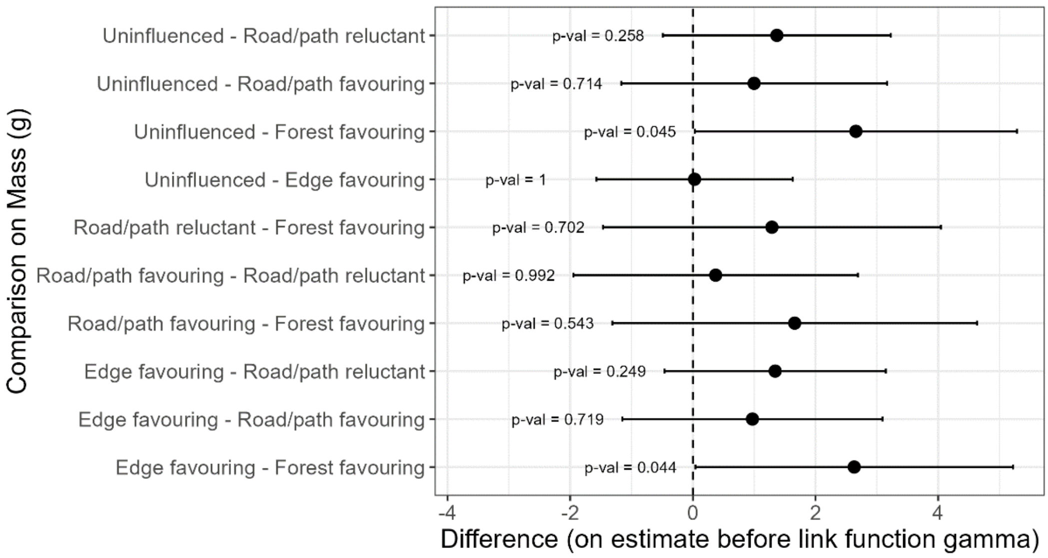
Appendix 6: Pairwise comparisons in the Tukey test of the effects of the type of plot on the total abundance (Figure 6 b). The Tukey test is based on a Poisson regression model of the total abundance in the visit depending on the type of plot, using a random effect for the area visited. The parameters shown here are the fitted parameters that need to be put in the link function (here exponential) to get the Poisson parameter used to assess the total abundance.



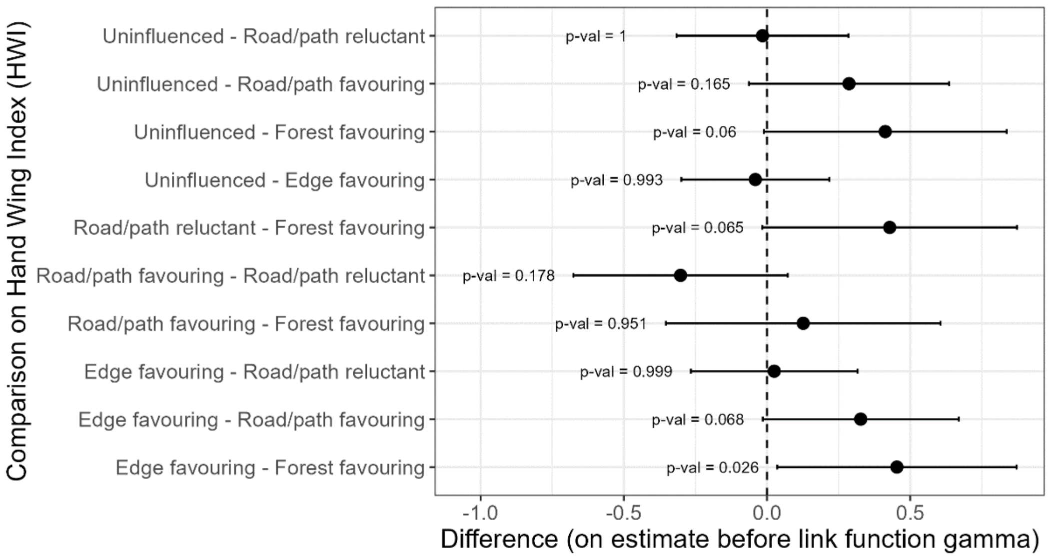
Appendix 7: Pairwise comparisons in the Tukey test of the effects of the type of plot on the Shannon Index (Figure 6 c). The Tukey test is based on a Gamma regression model of the Shannon Index in the visit depending on the type of plot, using a random effect for the area visited. The parameters shown here are the fitted parameters that need to be put in the link function (here exponential) to get the Gamma parameter used to assess the Shannon Index.



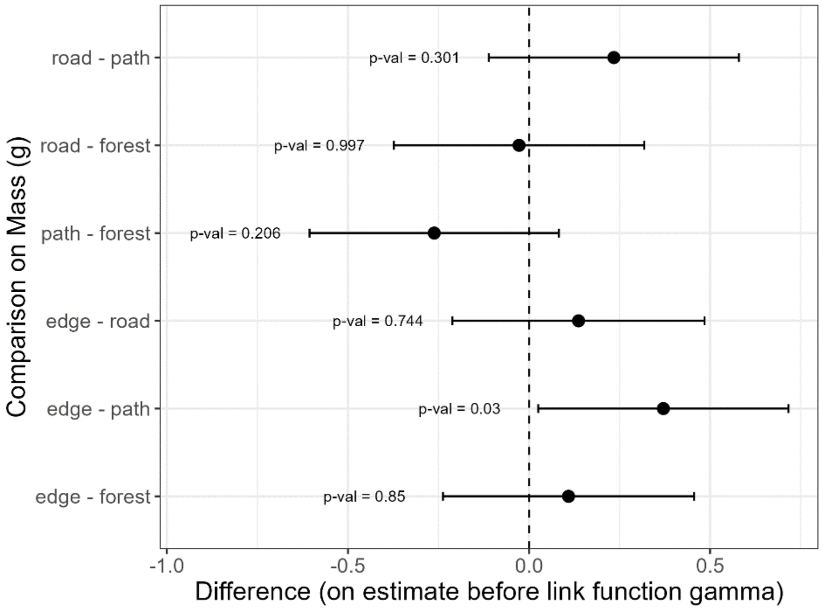
Appendix 8: Pairwise comparisons in the Tukey test of the effects of the type of pair of plots on the dissimilarity with the Jaccard Index on presence/absence data (Figure 7). The Tukey test is based on an ANOVA model of the Jaccard dissimilarity Index between two visits depending on the pair of type of plots, using a random effect for the pair of area.



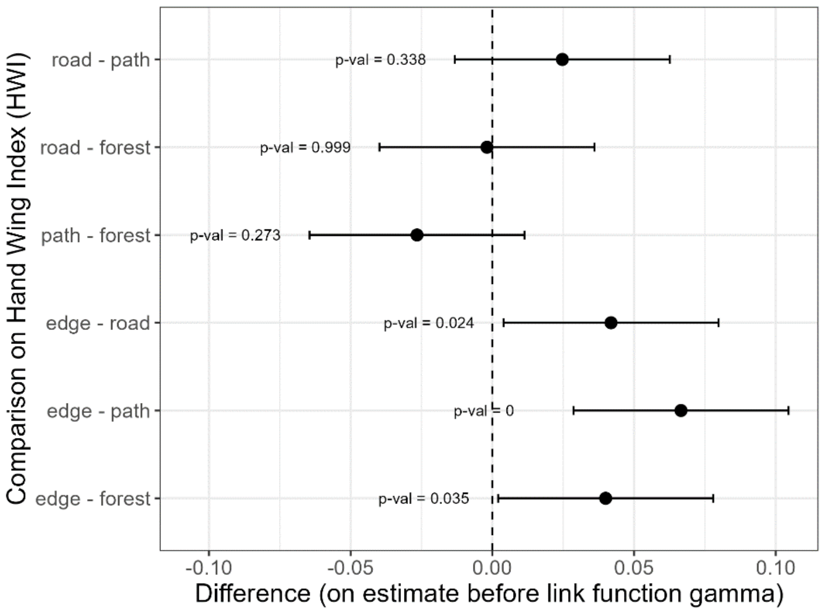
Appendix 9: Pairwise comparisons in the Tukey test of the mass of species depending on the preference of species (see Figure 10 a). The Tukey test is based on a Gamma regression model of the mass of the species depending on the group preference of the species.



Appendix 10: Pairwise comparisons in the Tukey test of the hand wing index of species depending on the preference of species (see Figure 10 b). The Tukey test is based on a Gamma regression model of the hand wing index of the species depending on the group preference of the species.



Appendix 11: Pairwise comparisons in the Tukey test of the weighted mean mass on a plot depending on the type of plot (see Figure 11 a). The Tukey test is based on a Gamma regression model of the weighted mean on mass per plot depending on the type of plot.



Appendix 12: Pairwise comparisons in the Tukey test of the weighted mean hand wing index on a plot depending on the type of plot (see Figure 11 b). The Tukey test is based on a Gamma regression model of the weighted mean on hand wing index per plot depending on the type of plot.

RESUME : Les routes ont des effets positifs et négatifs sur la diversité et l'abondance des oiseaux et modifient les communautés d'oiseaux. Si les effets négatifs l'emportent sur les effets positifs dans le cas des routes pavées à fort trafic, la situation est moins claire dans le cas des routes forestières non revêtues à faible trafic. Ce projet vise à comprendre les mécanismes qui sous-tendent l'effet des routes forestières sur les oiseaux, en explorant un potentiel effet de lisière (*edge effect*) autour des routes par la modification de la structure de la végétation, et une analyse fonctionnelle de l'effet espèce-spécifique, dans le sud de la Forêt Noire (Allemagne). Les résultats ne confirment pas le mécanisme d'un effet de lisière dû à la modification de la végétation dans les routes et les chemins par rapport aux forêts. Les communautés d'oiseaux dans les lisières sont significativement différentes des forêts, des routes et des chemins, alors que nous n'avons pas trouvé de différences entre les forêts, les routes et les chemins. Les résultats montrent un changement de faible ampleur dû aux routes et chemins dans les forêts, qui peut être légèrement négatif pour la diversité d'oiseaux. Enfin, l'analyse fonctionnelle ne permet pas non plus de confirmer l'existence d'un effet de lisière pour les routes et les chemins. L'effet de débordement (*spillover effect*) peut expliquer la majeure partie de l'effet de lisière dans les lisières, en notant que cet effet de débordement ne peut pas se produire dans les routes et les chemins, où il ne s'agit pas d'une interface entre deux habitats différents.

ABSTRACT: Roads have both positive and negative effects on bird diversity and abundances and modify the bird communities. While the negative effect outweighs the positive ones for high-traffic paved roads, it is less clear for low-traffic unpaved forest roads. This project aims at understanding the mechanisms behind the effect of forest roads on birds, exploring a potential edge effect around roads through the modification of the vegetation structure, and a functional analysis of the species-specific effect, in the Southern Black Forest (Germany). The results did not support the mechanism of an edge effect due to the vegetation change, in roads and paths compared to forests. The bird communities in edges are significantly different from forests, roads, and paths, while we cannot find differences between forest, roads, and paths. The results show a low magnitude change due to roads and paths in forests, which may be slightly negative on bird diversity. Finally, the functional analysis also cannot support an edge effect in roads and paths. The spillover effect may explain most of the edge effect in edges, noting that this spillover effect cannot occur in roads and paths, where it is not an interface between two different habitats.