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Master Thesis

A closer look into the living room of birds: Vertical stratification of the avian community in relation to forest management in the Wienerwald Biosphere Reserve

submitted by

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Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, 04.07.2023 Michaela MAISLINGER *(manu propria)*

Ignorance more frequently begets confidence than does knowledge: it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved by science.

Charles Darwin, The Descent of Man, 1871

Preface

This research was conducted with the support of the Natural History Museum Vienna, the Biosphärenpark Wienerwald Management GmbH, the Österreichische Bundesforste AG, and the Gesellschaft für Forschungsförderung Niederösterreich m.b.H.

The field work for this research was conducted in the Wienerwald Biosphere Reserve over the period February 2022 to June 2022, in cooperation with Eva Szekeres BSc.

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# Abstract

Structure-rich forests with vertical heterogeneity provide many different resources which can allow the coexistence of many bird species as they disperse among the different height strata. Intensive forest management practices influence the composition and age structure of forests, with consequences such as the loss of microhabitats for birds. In this study, I analysed the influence of forest management on the vertical distribution of birds in the Wienerwald Biosphere Reserve. The bird diversity was assessed with the point count method acoustically and visually in the managed zone and unmanaged core zone. The birds were classified to one of previously defined vertical strata. For the auditive method the ground, herb and shrub layer and the tree layer were used. For the visual method the ground and herb layer, the shrub layer, and the tree layer were used. The analysis revealed no evidence of a significant influence of forest management methods on overall species richness and individuals counted. The most unexpected results are the significantly higher numbers in insectivores and tree-cavity nesters, and a higher species richness of tree-cavity nesters in the tree layer in the managed forest parts compared to the tree layer in the unmanaged parts (regarding the auditive data). This suggests that the managed zone might provide more structures and resources for insectivores and tree-cavity nesters to allow the co-existence of many different species and/or individuals. The managed forest parts of the Wienerwald Biosphere Reserve do not undergo intensive use. Thus, maintaining forest stands with no or low management in a harvested forest matrix could contribute to better protection of forest bird fauna. Once the forest in the core zone has developed again into more natural stages, process protection might have a greater impact on the forest structure and thus also on bird diversity.

Kurzfassung

Strukturreiche Wälder mit vertikaler Heterogenität haben ein erhöhtes Ressourcenangebot, wodurch sich die unterschiedlichen Vogelarten in den verschiedenen Höhenschichten verteilen können. Waldbewirtschaftungsmethoden beeinflussen die Struktur der Wälder, was zum Verlust von Mikrohabitaten für Vögel führen kann. Mit dieser Studie habe ich den Einfluss von Waldbewirtschaftung auf die vertikale Verteilung von Vögeln im Biosphärenpark Wienerwald untersucht. Die Vogelvielfalt wurde mit der Punktzählmethode akustisch und visuell in der bewirtschafteten Zone und der unbewirtschafteten Kernzone erfasst. Die Vögel wurden einer der zuvor definierten Höhenschichten zugeordnet. Für die akustische Methode wurden die Boden-, Kraut- und Strauchschicht und die Baumschicht verwendet. Für die visuelle Methode wurden die Boden- und Krautschicht, die Strauchschicht und die Baumschicht verwendet. Es konnte kein signifikanter Einfluss der Bewirtschaftungsmethoden auf den Artenreichtum und die Individuenzahlen festgestellt werden. Besonders unerwartet sind die signifikant höheren Anzahlen von Insektenfressern und Baumhöhlenbrütern sowie ein höherer Artenreichtum an Baumhöhlenbrütern in der Baumschicht in den bewirtschafteten Waldteilen im Vergleich zur Baumschicht in den unbewirtschafteten Teilen (in Bezug auf die auditiven Daten). Die bewirtschaftete Zone hat möglicherweise mehr Strukturen und Ressourcen für Insektenfresser und Baumhöhlenbrüter, um die Koexistenz verschiedener Arten und/oder Individuen zu ermöglichen. Die bewirtschafteten Teile des Biosphärenparks Wienerwald werden nicht intensiv genutzt. Daher könnte die Beibehaltung von Waldteilen ohne oder mit geringer Bewirtschaftung in einer bewirtschafteten Waldmatrix zu einem besseren Schutz der Waldvogelfauna beitragen. Sobald sich der Wald in der Kernzone wieder in natürlichere Stadien entwickelt hat, könnte der Prozessschutz einen größeren Einfluss auf die Waldstruktur und damit auch auf die Vogelvielfalt haben.

1. Introduction

The avifauna is often used as an indicator of forest ecosystems as birds have various ecological functions (Roberge and Angelstam 2006; Şekercioğlu 2006; Larsen et al. 2010; Gregory and Strien 2010). For example, the ecosystem engineering of burrow and cavity diggers, the insect biomass control of insectivorous birds, and the seed dispersal of frugivorous birds are some of the most important avian ecosystem services (Gradwohl and Greenberg 1982; Mols and Visser 2002; Van Bael et al. 2003; Fayt et al. 2005; Şekercioğlu 2006). Forest birds, in their function as predators (predation of insects, etc.), are also an essential part of forest ecosystems – mainly because they are able to stabilize the predator-prey dynamics (Herrera 1984; Sekercioglu 2006). Therefore, the decline of avian diversity can result in ecological and economic consequences, for instance, when considering their suitability as bioengineers or their function as seed dispersers (Şekercioğlu 2006). The construction of cavity and burrow nests which are often used by other species is the major benefit of ecosystem engineering (Şekercioğlu 2006). Insectivorous birds can provide economic advantages as they can control the populations and behaviour of their invertebrate prey, thus influencing insect herbivores and the associated plant damage (Mols and Visser 2002; Şekercioğlu 2006). Seed dispersal enables the maintenance of plant diversity and reduces the risk of high mortality of seeds due to seed predators, herbivores, pathogens, and competitors (Janzen 1970; Harms et al. 2000; Packer and Clay 2000; Nathan and Muller-Landau 2000; Bacles et al. 2004). In fragmented landscapes, seed dispersal and recruitment are often reduced due to declining frugivorous bird populations, but seed dispersal can often compensate for reduced pollination (Cordeiro and Howe 2003; Bacles et al. 2004).

Forest management practices have a long history in Central Europe resulting in altered forest ecosystems and forest structure. Timber harvesting causes changes in the composition and age structure of forests and, consequently, a change in forest bird diversity (Kosenko and Kaigorodova 2001; Brazaitis and Angelstam, 2004; Vanderwel et al. 2007a; Tozer et al. 2010; Czeszczewik et al. 2015). Cavity-nesting birds, for example, are particularly sensitive to forest management practices because forestry measures often cause habitat fragmentation, habitat loss, and isolation of single populations (Kosenko and Kaigorodova 2001; Brazaitis and Angelstam, 2004; Czeszczewik et al. 2015). Intensive forestry processes like regular harvesting, removal of dead wood, and tree planting can influence habitat quality for various bird species (Simon et al. 2000; Vanderwel et al. 2007a; Czeszczewik et al. 2015). However, sustainable forest management practices can also lead to an increase in biodiversity when creating more heterogeneous habitats (Vanderwel et al. 2007a; Schall et al. 2018; Schulze et al. 2019). The management intensity should be kept as low as possible so that only individual trees are removed, and standing and lying deadwood can remain in the forests. The presence of standing and lying deadwood as well as old and mature trees plays an important role in providing sufficient habitat structures (Lassauce et al. 2011; Floren et al. 2014; Parisi et al. 2016). In this way, a structurally rich forest can develop that includes the many different stages of succession and can provide many different microhabitats with different structures and food resources for birds (Winter et al. 2015; Larrieu et al. 2018; Sever and Nagel 2019). Important forest structures for birds include canopy cover diversity, deadwood, diameter distribution, and varying tree age and height (Oettel and Lapin 2021). Forest management with high intensity, e.g. clear-cuts with complete tree removal at large scales or shelterwoods, should be avoided to promote avian diversity. Conversely, forestry measures should focus on the promotion of deadwood, the conservation of potential habitat trees, and the provisioning of unmanaged forest patches (Oettel and Lapin 2021). The creation of canopy openings and edge habitats may increase the abundance of some bird species that favour more open habitats, but maintaining mature trees is a major factor in the preservation of habitat quality for most forest birds (Simon et al. 2000; Vanderwel et al. 2007a; Balestrieri et al. 2015). Forest fragmentation and the associated habitat degradation should be avoided as this can affect the species composition and the genetic diversity in bird species (Kosenko and Kaigorodova 2001;

Brazaitis and Angelstam, 2004; Czeszczewik et al. 2015; Angelstam et al. 2018). A more sustainable approach to forest management can mimic natural processes and enhance structural diversity (Doyon et al. 2008; Oettel and Lapin 2021).

In the context of intensive forest management, the vertical heterogeneity of the vegetation is of relevance for the birds. Vertical heterogeneity in forests results in more microhabitats and allows consequent the coexistence between bird species and an increased avian diversity (Goetz et al. 2007; Böhm and Kalko 2009; Kwok 2009; Huang et al. 2014). Vegetation diversity is associated with the provision of various food resources for bird species (Jayson and Mathew 2003). Foliage density is generally positively correlated with bird diversity and abundance (Bell 1982; Jayson and Mathew 2003; Chmel et al. 2016). Vertical foliage segregation differs in forest ecosystems and has a large impact on the vertical distribution of birds (Jayson and Mathew 2003; Acharya and Vijayan 2017; Basham et al. 2022). Co-existing bird species with similar habitat requirements often disperse among the different tree strata for foraging (Pearson 1977; Bell 1982; Bernard 2001; Böhm and Kalko 2009; Kwok 2009). Depending on habitat and resource availability, bird species are able to use multiple vertical layers for their activities, as each species requires certain vegetation structures for activities like foraging, predator avoidance, nesting, or roosting (Holmes and Robinson 1981; Robin and Davidar 2002). In terms of foraging, preference is often given to those vegetation structures that are best suited to the morphological adaptations of the bird species (Forstmeier and Keßler 2001). The collared flycatcher (*Ficedula albicollis*), for example, mainly hunts insects in the air, taking a short flight from a perch and then returning to the perch. Therefore, vegetation that is too dense is not preferred as they would have difficulties foraging for insects. Varying species assemblages in different vertical strata occur due to specialisation based on the availability of resources and the physiological tolerance to microclimate (Stork and Grimbacher 2006; Acharya and Vijayan 2017). A structure-rich forest provides vertical heterogeneity and hence, increases bird species diversity.

Extractive forest management processes like timber harvesting can have an impact on vegetation structures in sense of e.g. tree girth, canopy height, or vertical stratification and as a result, decreases the vertical vegetation heterogeneity (Menon et al. 2019; Oettel and Lapin 2021). The proportion of dense, undisturbed forests in the landscape has an impact on the ability of harvested forests to protect native avifauna. Thus, maintaining old-growth forest stands in the harvested forest matrix could contribute to better protection of forest bird fauna. The provision of forest areas with no or low management is important for nature conservation, as they can represent a refuge for endangered species (Schröter et al. 2017; Oettel and Lapin 2021). Especially for the survival and breeding success of birds the creation of unmanaged zones can be a helpful tool in forestry management (Fernández-Juricic and Jokimäki 2001). This again underlines the relevance of adequate forest management required for biodiversity conservation.

In general, intensive forestry processes and the associated forest habitat alteration often cause the loss of essential microhabitats for birds (Newton 1994). Forest specialists are more affected from the population-reducing effects of harvesting than forest generalists or species in open areas and agricultural landscapes (Borghesio 2008; Elsen et al. 2017; Menon et al. 2019). Studies found that bird species dependent on a closed old-growth forest or lower understorey species are the most affected groups (Thiollay 1997; Czeszczewik et al. 2015; Perry et al. 2018). Especially endangered and rare forest birds are affected by the removal of old and mature trees (Wesołowski et al. 2005; Roberge et al. 2008; Lešo et al. 2019). In temperate zones, many forest bird species are dependent on the availability of tree cavities as they use them as nesting or sleeping site (Gibbons & Lindenmayer, 2002, as cited in Redolfi DeZan et al. 2016). Dead and decaying wood, which can often be found in unmanaged forests or forests with low management intensity, provides habitat and food resources for many different organisms and thus promotes biodiversity (Bobiec 2005). Forest specialists in general need a highly structured forest with large mature trees and a high diversity of dead wood as younger trees offer fewer possibilities for nesting (e.g. Brazaitis and Angelstam, 2004;

Gil-Tena et al. 2007; Ghadiri Khanaposhtani et al. 2013; Czeszczewik et al. 2015; Redolfi DeZan et al. 2016; Perry et al. 2018). Woodpeckers, for example, are adapted to the exploitation of dead wood as they can excavate their own cavity (Smith 2007). Therefore, woodpeckers need dead wood or large living trees. Other species such as European nuthatches (*Sitta europaea*), tits (e.g. *Parus major, Cyanistes caeruleus, Periparus ater*), treecreepers (*Certhia* sp.), flycatchers (*Ficedula* sp.), European starling (*Sturnus vulgaris*), field sparrow (*Passer montanus*), stock dove (*Columba oenas*), or tawny owl (*Strix aluco*) are dependent on natural holes or holes excavated by woodpeckers (Bobiec 2005; Aitken and Martin 2007; Blanc and Walters 2008; Wesołowski and Rowiński 2012). Furthermore, dead and decaying wood functions for many birds as a source of food. Insects and their larvae under the bark, for example, are an essential food resource for many woodpeckers (Bobiec 2005).

Insectivores are considered to be the most vulnerable groups as insects are dependent on specific micro-climate and vegetation structures (Thiollay 1997; Zanette et al. 2000; Sekercioglu et al. 2002; Menon et al. 2019). Insect abundances and biomass in forests generally decreased in the last decades (Seibold et al. 2019). Heterogeneity in vegetation structures can increase insect biodiversity in temperate forests (Knuff et al. 2020). Therefore, forest management can influence insect biodiversity as the vegetation structure gets altered (Perner and Malt 2003; Staab et al. 2023). The biomass of insects is expected to decrease in smaller or intensively managed forest patches with a less diverse forest structure and less canopy opening and gaps (Zanette et al. 2000; Schall et al. 2018; Staab et al. 2023), which can affect insectivores foraging behaviour and cause local abundance shifts as well as alterations of local presence. Smaller or managed forest patches often have the characteristics of forest edges and increased densities in herbs and/or shrubs can influence the foraging efficiency of insectivores, too (Ranney et al. 1981; Zanette et al. 2000).

Granivores and omnivores on the other hand are thought to be more adaptable to anthropogenically influenced landscapes and to take greater advantage of the resources available around human settlements (Thiollay 1997; Schulze and Riedl 2008). Forest raptors tend to be sensitive to human activities and the associated habitat degradation (Santangeli et al. 2012; Martínez et al. 2016; Jiménez-Franco et al. 2018). Especially raptors like the common buzzard (*Buteo buteo*) or northern goshawk (*Accipiter gentilis*) require old nests, which they can reuse in successive years (Santangeli et al. 2012; Jiménez-Franco et al. 2014, 2018). However, the preservation of old or unoccupied nests is often not considered when forestry measures are carried out (Santangeli et al. 2012; Jiménez-Franco et al. 2018). Timber harvesting or clearcutting often decreases the availability of habitat and nest sites for raptors (e.g. Santangeli et al. 2012; Jiménez-Franco et al. 2014; Martínez et al. 2016). Therefore, intensive forestry management processes which include the removal of mature trees and dead wood and which often lead to a homogenisation of vegetation structures are a great threat to insectivorous birds and cavity-nesting birds.

In many European regions, the populations of forest birds often are stable or show an increasing trend, mainly due to the increase in forest area in individual countries or the forest maturation (Gil-Tena et al. 2009; Sirami et al. 2010; Ram et al. 2017; Schulze et al. 2019; Gregory et al. 2019; Kamp et al. 2021; Bowler et al. 2021). Maturing forests result in taller and older trees which may lead to an increased supply of nesting sites and food resources. Less intense forest management methods like retention forestry or continuous cover forestry can support avian diversity (Gustafsson et al. 2012; Fedrowitz et al. 2014). However, the population-increasing effects of forest management are mainly seen in forest generalists whereas the populations of forest specialists are still decreasing (Sirami et al. 2010; Fraixedas et al. 2015; Kamp et al. 2021; Bowler et al. 2021; Reif et al. 2022). The populations of long-distance migratory birds are likely to decrease in Europe (Sanderson et al. 2006; Schulze et al. 2019; Kamp et al. 2021). In contrast to this, some resident bird species may be increasing in population due to a forest management which generates higher standing wood volumes and more structural diversity (Schall et al. 2018; Schulze et al. 2019). Populations of resident birds may be increasing because they face less competition from migratory birds, causing migratory birds to lose nest sites (Ahola et al. 2007). Nevertheless, climate change and the resulting longer growing season and milder winters may also have an increasing effect on the populations of birds (Schulze et al. 2019). The arrival of migratory birds at their breeding sites is dependent on the conditions at the non-breeding sites and during migration, and migrants often suffer fitness consequences when arriving too early or competition disadvantage if too late (Both et al. 2006; Vickery et al. 2014). However, more evidence now suggests that habitat alteration has a much greater impact in breeding areas than in wintering areas (Cresswell et al. 2020; Busch et al. 2020). Furthermore, intensively used homogeneous forests with a lack of herbaceous understory are less suitable for many migratory birds which prefer early successional habitats or which are ground-nesters, such as the leaf warblers (*Phylloscopus* sp.) (Fuller and Crick 1992; Hausner et al. 2003).

In this study, I analysed the distribution patterns of the bird diversity in the different vertical forest strata (ground and herb layer, shrub layer, tree layer) in relation to the forest management methods in the Wienerwald Biosphere Reserve. The Wienerwald biosphere reserve is part of the Central European deciduous beech forest and is known for its rich biodiversity (UNESCO 2020). More than 60% of the whole Wienerwald Biosphere Reserve are forests with the beech (*Fagus sylvaticus*) as the dominant tree species and an area of approximately 5400 ha (5% of the total area) is declared as core zone, which is a nature reserve protected by law and in which no forestry practices are carried out (UNESCO 2020; Biosphärenpark Wienerwald Management GmbH 2021a, b). Trees in the core zone are left to themselves, thus they can live for several hundred years and remain in the natural cycle as dead and decaying wood (Biosphärenpark Wienerwald Management GmbH 2021b). The managed parts of the Wienerwald Biosphere Reserve are separated into the transition zone, which is used for sustainable economic and recreational activities, and the buffer zone, which consists mainly of open areas for cultivation and agriculture (Biosphärenpark Wienerwald Management GmbH 2021c). Forestry management processes are not restricted in both managed zones, but innovative and sustainable management methods are preferred (Biosphärenpark Wienerwald Management GmbH 2021c).

Hence, I compared the vertical stratification of birds between the unmanaged core zone and the managed forest stands in the Wienerwald Biosphere Reserve. I hypothesize that avian species richness, abundance, and diversity among all strata is higher in the unmanaged core zone than in the managed parts. I expect that forestry processes can lead to a homogenisation of the forest structure, whereas an increase in the complexity of vegetation results in higher resource availability and therefore in higher species richness and greater avian abundance. For this reason, I hypothesize that the decreased vegetation heterogeneity in the managed forest stands in the Wienerwald Biosphere Reserve is resulting in a decreased bird species diversity and abundance. Furthermore, I analysed whether the different functional groups (foraging, migratory behaviour, nesting type) and forest specialists differ in their preference for vertical strata. I expect the unmanaged forest parts to be more structural diverse with more dead and decaying wood. Thus, I expect more forest specialists like insectivores and tree-cavity nesters (e.g. woodpeckers) in forest patches of the unmanaged core zone. Following other studies, densities should be the highest in the understorey (Larrivée and Buddle 2009; Ulyshen 2011; Aikens et al. 2013) arthropod and therefore, I suppose the species richness and abundances of insectivorous birds to be highest in the lower vertical layers. Granivorous and omnivorous birds are expected to forage in all vertical strata. I expect birds to prefer the strata where they nest, i.e., ground-nesting birds are more likely to be on the ground and shrub and tree-nesting birds are more likely to be in the higher strata. Regarding the migration strategy, I do not expect any major differences in terms of preference for specific strata.

2. Material & Methods

2.1. Study area

The study was conducted in 115 to 150-year-old forest stands in the unmanaged core zone as well as in the managed parts of the Wienerwald Biosphere Reserve in the northwest of Vienna (Figure 1).

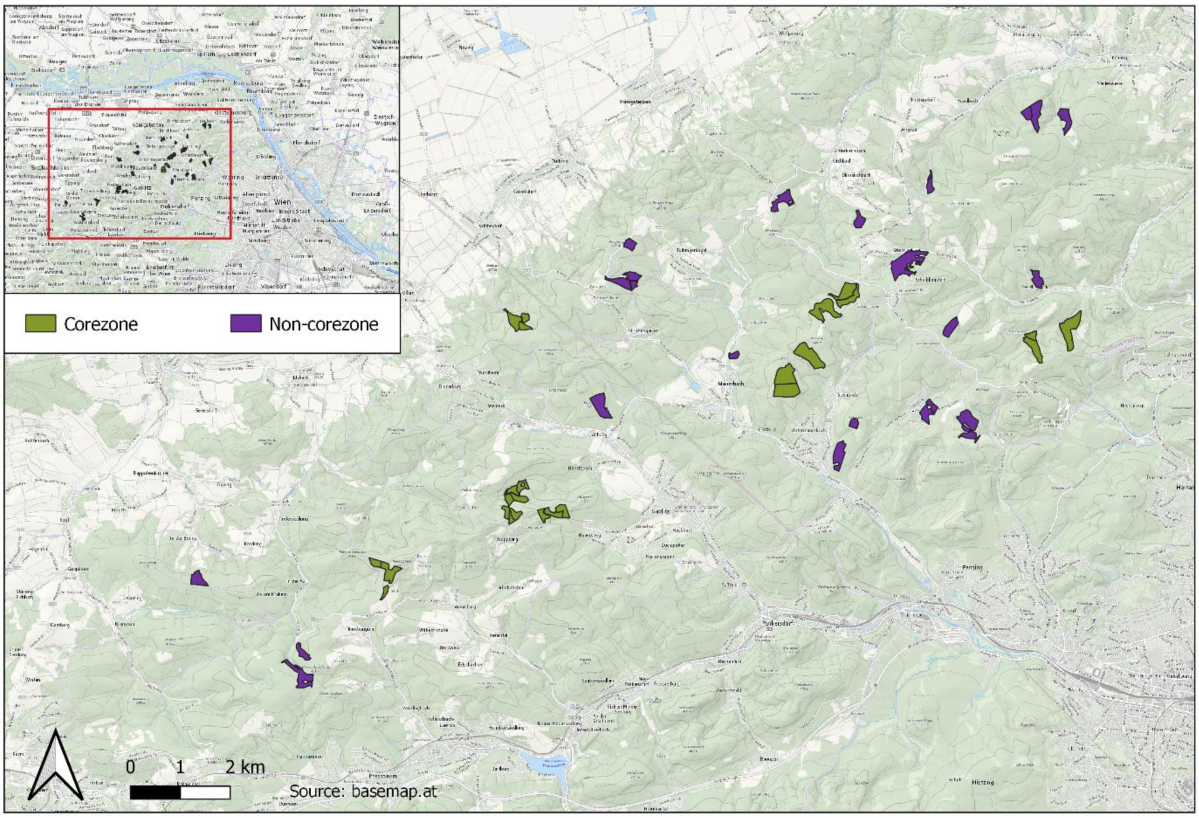

Figure 1: Plot locations of the core zone (green) and non-core zone (purple) within the study area. The study area is located in the Wienerwald Biosphere Reserve in the northwest of Vienna.

The Wienerwald Biosphere Reserve is shaped by different geological and climatic conditions and climatic zones and a long history of human land use (Berger and Ehrendorfer 2011). The geology ranges from flysch, carbonate and old sea basins with sediment deposits and the altitude ranges from approximately 160 m to nearly 900 m above sea level (Köck et al. 2009; Berger and Ehrendorfer 2011). Due to the varieties of soils, various distinctive plant communities emerged (Köck et al. 2009). The most common plant community in the Wienerwald Biosphere Reserve are the beech forests as they can grow on both flysch and carbonate (Berger and Ehrendorfer 2011). In addition to being a UNESCO Biosphere Reserve, large parts of the Wienerwald Biosphere Reserve are protected by the Natura 2000 network of nature protection areas (Köck et al. 2009). The Wienerwald Biosphere Reserve consists of a core, a buffer and a development zone, whereas the forest patches in the core zone are not managed and human intervention is extremely limited (Köck et al. 2009). In the buffer zone, ecologically sustainable activities and land use are allowed, whereas the development zone serves as settlement and recuperation area (Köck et al. 2009). The forest management affects the vertical stratification and the composition of the tree age structure and the tree species composition (Paillet et al. 2010). This subsequently influences the incidence of light, temperature and humidity and amount of litter and dead wood in the individual forest systems (Berg et al. 1994; Christensen et al. 2005). Natural forests like the core zone often show a higher amount of dead and decaying wood, older and larger trees and more trees with a large diameter compared to managed forests like the buffer and the development zone (Paillet et al. 2010). Therefore, they often contain a higher number of plant species (Økland et al. 2003). Those impacts are stronger, the more time has passed since the abandonment of forestry management (Paillet et al. 2010).

2.2. Bird data collection

I conducted the study together with Eva Szekeres in 25 survey plots in the managed forest patches and 25 survey plots in the unmanaged forest patches of the Wienerwald Biosphere Reserve (Figure 1). In each survey plot we defined three survey points in a distance of at least 100 m from each other and, if possible, 100 m from the edge of the survey plots. The coordinates of the survey points were recorded with a smartphone using Locus Map Pro (Asamm Software r. o. 2021) and the exact location of the survey points in the forest were marked with coloured flagging. Therefore, we had 50 survey plots with 150 survey points in total. We sampled the plots in three sampling rounds, so each survey plot was visited three times. To avoid any kind of replication, we varied the order of the plot visits in every sampling round. This allowed us to maximise randomisation, i.e. the study plots were not always visited in the same order. The point count method was used to assess the bird diversity (Sutherland 2006). At each survey point we simultaneously assessed the bird diversity acoustically and visually in a radius of 50 m for five minutes taking care not to count any individuals twice. For the acoustical assessment method, the birds heard in the 50 m radius were noted. In order to identify birds that could not be identified acoustically in the forest we additionally recorded the bird sounds with a voice recorder. For the visual assessment method, the birds spotted with and without binoculars were noted. We identified each bird observed by species and sex. For the vertical stratification, we noted in which vertical stratum each bird was observed. For the acoustical assessment method, the observed birds were classified to one of two vertical strata. The height classes used for the auditive method were the ground, herb and shrub layer (0 – 10 m) and the tree layer (> 10 m). For the visual method, the observed birds were classified to one of three vertical strata. The height classes used for the visual method were the ground and herb layer (0 – 1 m) the shrub layer (1 – 10 m) and the tree layer (> 10 m). The bird observations were conducted for a maximum of four consecutive hours, starting at sunrise. For optimal recording conditions we eschewed rain (stronger than drizzle) and wind speed above 15 km/h. Stronger rain and higher wind speed impedes the visual detectability and the acoustical perception of bird sounds. The data collection period lasted from mid-March to mid-June, coinciding with the period of the highest activity and visibility of breeding birds in the Wienerwald Biosphere Reserve.

The observed birds were classified into varying functional groups according to the diet, the migratory behaviour and the nesting site (Appendix 1-2). Dietary groups were classified into ‘omnivores’, ‘granivores’, ‘insectivores’ and ‘carnivores’ according to the main food group of each species during the breeding season (Renner and Hoesel 2017; Svensson 2018; Schweizerische Vogelwarte Sempach 2023). The migratory behaviour groups were classified into ‘residents’ (non-migratory species which remain in the breeding area during the winter), ‘short-distance migrants’ (species that migrate only short distances in winter or where only part of the population migrates) and 'long-distance migrants' (species that migrate across the Mediterranean or the Sahara in winter) (Khil 2018; Schweizerische Vogelwarte Sempach 2023). The nesting site groups were grouped in ‘ground nesters’, ‘tree or shrub breeders’, ‘tree-cavity nesters’, ‘brood parasitism’ and ‘earth-cavity breeders’ (Svensson 2018; Schweizerische Vogelwarte Sempach 2023). The classification was deliberately kept simple to avoid an overwhelming number of classes and thus allow for a better statistical evaluation.

2.3. Habitat parameters

In addition to data on bird diversity, we obtained some habitat parameters (forest age, beech proportion [%], exposition, slope, area [ha]) from the Österreichische Bundesforste AG (Appendix 3). Furthermore, several environmental parameters were recorded. In mid-June, when the canopy was fully formed, the percentage of canopy cover as well as the percentage of cover of shrubs and herbs at each counting point was determined. The diameter at breast height (DBH) of five representative trees per survey point was measured with a measuring tape. To assess the percentage of canopy cover, one measurement was taken at each representative tree and in each cardinal direction with a spherical densiometer. The percentage of the cover of the herb and shrub layers on every counting point was estimated visually. The mean and standard deviation (SD) of the DBH, the mean and standard deviation (SD) of the canopy cover, the mean of the shrub cover and the mean of the herb cover per survey point was calculated (calculated parameters in Appendix 4).

2.4. Statistical analysis

I performed separate analyses for the auditive and visual counting method as the classification of the vertical stratification differed between the two methods. As no extreme outliers occurred, I decided to keep all outliers in my data as they often capture valuable information for my study. Prior to modelling, I used Pearson's correlation coefficient to test for collinearity amongst explanatory variables (Appendix 5). If the correlation coefficient between a pair of covariates was greater than |0.6|, only one was included in the model (Akoglu 2018). However, no correlation between the habitat parameters occurred and all variables were included into the analysis.

The relationship between species richness and sampling effort between the different vertical strata was studied with accumulation curves for each observational method. I plotted the accumulation curves for observed species richness as well as species richness estimates produced by Chao 1 (Chao 1984) for the different vertical strata using the package 'vegan'. Chao 1 was used as this is an abundance-based species estimator which assumes Poisson distribution and corrects for variances.

A generalised linear model (GLM) for binomial data was used to test the influence of habitat parameters on the forest management method. An *a priori* full model was created and a stepwise model selection was done with AIC (Akaike Information criterion). The resulting models were then ranked by increasing AIC values and Akaike weight (w) and the best fitted model was chosen for the analysis. The species total abundance (= number of detected individuals) and the species richness (= number of detected species) were calculated per survey point for each stratum in the core zone and non-core zone as well as for each interaction group (stratum * functional group). The influence of the strata and the forestry management (both as interaction with the functional group) on the total abundance and the species richness were tested with a generalized linear model (GLM) using a Poisson distribution and an ANOVA. The differences of the different functional groups (diet, migratory behaviour, nesting site) in the different strata have been tested with a GLM using the Poisson distribution and an ANOVA. Post-hoc pairwise comparisons of the vertical strata for the visual method and different interaction groups (stratum * forest management method, stratum * functional group, stratum * forest management method * functional group) for both recording methods were performed with a holm correction using the package 'multcomp'.

Generalised Linear Mixed Models (GLMM) were used to evaluate the influence of habitat parameters on species richness and overall bird abundance. 20 *a priori* models (per response variable) were fitted using GLMMs, using the forest management method and the stratum as random effects. AICc (Akaike Information criterion corrected for small sample sizes) was used to rank the different models due to their relative likelihood. The best fitted model with the highest AICc weight (w) and the lowest ΔAICc was selected, as it is clearly the most plausible if the next-ranked model has ΔAIC > 2. All models with a ΔAICc < 2 are statistically identical, which means that none of these models can be considered the most plausible. ANOVA (using Type II Wald-χ^2-tests) was then performed on all models with a ΔAICc < 2, and on the full model (model with all habitat parameters as explanatory variables). The outputs were considered to decide which parameters should be reported.

I assessed differences in bird species composition among strata and forest management methods using non-metric multidimensional scaling (NMDS). For analysing the beta-diversity I calculated Bray-Curtis dissimilarity indices with the function 'vegdist' and measured the multivariate dispersion with non-Euclidean distances with the function 'betadisper', both functions in the 'vegan' package. The differences between the groups (strata, strata * forest management method) were tested with ANOVA, Tukey's HSD and permutational multivariate analysis of variance using distance matrices with the function 'adonis' in 'vegan'.

All analyses were performed in R version 4.2.1 and an α-level of 0.05. For the observational data (total abundance, species richness) the distribution patterns were tested and for the further analysis Poisson distributions were used. The GLMMs were performed using the 'lme4' and 'AICcmodavg' packages. ANOVA was performed using the package 'car'.

3. Results

3.1. Effects of forest management methods on vegetation structure

The core zone and non-core zone of the Wienerwald Biosphere Reserve differed significantly in canopy cover mean, cover of shrubs mean, forest age, proportion of beech and slope (Figures 2a-g, Appendix 6). The DBH mean and the canopy cover SD were not significantly different in both forest management zones (Figures 2a-g, Appendix 6).

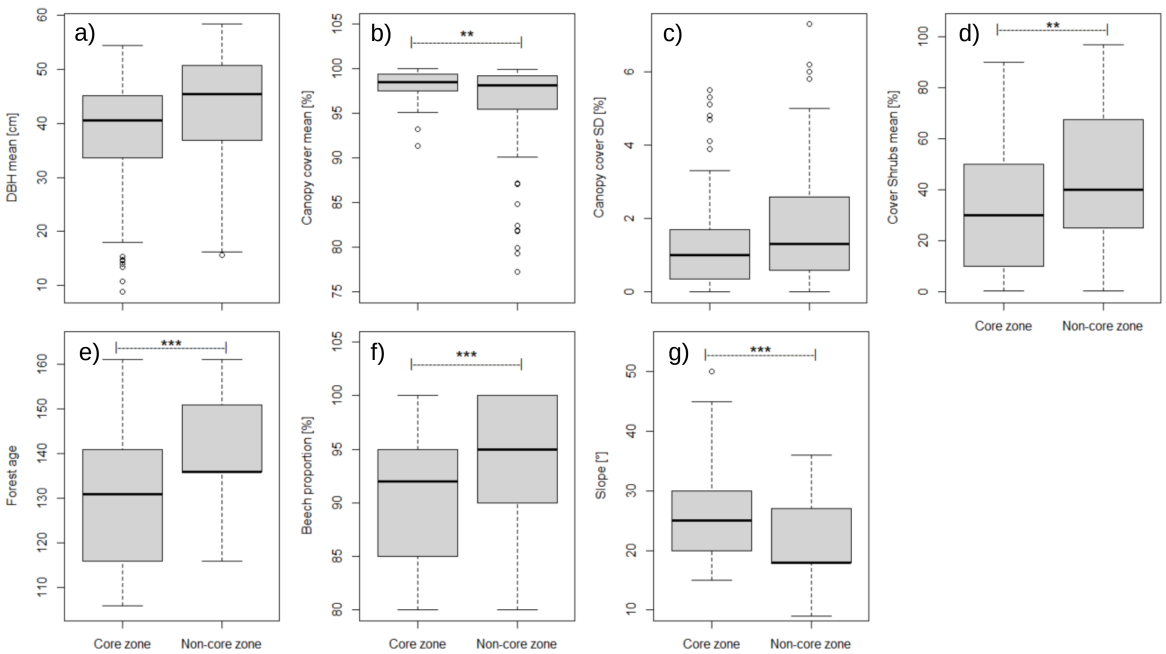

Figure 2: Results of the model testing for the relation between the forest management method and (a) DBH mean, (b) canopy cover mean, (c) canopy cover SD, (d) cover shrubs mean, (e) forest age, (f) beech proportion [%], and (g) slope [°]. Model outputs are given in Table 1.

3.2. Species accumulation curve & species observed

We recorded 55 bird species of 22 families within the Wienerwald Biosphere Reserve (Appendix 7). A total of 4867 individuals were detected, with 4371 individuals recorded acoustically and 496 individuals recorded visually (Appendix 7). Nearly 25% of all counts (1209 individuals) could be assigned to a vertical stratum, of which almost all visually observed birds (495 individuals) and about 16% of the acoustically observed birds (714 individuals) could be assigned to a stratum (Appendix 7). As revealed by the accumulation curves (Figure 3), species richness of the different strata increased with increasing numbers of survey points. The species accumulation curve with the estimated species richness produced by Chao 1 shows a similar pattern as the real species accumulation curve (Figures 3a-b). The species accumulation curves from the auditive method reach closely an asymptote (Figure 3a), whereas the species accumulation curves for the visual method did not reach an asymptote (Figure 3b).

During this study, bird species recorded in the Wienerwald Biosphere Reserve used different vertical strata, ranging from the ground to the tree layer, and certain species showed a preference for a particular vertical stratum (Figures 4-5). For example, *Erithacus rubecula* was more frequent in the ground and herb layer and *Fringilla coelebs* in the higher strata (Figures 4-5). Some species used only one or two strata, such as *Columba oenas* and *Dendrocopus major* in the upper parts of the forest, and *Sylvia atricapilla* and *Troglodytes troglodytes* were mostly found in the ground and herb layer (Figures 4-5).

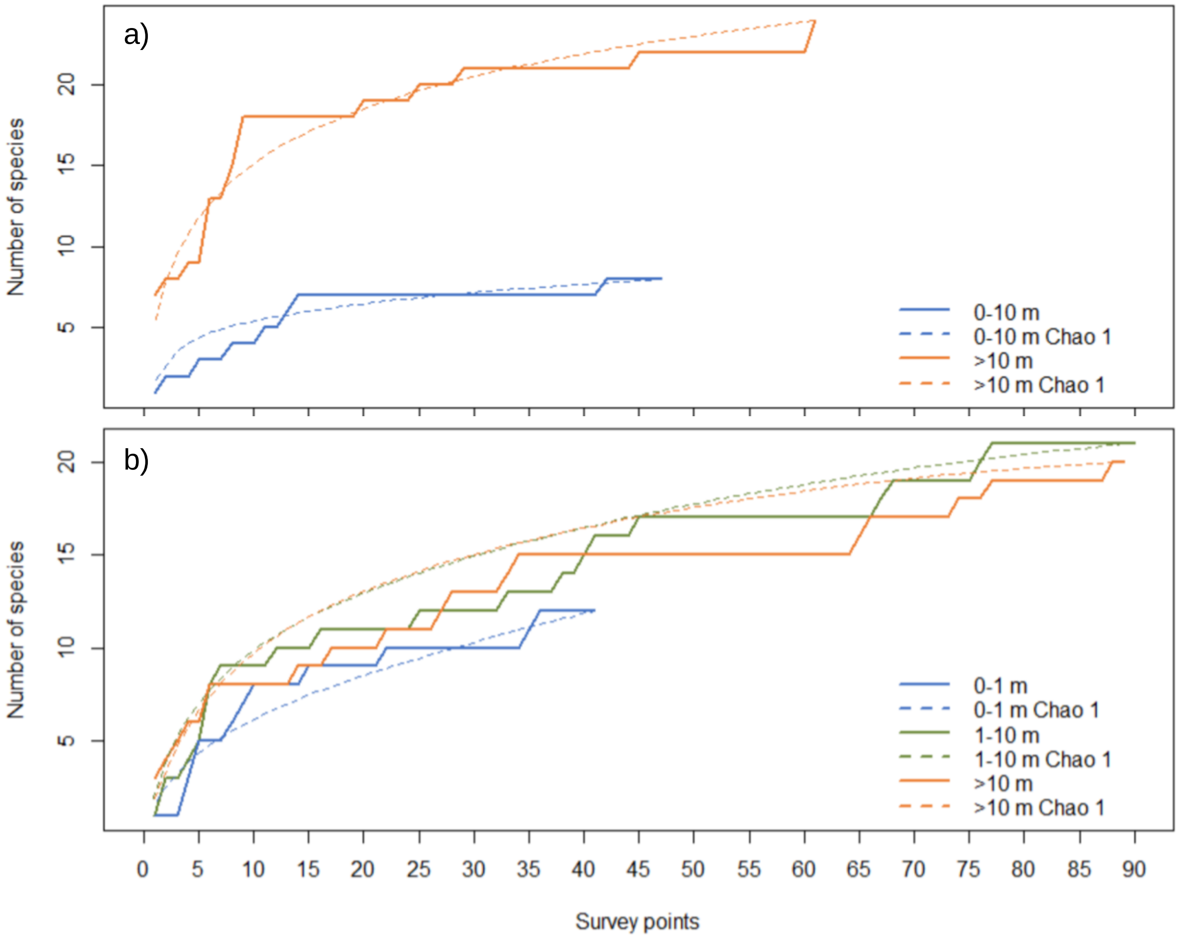

Figure 3: Species accumulation curve for species richness (solid line) and estimated species richness produced by Chao 1 (dashed line) for (a) acoustically observed birds in the different strata, and (b) visually observed birds in the different strata.

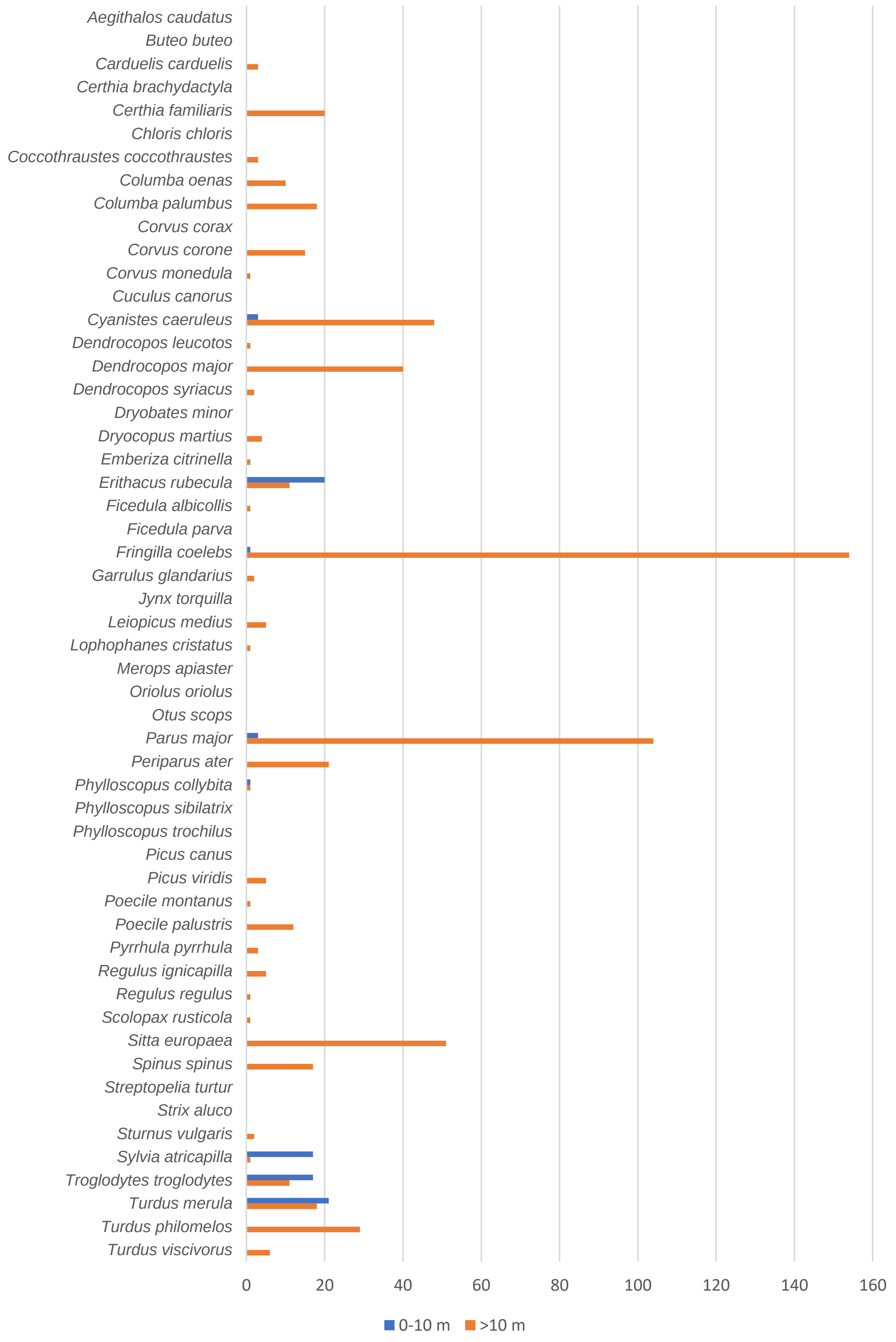

Figure 4: Total number of individuals detected for each species within the different strata for the auditive method

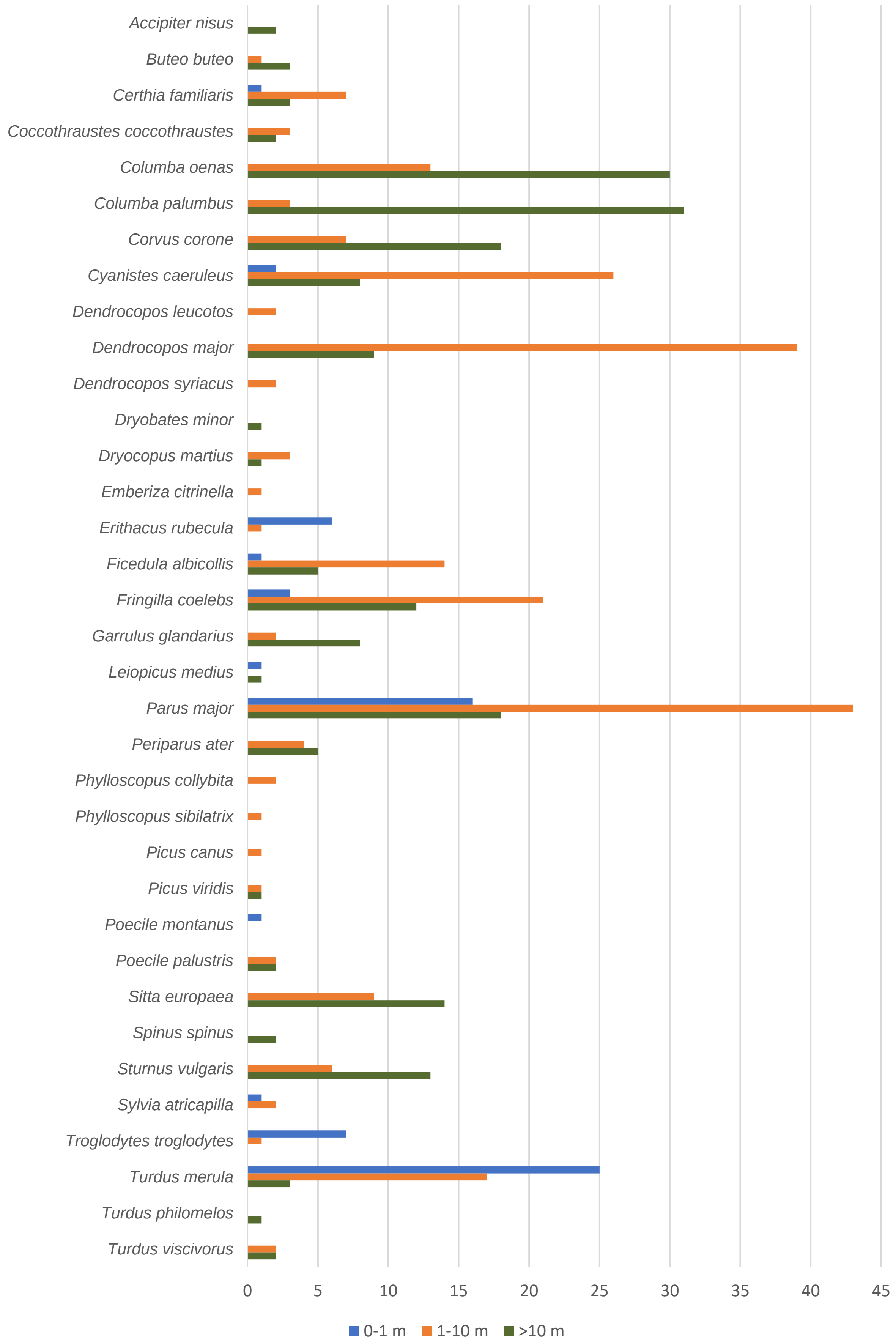

Figure 5: Total number of individuals detected for each species within the different strata for the visual method. .

3.3. Effects of habitat parameters on bird diversity

I found several models that are almost equivalently supported by the data (models with ΔAICc < 2, listed in Tables 1-4). These models are statistically identical and no model is clearly most plausible. The results also show that the full models including the parameters "forest age" and "slope" do not fit the data best (full models listed in Tables 1-4). Forest age and slope therefore apparently do not have to be included in the models. As model selection was done to test which variables affected the species richness the most, I found that canopy cover mean and cover herbs mean explained the species richness for acoustically observed birds the most (GLMM models listed in Table 1, Figures 6a-b, parameters of the best supported models listed in Appendix 8). Canopy cover mean explained the species richness for the visually observed birds the most (GLMM models listed in Table 3, Figure 6c, parameters of best supported model listed in Appendix 9). When regarding the total number of individuals detected, I found no significantly influencing parameters for the acoustically observed birds. However, DBH mean had the greatest effect on the total abundance for the visually observed birds (GLMM models listed in Table 4, Figure 6d, parameters of best supported model listed in Appendix 9).

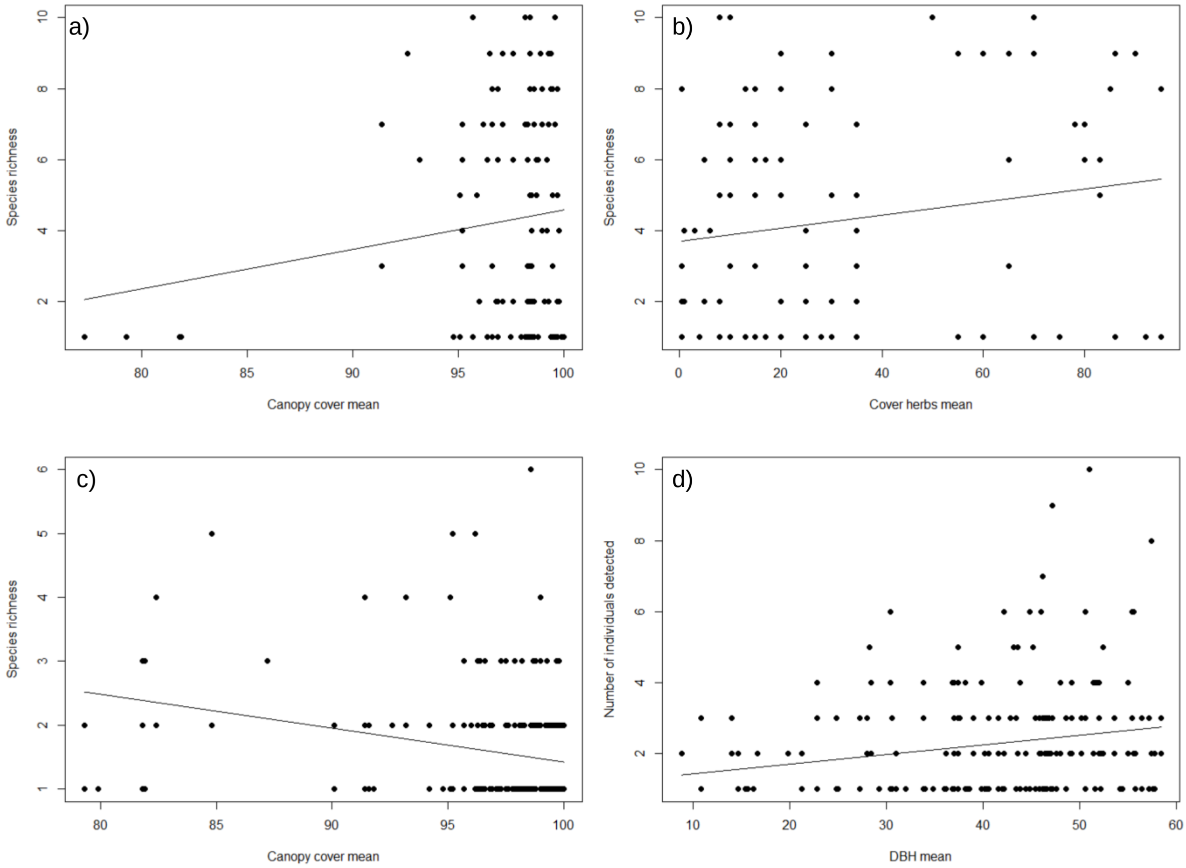

Figure 6: Effects of (a) canopy cover mean on species richness for acoustically observed birds, (b) cover herbs mean on species richness for acoustically observed birds, (c) canopy cover mean on species richness for visually observed birds, and (d) DBH mean on total number of detected individuals for visually observed birds

Table 1: Full generalized linear models (GLMMs) fitting species richness as response to the different habitat parameters for the auditive observations. Stratum and forest management method were used as random factors. All models with a ΔAICc < 2 and the full model (m1) are highlighted in bold.

		Habitat parameters									Model selection					
R code reference	**Model**	**DBH mean**	**DBH SD**	**Canopy cover mean**	**Canopy cover SD**	**Cover shrubs mean**	**Cover herbs mean**	**Forest age**	**Beech proportion**	**Slope**	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**
m16	**16**	*	*	*	*		*				9	437.47	**0**	0.17	0.17	-208.81
m13	**13**	*	*	*	*	*	*		*		11	438.37	**0.90**	0.11	0.27	-206.81
m14	**14**	*	*	*	*	*	*				10	438.46	**1.00**	0.10	0.38	-208.1
m17	**17**	*	*	*	*						8	438.84	**1.37**	0.08	0.46	-210.69
m19	**19**	*		*	*						7	439.35	**1.88**	0.07	0.53	-212.12
m18	18	*	*	*							7	439.52	2.05	0.06	0.59	-212.20
m15	15	*	*	*	*	*					9	440.06	2.59	0.05	0.63	-210.11
m2	2	*	*	*	*	*	*	*	*		12	440.06	2.60	0.05	0.68	-206.39
m11	11	*	*	*	*	*	*	*			11	440.25	2.78	0.04	0.72	-207.75
m4	4	*	*	*	*	*	*		*		12	440.34	2.87	0.04	0.76	-206.53
m20	20	*		*							6	440.42	2.96	0.04	0.80	-213.80
m12	12	*	*	*	*	*	*			*	11	440.63	3.16	0.03	0.83	-207.94
m6	6	*	*	*	*		*	*	*	*	12	440.66	3.20	0.03	0.87	-206.69
m7	7	*	*	*		*	*	*	*	*	12	440.95	3.48	0.03	0.90	-206.83
m10	10		*	*	*	*	*	*	*	*	12	441.00	3.54	0.03	0.93	-206.86
m5	5	*	*	*	*	*		*	*	*	12	441.25	3.78	0.03	0.95	-206.98
m1	**1**	*	*	*	*	*	*	*	*	*	13	442.40	**4.93**	0.01	0.97	-206.26
m3	3	*	*	*	*	*	*	*		*	12	442.68	5.21	0.01	0.98	-207.70
m9	9	*		*	*	*	*	*	*	*	12	442.82	5.36	0.01	0.99	-207.77
m8	8	*	*		*	*	*	*	*	*	12	442.96	5.49	0.01	1	-207.84

Table 2: Full generalized linear models (GLMMs) fitting total number of individuals detected as response to the different habitat parameters for the auditive observations. Stratum and forest management method were used as random factors. All models with a ΔAICc < 2 and the full model (m21) are highlighted in bold.

		Habitat parameters									Model selection					
R code reference	**Model**	**DBH mean**	**DBH SD**	**Canopy cover mean**	**Canopy cover SD**	**Cover shrubs mean**	**Cover herbs mean**	**Forest age**	**Beech proportion**	**Slope**	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**
m38	**38**	*	*	*							7	554.06	**0**	0.3	0.3	-269.47
m39	**39**	*		*	*						7	554.19	**0.13**	0.28	0.59	-269.53
m37	**37**	*	*	*	*						8	555.26	**1.20**	0.17	0.75	-268.9
m36	36	*	*	*	*		*				9	557.11	3.05	0.07	0.82	-268.64
m35	35	*	*	*	*	*					9	557.61	3.55	0.05	0.87	-268.89
m34	34	*	*	*	*	*	*				10	559.51	5.45	0.02	0.89	-268.62
m31	31	*	*	*	*	*	*	*			11	559.99	5.93	0.02	0.91	-267.62
m26	26	*	*	*	*		*	*	*	*	12	560.85	6.79	0.01	0.92	-266.78
m27	27	*	*	*		*	*	*	*	*	12	560.95	6.89	0.01	0.93	-266.83
m30	30		*	*	*	*	*	*	*	*	12	561.12	7.06	0.01	0.94	-266.92
m40	40	*		*							12	561.12	7.06	0.01	0.94	-266.92
m33	33	*	*	*	*	*	*		*		11	561.2	7.14	0.01	0.95	-268.23
m28	28	*	*		*	*	*	*	*	*	12	561.24	7.18	0.01	0.96	-266.98
m25	25	*	*	*	*	*		*	*	*	12	561.27	7.21	0.01	0.97	-266.99
m22	22	*	*	*	*	*	*	*	*		12	561.46	7.40	0.01	0.98	-267.09
m23	23	*	*	*	*	*	*	*		*	12	561.7	7.64	0.01	0.98	-267.21
m32	32	*	*	*	*	*	*			*	11	561.8	7.74	0.01	0.99	-268.53
m29	29	*		*	*	*	*	*	*	*	12	562.69	8.64	0	0.99	-267.71
m21	**21**	*	*	*	*	*	*	*	*	*	13	563.37	**9.31**	0	1	-266.75
m24	24	*	*	*	*	*	*		*		12	563.63	9.57	0	1	-268.17

Table 3: Full generalized linear models (GLMMs) fitting species richness as response to the different habitat parameters for the visual observations. Stratum and forest management method were used as random factors. All models with a ΔAICc < 2 and the full model (m1) are highlighted in bold.

		Habitat parameters									**Model selection**					
R code reference	**Model**	**DBH mean**	**DBH SD**	**Canopy cover mean**	**Canopy cover SD**	**Cover shrubs mean**	**Cover herbs mean**	**Forest age**	**Beech proportion**	**Slope**	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**
m19	**19**	*		*	*						7	558.09	**0**	0.38	0.38	-271.78
m20	**20**	*		*							6	559.09	**0.99**	0.23	0.61	-273.35
m17	17	*	*	*	*						8	560.23	2.13	0.13	0.74	-271.77
m18	18	*	*	*							7	561.09	3.00	0.08	0.83	-273.28
m16	16	*	*	*	*		*				9	562.05	3.96	0.05	0.88	-271.6
m15	15	*	*	*	*	*					9	562.35	4.26	0.05	0.93	-271.74
m14	14	*	*	*	*	*	*				10	564.16	6.06	0.02	0.94	-271.55
m13	13	*	*	*	*	*	*		*		11	564.88	6.78	0.01	0.96	-270.8
m11	11	*	*	*	*	*	*	*			11	566.35	8.26	0.01	0.96	-271.54
m12	12	*	*	*	*	*	*			*	11	566.37	8.28	0.01	0.97	-271.55
m6	6	*	*	*	*		*	*	*	*	12	566.96	8.87	0	0.97	-270.72
m9	9	*		*	*	*	*	*	*	*	12	566.97	8.88	0	0.98	-270.73
m5	5	*	*	*	*	*		*	*	*	12	567.01	8.92	0	0.98	-270.75
m4	4	*	*	*	*	*	*		*		12	567.03	8.93	0	0.99	-270.76
m2	2	*	*	*	*	*	*	*	*		12	567.05	8.96	0	0.99	-270.77
m8	8	*	*		*	*	*	*	*	*	12	567.47	9.38	0	0.99	-270.98
m3	3	*	*	*	*	*	*	*		*	12	568.59	10.49	0	1	-271.54
m1	**1**	*	*	*	*	*	*	*	*	*	13	569.21	**11.12**	0	1	-270.72
m10	10		*	*	*	*	*	*	*	*	12	569.39	11.29	0	1	-271.94
m7	7	*	*	*		*	*	*	*	*	12	569.52	11.43	0	1	-272.00

Table 4: Full generalized linear models (GLMMs) fitting total number of indiviuals detected as response to the different habitat parameters for the visual observations. Stratum and forest management method were used as random factors. All models with a ΔAICc < 2 and the full model (m21) are highlighted in bold.

		Habitat parameters									**Model selection**					
R code reference	**Model**	**DBH mean**	**DBH SD**	**Canopy cover mean**	**Canopy cover SD**	**Cover shrubs mean**	**Cover herbs mean**	**Forest age**	**Beech proportion**	**Slope**	**K**	**AICc**	**ΔAICc**	**AICcWt**	**Cum.Wt**	**LL**
m39	**39**	*		*	*						7	819.25	**0**	0.38	0.38	-402.36
m38	**38**	*	*	*							7	819.96	**0.72**	0.26	0.64	-402.72
m37	**37**	*	*	*	*						8	820.94	**1.69**	0.16	0.8	-402.13
m36	36	*	*	*	*		*				9	822.58	3.33	0.07	0.87	-401.86
m35	35	*	*	*	*	*					9	823.04	3.79	0.06	0.93	-402.09
m34	34	*	*	*	*	*	*				10	824.73	5.49	0.02	0.95	-401.84
m32	32	*	*	*	*	*	*			*	11	826.64	7.39	0.01	0.96	-401.68
m31	31	*	*	*	*	*	*	*			11	826.83	7.58	0.01	0.97	-401.78
m33	33	*	*	*	*	*	*		*		11	826.93	7.68	0.01	0.98	-401.83
m26	26	*	*	*	*		*	*	*	*	12	828.75	9.5	0	0.98	-401.62
m28	28	*	*		*	*	*	*	*	*	12	828.76	9.52	0	0.98	-401.62
m23	23	*	*	*	*	*	*	*		*	12	828.79	9.54	0	0.99	-401.64
m24	24	*	*	*	*	*	*		*		12	828.81	9.56	0	0.99	-401.65
m22	22	*	*	*	*	*	*	*	*		12	829.06	9.82	0	0.99	-401.77
m29	29	*		*	*	*	*	*	*	*	12	829.24	10.00	0	0.99	-401.86
m25	25	*	*	*	*	*		*	*	*	12	829.58	10.34	0	1	-402.03
m27	27	*	*	*		*	*	*	*	*	12	829.88	10.63	0	1	-402.18
m21	**21**	*	*	*	*	*	*	*	*	*	13	831.01	**11.76**	0	1	-401.62
m30	30		*	*	*	*	*	*	*	*	12	833.09	13.85	0	1	-403.79
m40	40	*		*							12	833.09	13.85	0	1	-403.79

3.4. Bird diversity in different strata

The analyses for the auditive data showed that the species richness differed significantly between the two strata, with significantly more species in the higher stratum (Figure 7a, Appendix 10). Significantly more species were detected in the upper layer in both the core-zone and non-core zone, whereas no significant difference occurred between the different forest management methods within the strata (Figure 7b, Appendices 10-11). When regarding the total number of individuals detected, I found similar patterns. Significantly more individuals were detected in the higher stratum when regarding both the complete dataset and separated into the two forest management methods (Figures 7c-d, Appendices 10-11).

For the visually observed birds I found significantly more species in the middle layer, but no differences in core zone and non-core zone (7e-f, Appendices 10-11). In the middle stratum, significantly more individuals were found compared to the lower and upper layer, and significantly more individuals could be detected in the highest stratum compared to the lowest stratum (Figure 7g, Appendices 10-11). When comparing the different forest management methods, no significant difference in the number of individuals detected could be found (Figure 7h, Appendices 10-11). Regarding the non-core zone, significantly more individuals were detected in the tree layer compared to the ground and herb layer (Figure 7h, Appendices 10-11).

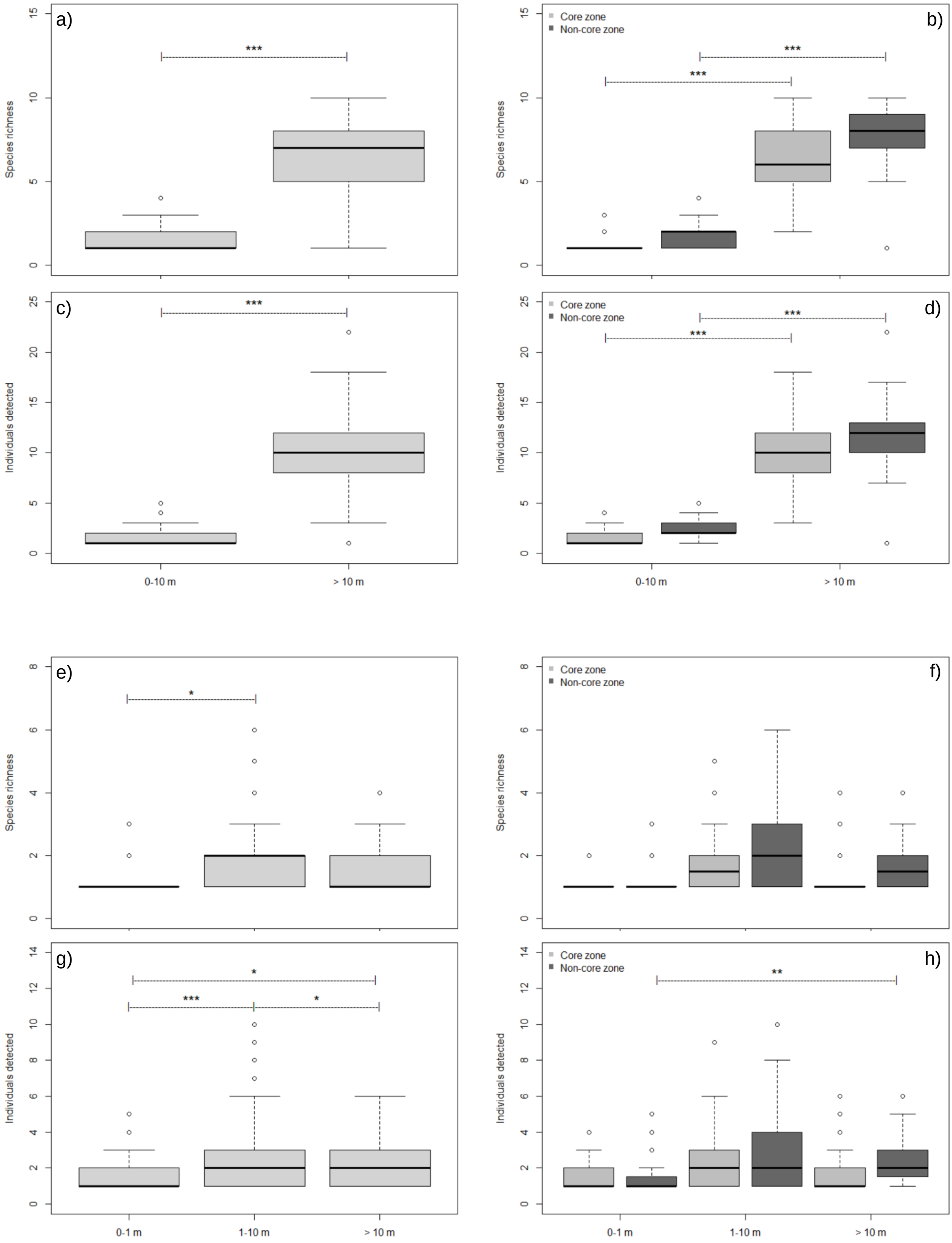

Figure 7: Results of the models testing for the relation between the species richness or total number of individuals detected and the vertical strata as well as the forest management method for the auditive method (a-d) and visual method (e-h).

Regarding the auditive data, the ANOVA showed a significant difference in the community composition between the vertical strata (F(1) = 14.489, $p < 0.001$). The analysis of variance using distance matrices showed a significant difference in community composition between the upper and lower layer (F(1) = 34.77, $p = 0.001$) as well as differences between the interaction groups (strata * forest management) (F(3) = 12.807, $p = 0.001$). However, I found a significant difference in community composition between the two strata in the core zone (Table 5). The NMDS-Plots (Figures 8a-b) visualize the differences between the two strata.

Considering the visual data, the ANOVA showed a significant difference in the community composition between the vertical strata (F(2) = 15.634, $p < 0.001$). The analysis of variance using distance matrices found a significant difference in community composition between the three vertical strata (F(2) = 7.163, p = 0.001) and between the interaction groups (strata * forest management) (F(5) = 3.996, p = 0.001). With the TukeyHSD I found in the core zone a significant difference in community composition between the lowest and middle stratum and between the lowest and highest stratum (Table 5). Further significant differences are between the lowest layer in the core zone and the middle layer in the non-core zone, between the lowest layer in the core zone and the highest layer in the non-core zone, and between the highest layer in the core zone and the lowest layer in the non-core zone (Table 5). The NMDS-Plots (Figures 8c-d) visualize the differences between the three strata.

Table 5: Result of TukeyHSD of interactions. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Comparison of parameter interactions	Diff	Lwr	Upr	P adjusted
Auditive	Core/A – Noncore/A	-0.041	-0.125	0.044	0.595
	Core/A – Core/B	-0.099	-0.161	-0.038	**< 0.001**
	Core/A– Stratum- B NonCore	-0.051	-0.132	0.031	0.374
	Noncore/A – Core/B	-0.059	-0.131	0.014	0.159
	Noncore/A – Noncore/B	-0.010	-0.100	0.080	0.992
	Core/B – Noncore/B	0.049	-0.020	0.118	0.260
Visual	Noncore/A – Core/A	0.029	-0.025	0.082	0.641
	Core/B – Core/A	0.065	0.018	0.113	**0.001**
	Noncore/B – Core/A	0.055	0.009	0.100	**0.009**
	Core/C – Core/A	0.076	0.027	0.125	**< 0.001**
	Noncore/C – Core/A	0.066	0.019	0.113	**0.001**
	Core/B – Noncore/A	0.037	-0.004	0.077	0.099
	Noncore/B – Noncore/A	0.026	-0.013	0.065	0.392
	Core/C – Noncore/A	0.047	0.005	0.090	**0.020**
	Noncore/C – Noncore/A	0.037	-0.003	0.078	0.091
	Noncore/B – Core/B	-0.011	-0.041	0.019	0.908
	Core/C – Core/B	0.011	-0.025	0.046	0.956
	Noncore/C – Core/B	0.001	-0.032	0.033	1.000
	Core/C – Noncore/B	0.021	-0.012	0.054	0.433
	Noncore/C – Noncore/B	0.011	-0.019	0.042	0.891
	Noncore/C – Core/C	-0.010	-0.045	0.025	0.964

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

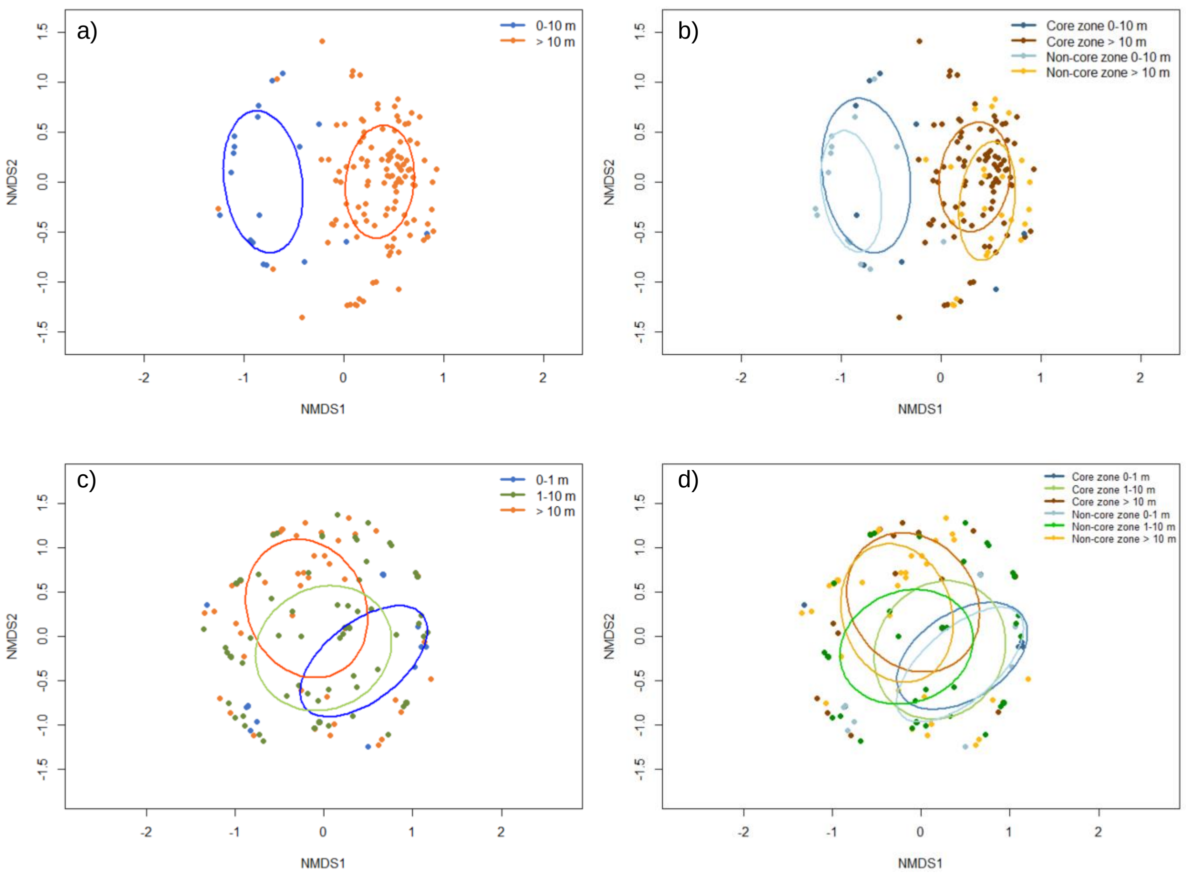

Figure 8: Nonmetric multidimensional scaling (NMDS) plot with two axes (k = 2) showing bird species composition similarity among the different strata for (a) acoustically and (c) visually observed birds. The bird species composition similarity among the different strata and the different forest management methods is shown in the NMDS plots (k = 2) for (c) acoustically and (d) visually observed birds. Ovals represent standard deviation of the points.

3.5. Functional diversity

3.5.1. Dietary groups

For the dietary groups, regarding the auditive data, I found a significant influence of the stratum for both the species richness and the total abundance detected, and a significant influence of the forest management method on the total abundance detected (Appendix 12). The species richness in insectivores was significantly higher in the higher stratum than in the lower stratum ($p < 0.001$, Figure 10a, Appendix 13). The insectivores showed a higher species richness in the upper layer when compared to the omnivores and granivores ($p < 0.001$, Figure 10a, Appendix 13). I found no significant differences between the core zone and non-core zone within the different strata (Figure 10b, Appendix 13). Significantly more insectivores were found in the higher stratum compared to the omnivores and granivores ($p < 0.001$, Figure 10b, Appendix 13). Furthermore, the number of individuals detected was higher in granivores than in omnivores regarding the upper layer ($p < 0.001$, Figure 10c, Appendix 13). The total number of individuals detected differed significantly between the core zone and non-core zone in insectivores, with significantly more insectivores in the upper layer in the non-core zone ($p = 0.032$, Figure 10d, Appendix 13).

Considering the visual observations, the stratum and the forest management had no significant influence on the species richness or the total abundance detected regarding the dietary groups (Appendix 11). I found no significant difference in the species richness due to dietary class within the strata and no significant difference when compared the core zone and non-core zone (Figures 11a-b, Appendix 13). For the number of individuals detected I found significantly more insectivores in the middle layer compared to insectivores in the lower layer respectively granivores in the middle layer ($p = 0.023$ resp. $p < 0.007$, Figure 11c, Appendix 13). No significant differences between the two forest management methods could be detected, but the insectivores in the non-core zone differed significantly between the first two strata ($p = 0.042$, Figure 11d, Appendix 13).

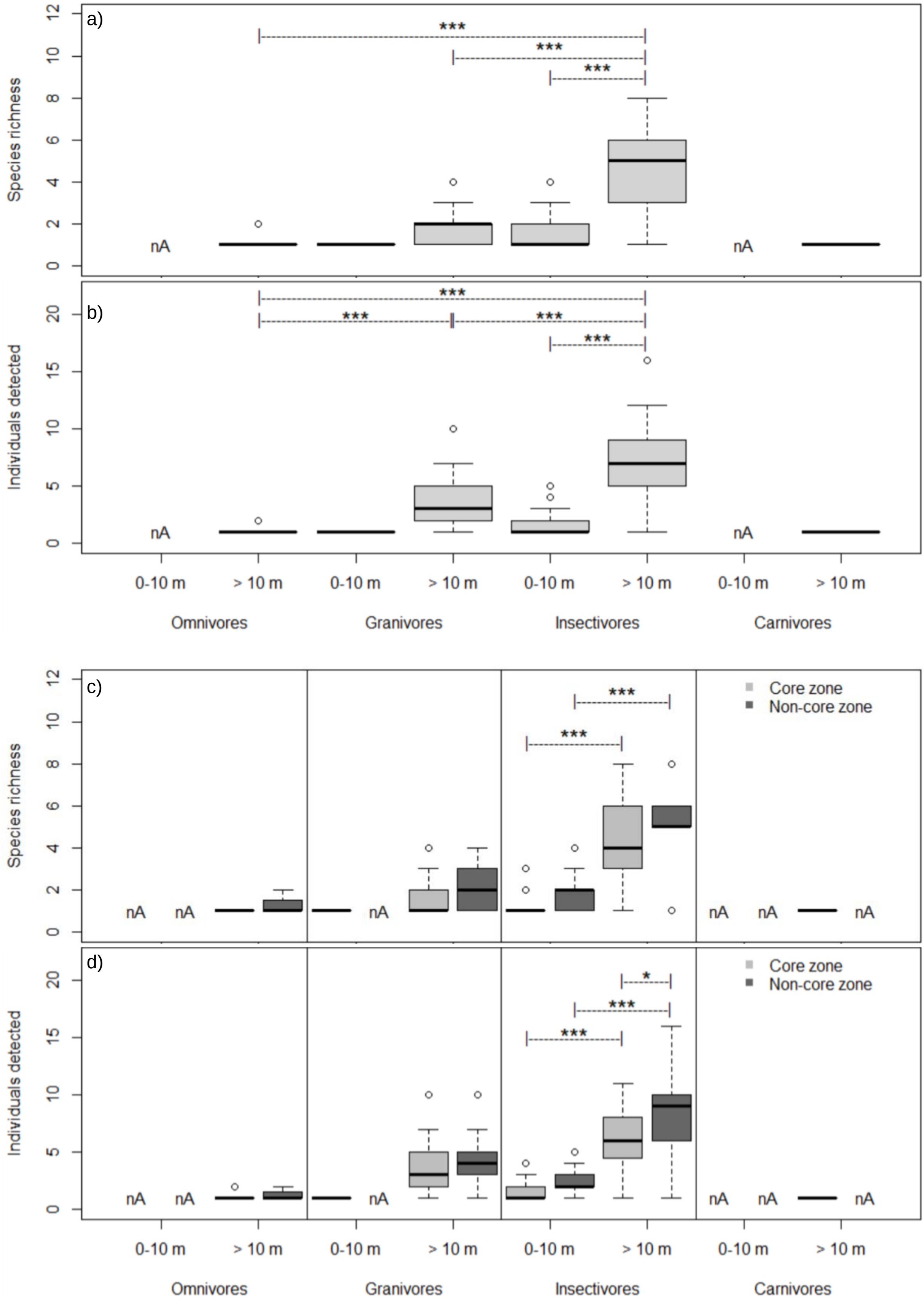

Figure 9: Results of the models testing for the relation the vertical strata as well as the forest management method and the species richness (a, c) or total number of individuals detected (b, d) for dietary classes (auditive method).

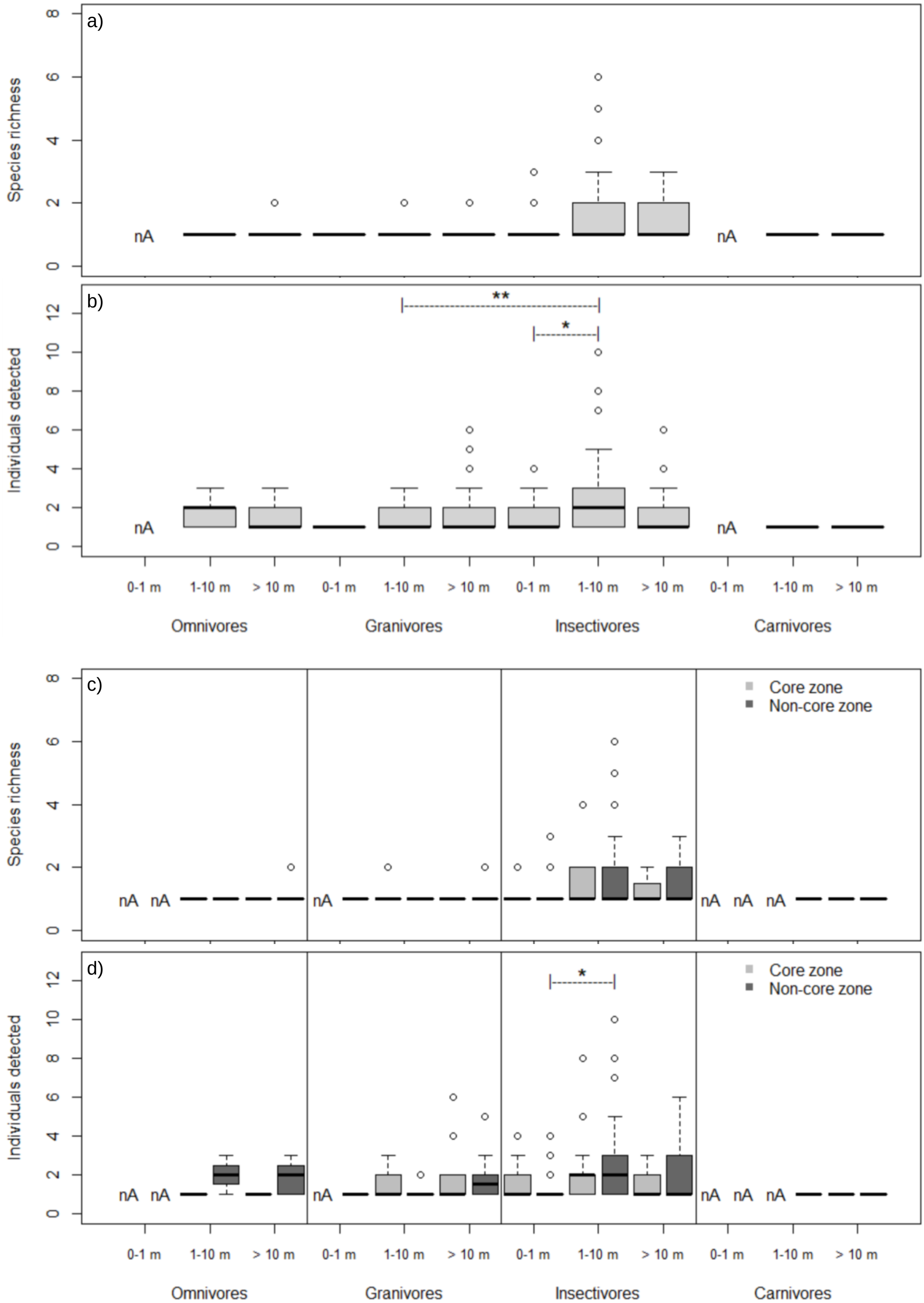

Figure 10: Results of the models testing for the relation the vertical strata as well as the forest management method and the species richness (a, c) or total number of individuals detected (b, d) for dietary classes (visual method).

3.5.2. Migratory behaviour groups

When comparing the species richness of the different migratory behaviour groups in the different strata for the acoustically observed birds, I found a significant influence of the stratum and the forest management method on both the species richness and the total detected abundance (Appendix 14). I found significantly more short-distance migratory species in the upper layer ($p < 0.001$, Figure 11a, Appendix 15). This pattern was similar when comparing the different forest management methods, whereas I found no significant difference between core zone and non-core zone within the strata (Figure 11b, Appendix 15). I found significantly more individuals in the higher stratum in both residents and short-distance migrants ($p = 0.040$ resp. $p < 0.001$, Figure 11c, Appendix 15). Significantly more individuals were detected in the non-core zone compared to the core zone within the residents in the upper layer ($p < 0.015$, Figure 11d, Appendix 15). When comparing core zone to non-core zone, I found significantly more short-distance migrants in the upper layer in both zones ($p < 0.001$, Figure 11d, Appendix 15).

For the migratory behaviour groups regarding the visual data, I found no significant influence of the vertical strata or the forest management method on the species richness or the total abundance detected (Appendix 14). I found no significant differences in species richness between the different strata and the different strata combined with the core zone and non-core zone (Figures 12a-b, Appendix 15). For the total number of individuals detected I found similar patterns with no significant differences (Figures 12c-d, Appendix 15).

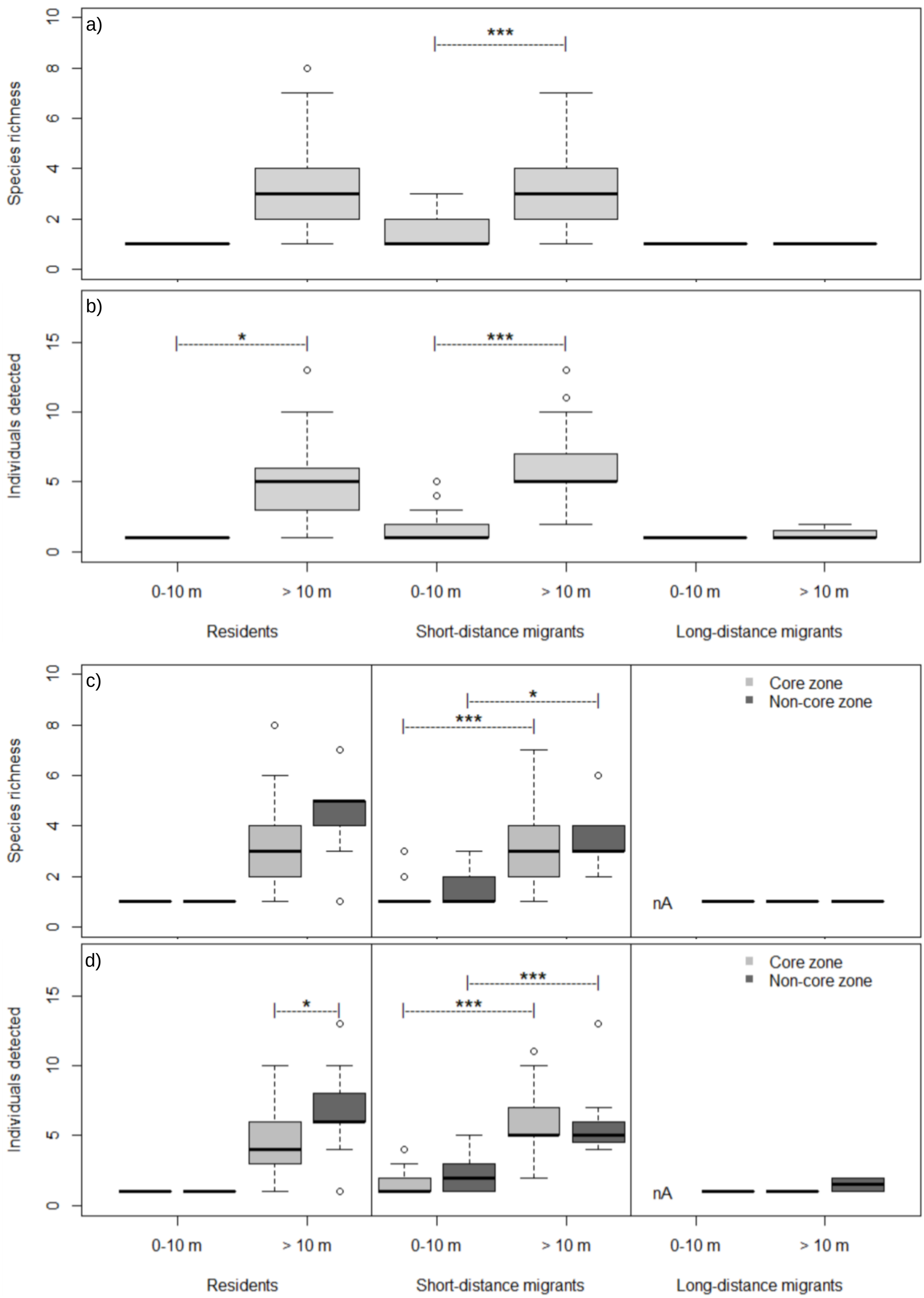

Figure 11: Results of the models testing for the relation the vertical strata as well as the forest management method and the species richness (a, c) or total number of individuals detected (b, d) for migratory behaviour classes (auditive method).

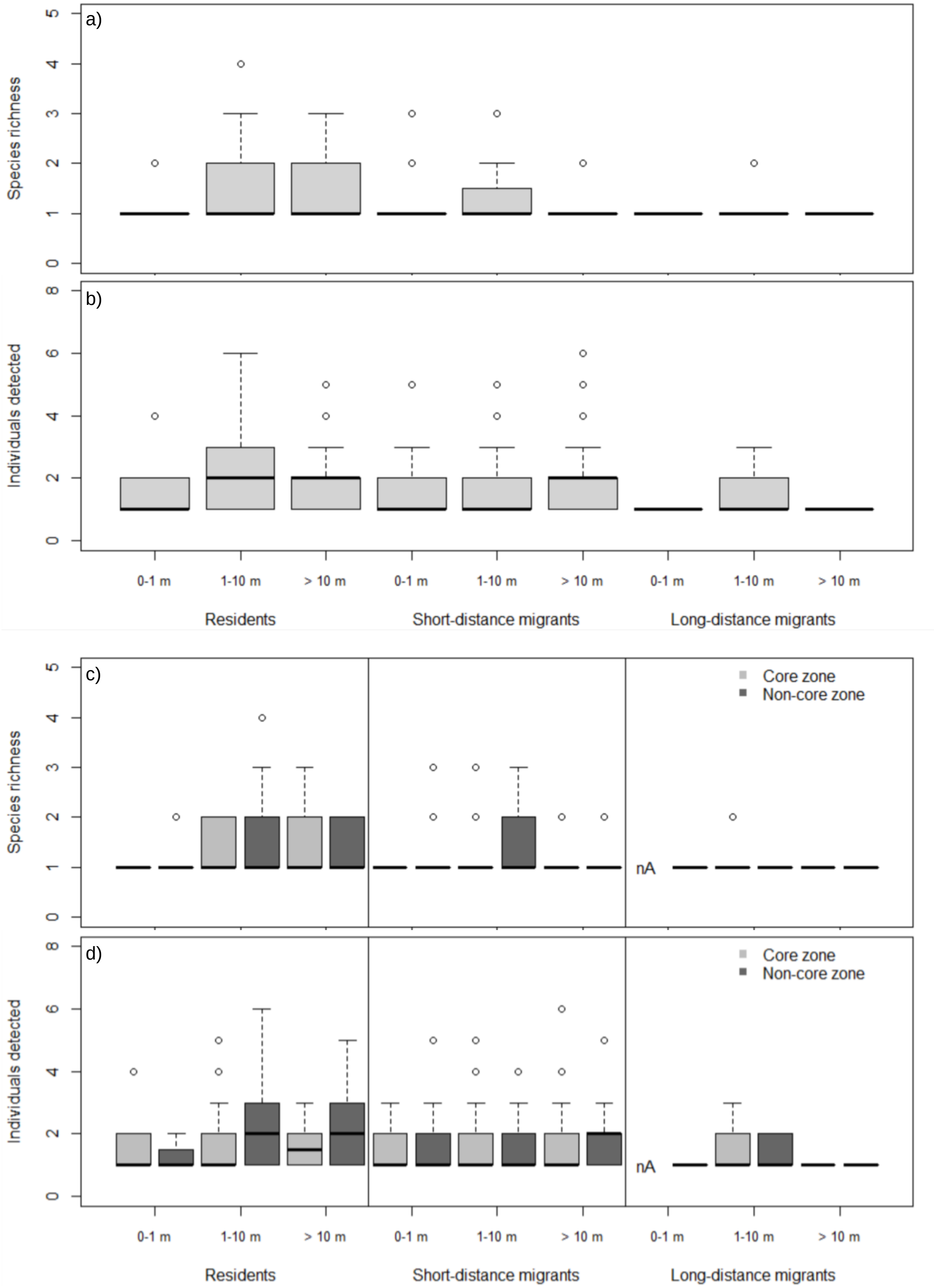

Figure 12: Results of the models testing for the relation the vertical strata as well as the forest management method and the species richness (a, c) or total number of individuals detected (b, d) for migratory behaviour classes (visual method).

3.5.3. Nesting site groups

With the auditive method, I found that stratum and forest management method have a significant effect on the species richness and the total abundance detected for the nesting site groups (Appendix 16). The species richness was significantly higher in the upper layer within the tree and shrub breeders (*p* < 0.001, Figure 13a, Appendix 17). Significantly more tree-cavity nesting and tree/shrub breeding species were found in the higher stratum compared to the ground breeders (*p* < 0.001, Figure 13a, Appendix 17). When comparing core zone to non-core zone, I found a significant difference between the two forest management methods in the upper layer within the tree-cavity nesters (*p* = 0.015, Figure 13b, Appendix 17). I found similar patterns in the total number of individuals detected, with significantly more individuals detected in the upper layer within tree/shrub breeders compared to the lower layer in tree/shrub breeders as well as the upper layer in the ground breeders (*p* < 0.001, Figure 13c, Appendix 17). Significantly more individuals were recorded in the upper layer in tree-cavity nesters compared to the tree-cavity nesters in the lower stratum and the ground breeders in the higher stratum (*p* = 0.019 resp. *p* < 0.001, Figure 13c, Appendix 17). I found a significant difference between core zone and non-core zone in the upper layer within the tree-cavity nesters, with significantly more individuals in the non-core zone (*p* < 0.001, Figure 13d, Appendix 17).

For the nesting site groups regarding the visual observations, I found no significant influence of the vertical strata and the forest management methods on the species richness and the total abundance detected (Appendix 16). Furthermore, no significant differences in species richness due to the different strata or the strata combined with the forest management method could be detected (Figures 14a-b, Appendix 17). Significantly more tree-cavity nesters were recorded in the middle layer compared to the tree/shrub breeders (*p* = 0.019, Figure 14c, Appendix 17). No significant differences between the core zone and non-core zone could be detected in the total abundance (Figure 14d, Appendix 17).

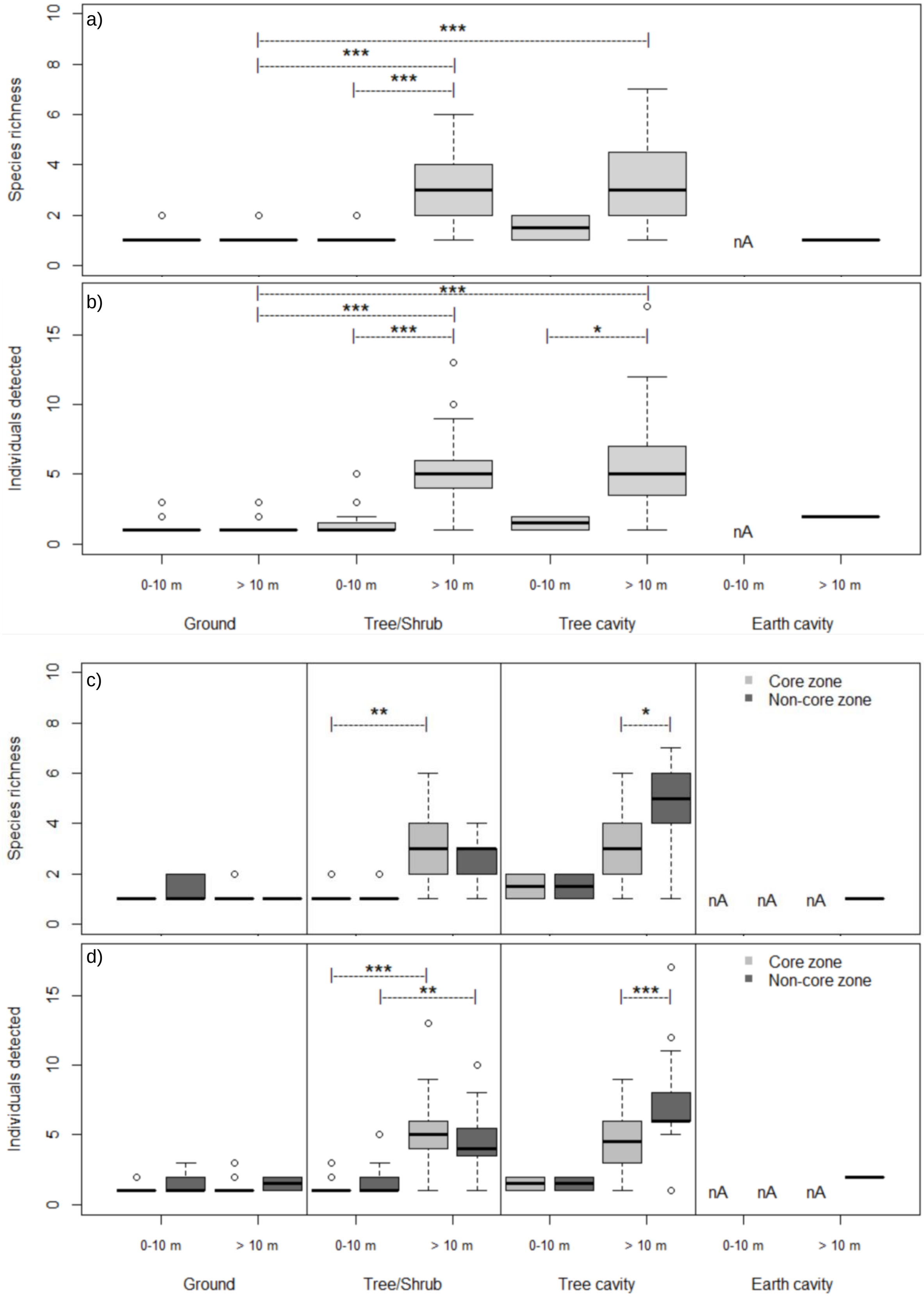

Figure 13: Results of the models testing for the relation the vertical strata as well as the forest management method and the species richness (a, c) or total number of individuals detected (b, d) for nesting site classes (auditive method).

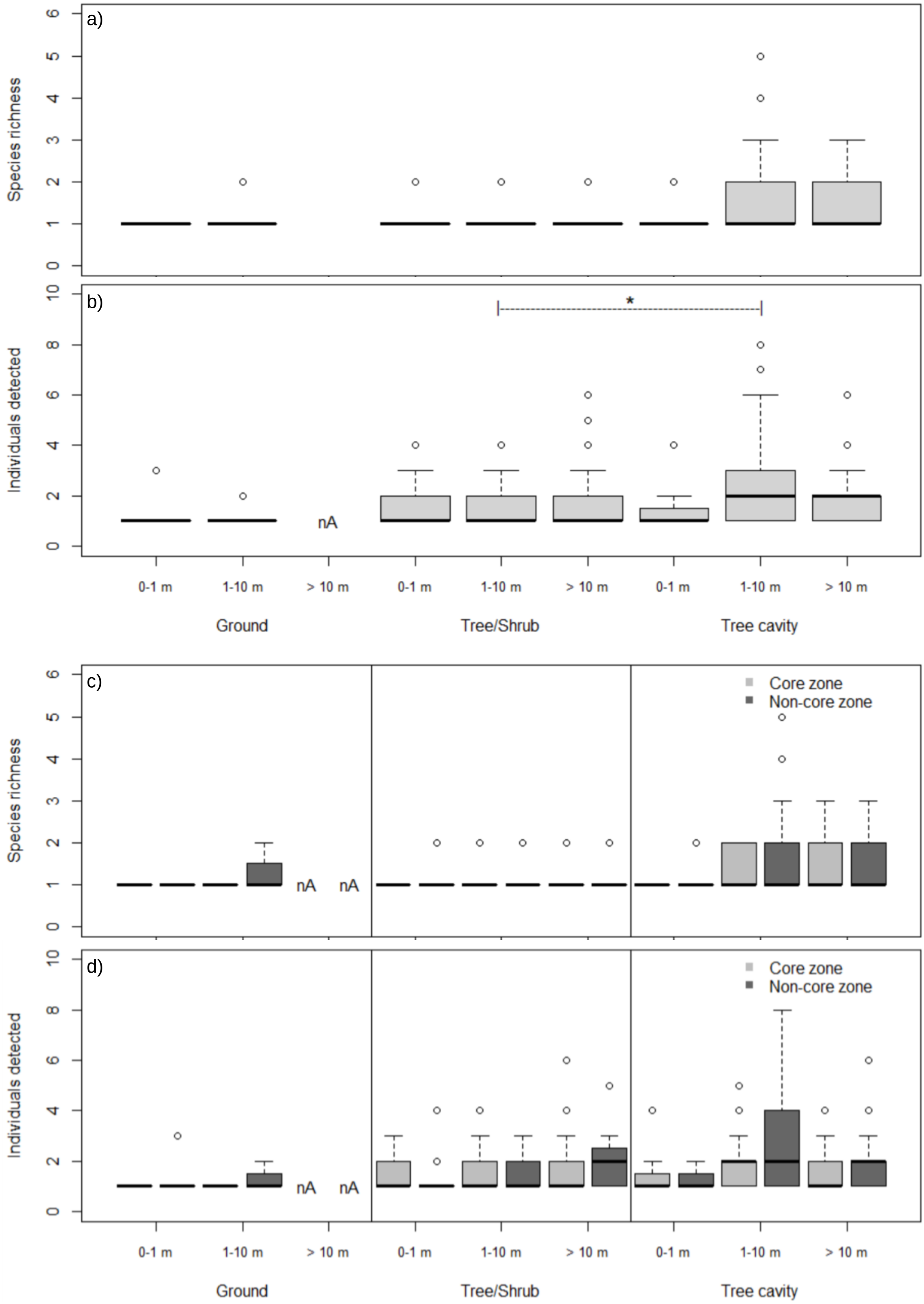

Figure 14: Results of the models testing for the relation the vertical strata as well as the forest management method and the species richness (a, c) or total number of individuals detected (b, d) for nesting site classes (visual method).

4. Discussion

4.1. Effects of habitat parameters on bird diversity

In this study, I found that the species richness of acoustically observed birds increased with increasing canopy cover. This result contrasts with the general concept that canopy openings in forests often cause increased biodiversity (Bengtsson et al. 2000; Muscolo et al. 2014). In tropical and subtropical forests, bird species richness is often increasing as a result of canopy openings due to the death of single trees or a group of trees (Felton et al. 2008; Withey 2013). A higher amount of deadwood and small-scale canopy gaps will contribute to greater species richness in temperate forests, too (e.g. Czeszczewik et al. 2015; Redolfi DeZan et al. 2016; Lešo et al. 2019; Lewandowski et al. 2021). Naturally occurring treefall gaps in the canopy of temperate forests also appear to have population-increasing effects on birds (Faccio 2003; Gharehaghaji et al. 2012; Przepióra et al. 2020; Lewandowski et al. 2021). Natural disturbances like lightning strikes (Yanoviak et al. 2015), storms (Battles et al. 2017), fungal pathogens (Goheen and Hansen 1993), heavy snowfall (Song et al. 2017), or extreme temperatures (Kuuluvainen 2002) can lead to the death of trees and thus to the creation of canopy gaps. Canopy gaps are a part of the natural forest succession and provide space for tree regeneration or the growth of other vegetation (Muscolo et al. 2014). Openings of the canopy cover often promote the growth of ground vegetation, resulting in an occurrence of phytophagous and flower-visiting insects, and thus an increase in the number of birds foraging (Blake and Hoppes 1986; Keller et al. 2003; Gálhidy et al. 2006; Moorman et al. 2007).

The positive correlation between species richness of acoustically observed birds and canopy cover indicated by my results may be because nearly all plots have a mean canopy cover of over 90%. Therefore, the influence of canopy openings might not have been fully captured. In contrast to this, the decreasing effect of canopy cover on the species richness of visually observed birds may be related to the reduced detectability of birds due to the growing and increasingly dense vegetation. As a result, the increasingly dense vegetation made it more difficult to observe birds visually, especially in the shrub and tree layers. Similarly, the finding that more individuals were observed visually in plots with a larger average DBH mean might be related to the fact that more mature beech stands with a larger DBH often have less shrub vegetation, thus enhancing the birds' detectability. Conversely, the acoustic observations were almost independent of the vegetation growth. Other studies have noted the same problem with visual observations (Blake and Loiselle 2001; Felton et al. 2008; Acharya and Vijayan 2017). Due to dense vegetation, especially visual bird censuses from the ground might be more difficult (Felton et al. 2008; Acharya and Vijayan 2017). There might be a relative detection bias at higher strata due to a better visibility of birds in the lower strata (Acharya and Vijayan 2017). Particularly small, non-vocalising bird species often are difficult to identify in the canopy of tall forests (Blake and Loiselle 2001).

My findings on the species richness increase due to increased cover of herbs suggest that increased insect abundance caused by the herb layer may provide more food resources especially for different insectivorous birds. Many studies showed that arthropod densities should be the highest in the understorey (Larrivée and Buddle 2009; Ulyshen 2011; Aikens et al. 2013). The result is in line with other studies from different regions, where the densities of insectivorous birds are higher in the lower vertical strata (Greenberg 1981; Koen 1988; Jayson and Mathew 2003; Chmel et al. 2016). Even though this result was obtained from the acoustic observations only, it is an important finding as this emphasizes the relevance of a structure-rich forest with a well-developed herb layer for avian biodiversity.

4.2. Vertical stratification of bird diversity

The main objective of the study was to identify differences in the avian diversity related to the forest management method and the vertical strata in the Wienerwald Biosphere Reserve. The outcome showed differences in species richness and individuals detected in the different vertical layers. The results showed that there are different bird communities in the vertical strata of the forest. Another part of the analysis revealed no evidence of a significant influence of forest management methods on overall species richness and individuals counted.

The generally low species richness discovered in the ground layer is in contrast to my expectations. The result is also contrary to the assumption mentioned above that species richness increases with an increased cover of herbs due to higher insect abundances and the associated possibility for coexistence of different birds. However, others showed that birds utilize mid-story or sub-canopy layers more than the ground layer and the top tree layer (Acharya and Vijayan 2017). Especially in closed canopy forests less food and microhabitat resources are available, which may lead to a low avian diversity at the ground layer. Furthermore, the presence of non-avian competitors and predators may affect the vertical distribution of birds (Acharya and Vijayan 2017). More data on the seasonal and/or daily stratification patterns of birds, the foliage, and the different food availability in different strata could contribute to a better understanding of the stratification patterns of birds in the Wienerwald Biosphere Reserve.

Birds may use the vertical strata at a different intensity due to the unequal distribution of resources in the vertical strata (Jayson and Mathew 2003; Ulyshen et al. 2011; Aikens et al. 2013). However, there are many factors influencing the vertical stratification patterns of vertebrates. Basham et al. (2022) indicated latitude as the most important explanatory variable for vertical stratification patterns. Gradients in rainfall, solar radiation, and seasonality across latitude result in different ecosystems. The abundance and richness of birds in forests closer to the equator tend to be stratified in the higher vertical strata (Basham et al. 2022). This could be due to differences in vertical forest structure depending on latitude. Forests closer to the equator are characterised by greater vertical complexity, species richness, tree density, canopy height, and canopy epiphytes (Gouveia et al. 2014; Ashton et al. 2016; Taylor et al. 2021). With increasing altitude, vegetation in the understorey increases and decreases in the canopy, leading to bird communities in montane forests preferring the understorey, while in lowland forests they tend to be in the canopy (Asner et al. 2014; Acharya and Vijayan 2017). The habitat structure plays an important role in vertical stratification, with more bird species in forests with a higher foliage density (Orians 1969; Pearson 1977; Acharya and Vijayan 2017).

Furthermore, what is also linked to foliage density is the distribution of food resources in forests (Thiel et al. 2021). Species in a bird community have different food requirements and therefore, the varying dietary groups with specialised foraging niches may have different stratification patterns (Pearson 1977; Bell 1982; Bernard 2001). Fluctuations in light and heat can affect the daily vertical movements of birds (Bell 1982; Rajaonarivelo et al. 2020). With rising temperatures and decreasing humidity levels in the middle of the day, birds in forests often shift downwards to avoid heat and hydric stress (Batáry et al. 2014; Parker (1995) as cited in Rajaonarivelo et al. 2020). In tropical forests, birds often use the canopy for their singing activities as the transmission of the sounds might be better in the higher strata compared to the dense vegetation in the lower strata (Brown and Handford 2003; van Dongen and Mulder 2006; Rajaonarivelo et al. 2020). Since the recordings were made in the early morning hours, the preference for singing in the higher strata or the fact that the species move to the lower strata at midday when temperatures are higher could explain the lower species richness in the lower strata. In addition to abiotic factors, birds are influenced by both competition and predation in their use of vertical strata (Chmel et al. 2016; Acharya and Vijayan 2017). The distribution to the different vertical layers with different resources allows the coexistence of multiple species (Chmel et al. 2016). Predation can be avoided by avoiding the canopy with the associated canopy predators such as raptors and owls (Rex et al. 2011;

Acharya and Vijayan 2017). Supporting this explanation, I found raptors like *Accipiter nisus* and *Buteo buteo* restricted to the upper layers. Birds disperse in the different strata because of their interactive reproductive behaviour, which is associated with courtship and territoriality (Basham et al. 2022).

In temperate forests, arthropods are decreasing in their density with increasing canopy height (Larrivée and Buddle 2009; Ulyshen 2011; Aikens et al. 2013). The general pattern of higher abundances of arthropods near the forest ground would imply that the insectivorous birds would also tend to forage close to the ground. However, many predators of forest arthropods are generally more often found in the upper canopy (Ulyshen 2011). My results reflect those of Ulyshen (2011) who also found that many predators of forest arthropods, including birds, are generally more often found in the upper canopy. Breeding birds are restricted in their habitat use by nesting site requirements (Hutto 1985). It is therefore not surprising that birds nesting in shrubs or trees have been found more often in the higher strata, while ground-nesting birds have been detected more often in the ground and herb layer. My results suggest that there are no preferred vertical strata due to the migration strategy. Most residents and short-distance migrants are found in the higher strata. These results are probably related to the fact that most of the species found are insectivores and birds nesting in trees, shrubs, or tree cavities. However, it remains unclear to which degree the use of vertical strata is attributed to migration behaviour. In this study, I found evidence for species using different vertical niches within guilds, which suggests that vertical stratification could be favoured by reduced interspecific competition. My results show a broad distribution of species richness within the individual feeding, migration, and nesting classes. This wide dispersion suggests that species within a class may partition in different vertical vegetation layers to allow coexistence.

Contrary to expectations, this study found a higher species richness in tree cavity nesters in the non-core zone (in the upper layers) and higher numbers of detected individuals in insectivores and tree cavity nesters in the non-core zone (in the upper layers). This finding was unexpected and suggests that the managed non-core zone of the Wienerwald Biosphere Reserve should provide more structures for insectivores and tree cavity nesters to allow the co-existence of many different species and many individuals. Unmanaged forests or forests with low management intensity usually have more mature trees with more standing and lying deadwood, as older trees are more prone to branch fall. Deadwood often provides many tree cavities for nesting. The falling of trees creates more openings in the canopy, which in turn leads to more growth of herbs and shrubs. A structure-rich forest with a consequent increased range of suitable microhabitats can enhance invertebrate biomass (Zanette et al. 2000; Perner and Malt 2003; Schall et al. 2018). Therefore, more microhabitats may be available in unmanaged forests, providing more foraging and nesting resources for different bird species (Bobiec 2005). Forest specialists are often found in forest stands with larger and/or older trees and higher availability of tree cavities for nesting (Brazaitis and Angelstam, 2004; Gil-Tena et al. 2009; Ghadiri Khanaposhtani et al. 2013; Bergner et al. 2015; Czeszczewik et al. 2015; Redolfi DeZan et al. 2016; Perry et al. 2018). Intensively managed forests with a simplified forest structure often result in habitat alteration and loss of microhabitats for birds (Newton 1994; Simon et al. 2000; Vanderwel et al. 2007b; Czeszczewik et al. 2015).

In contrast to many studies conducted in this field, the managed forest parts of the Wienerwald Biosphere Reserve do not undergo intensive use. Only as much wood should be removed from the managed forest stands as can grow back again - the biosphere reserve relies on sustainable management plans here. On the one hand, previously selected vital trees are removed to create space and light in the canopy for other trees. On the other hand, parts of the old trees are removed during end uses to provide more light for the germinating trees. Overall, the management plan is focused on natural diversity and regeneration. The data in this study showed that the non-core zone of the Wienerwald Biosphere Reserve has slightly older forests with more canopy openings, a more developed shrub layer, and generally a higher proportion of beech in the plots. The forests of the Wienerwald were designated as Biosphere Reserve by UNESCO in 2005. Therefore, process conservation in the core zone and the associated abandonment of use as a commercial forest were initiated less than 20 years ago. In the second half of the 19th century, the forests of the Wienerwald suffered intensive deforestation (Köck et al. 2009). Before becoming a Biosphere Reserve, the Wienerwald was protected by law as a green belt of forest and meadow around Vienna (Köck et al. 2009). Therefore, the most likely explanation for the small differences in bird diversity between the core zone and non-core zone is that the two forest areas do not yet differ greatly in structure and age. The effect that the designation as a biosphere reserve core zone should have will show only after a few years. Once the forest can again develop towards more natural stages, differences to the managed zones might be detectable. It may then also be possible to detect differences in bird diversity. Forest specialists that depend on structures such as tree holes and deadwood will then tend to be found in the core zone. However, the managed forest parts of the Wienerwald Biosphere Reserve will probably not change greatly, as no intensive use as a commercial forest is planned.

A further study with more focus on the habitat parameters and available resources in the two differently managed parts of the Wienerwald Biosphere Reserve is therefore suggested. For example, the proportion of deadwood or foliage would be further interesting parameters to investigate the influence of the two forest management methods on bird diversity. In addition, a comparison with other beech forests or commercial forests would be interesting. In this way, the effect of forestry measures on bird diversity in the Wienerwald Biosphere Reserve could be better illustrated. Furthermore, regular repetitions of the monitoring are necessary to observe and better represent the development of the core zone. In a few years, it will probably already be possible to see a difference in the habitat structures between the core zone and the managed non-core zone of the biosphere reserve. Additional research is needed to better understand the vertical distribution of birds in the Wienerwald Biosphere Reserve. For example, it would be possible to investigate in which strata various activities such as nesting, roosting, or foraging take place. This would provide additional information about and could demonstrate the sensitivity and vertical movements of birds to varying environmental conditions.

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List of abbreviations

The following table describes the definition of various abbreviations and acronyms used throughout this thesis. The page on which each one is defined or first used is also given.

Abbrevation	**Meaning**	**Page**
AICc	Akaike Information criterion corrected for small sample sizes. The smaller the AIC value, the better the model fit.	8
ΔAICc	The difference in AIC score between the best model and the model being compared.	8
AICcWt	AICc weight, which is the proportion of the total amount of predictive power provided by the full set of models contained in the model being assessed.	15
Cum.Wt	The sum of the AICc weights.	15
df	Degrees of freedom	55
k	The number of parameters in the model	20
LL	Log-likelihood. This is the value describing how likely the model is, given the data.	15
SD	Standard deviation	8
SE	Standard error	56

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Appendix

Appendix 1: Functional traits of all bird species found for diet (a = omnivore, b = granivore, c = insectivore, d = carnivore), migratory behaviour (a = resident, b = short-distance migrant, c = long-distance migrant), and nesting site (a = ground nester, b = nest in trees/shrubs, c = tree cavity nester, d = brood parasitism, e = earth cavity nester).

Species	Species English name	Family	Order	Diet	Migratory behaviour	Nesting site
Accipiter nisus	Sparrowhawk	Accipitridae	Accipitriformes	d	b	b
Aegithalos caudatus	Long-tailed tit	Aegithalidae	Passeriformes	c	a	b
Buteo buteo	Common buzzard	Accipitridae	Accipitriformes	d	a	b
Carduelis carduelis	European goldfinch	Fringillidae	Passeriformes	b	a	b
Certhia brachydactyla	Short-toed treecreeper	Certhiidae	Passeriformes	c	a	c
Certhia familiaris	Eurasian treecreeper	Certhiidae	Passeriformes	c	a	b
Chloris chloris	Green finch	Fringillidae	Passeriformes	b	a	b
Coccothraustes coccothraustes	Hawfinch	Fringillidae	Passeriformes	b	a	b
Columba oenas	Stock dove	Columbidae	Columbiformes	b	b	c
Columba palumbus	Wood pigeon	Columbidae	Columbiformes	b	b	b
Corvus corax	Common raven	Corvidae	Passeriformes	a	a	b
Corvus corone/cornix	Carrion/Hooded crow	Corvidae	Passeriformes	a	a	b
Corvus monedula	Western jackdaw	Corvidae	Passeriformes	a	a	c
Cuculus canorus	Common cuckoo	Cuculidae	Cuculiformes	c	c	d
Cyanistes caeruleus	Blue tit	Paridae	Passeriformes	c	b	c
Dendrocopos leucotos	White-backed woodpecker	Picidae	Piciformes	c	a	c
Dendrocopos major	Great spotted woodpecker	Picidae	Piciformes	c	a	c
Dendrocopos syriacus	Syrian woodpecker	Picidae	Piciformes	c	a	c
Dryobates minor	Lesser spotted woodpecker	Picidae	Piciformes	c	a	c
Dryocopus martius	Black woodpecker	Picidae	Piciformes	c	a	c
Emberiza citrinella	Yellowhammer	Emberizidae	Passeriformes	b	b	a
Erithacus rubecula	European robin	Muscicapidae	Passeriformes	c	b	a
Ficedula albicollis	Collared flycatcher	Muscicapidae	Passeriformes	c	c	c
Ficedula parva	Red-breasted flycatcher	Muscicapidae	Passeriformes	c	c	b
Fringilla coelebs	Common chaffinch	Fringillidae	Passeriformes	b	b	b
Garrulus glandarius	Eurasian jay	Corvidae	Passeriformes	a	a	b
Jynx torquilla	Eurasian wryneck	Picidae	Piciformes	c	c	c
Leiopicus medius	Middle spotted woodpecker	Picidae	Piciformes	c	a	c
Lophophanes cristatus	Crested tit	Paridae	Passeriformes	c	a	c
Merops apiaster	European bee-eater	Meropidae	Coraciiformes	c	c	e
Oriolus oriolus	Crested tit	Oriolidae	Passeriformes	c	c	b
Otus scops	Eurasian scops owl	Strigidae	Strigiformes	c	c	c
Parus major	Great tit	Paridae	Passeriformes	c	a	c
Periparus ater	Coal tit	Paridae	Passeriformes	c	a	c
Phylloscopus collybita	Common chiffchaff	Phylloscopidae	Passeriformes	c	c	a
Phylloscopus sibilatrix	Wood warbler	Phylloscopidae	Passeriformes	c	c	a
Phylloscopus trochilus	Willow warbler	Phylloscopidae	Passeriformes	c	c	a
Picus canus	Grey-headed woodpecker	Picidae	Piciformes	c	a	c
Picus viridis	European green woodpecker	Picidae	Piciformes	c	a	c
Poecile montanus	Willow tit	Paridae	Passeriformes	c	a	c
Poecile palustris	Marsh tit	Paridae	Passeriformes	c	a	c
Pyrrhula pyrrhula	Eurasian bullfinch	Fringillidae	Passeriformes	b	a	b
Regulus ignicapilla	Common firecrest	Regulidae	Passeriformes	c	b	b
Regulus regulus	Goldcrest	Regulidae	Passeriformes	c	b	b
Scolopax rusticola	Eurasian woodcock	Scolopacidae	Charadriiformes	d	b	a
Sitta europaea	European nuthatch	Sittidae	Passeriformes	c	a	c
Spinus spinus	Eurasian siskin	Fringillidae	Passeriformes	b	b	b
Streptopelia turtur	European turtle dove	Columbidae	Columbiformes	b	c	b
Strix aluco	Tawny owl	Strigidae	Strigiformes	d	a	c
Sturnus vulgaris	Common starling	Sturnidae	Passeriformes	c	b	c
Sylvia atricapilla	Eurasian blackcap	Sylviidae	Passeriformes	c	b	b
Troglodytes troglodytes	Eurasian wren	Troglodytidae	Passeriformes	c	b	a
Turdus merula	Common blackbird	Turdidae	Passeriformes	c	b	b
Turdus philomelos	Song thrush	Turdidae	Passeriformes	c	b	b
Turdus viscivorus	Mistle thrush	Turdidae	Passeriformes	c	b	b

Appendix 2: Classification of different environmental parameters and functional groups.

Type	**Class**	**R code reference**	**Description**
Diet	Omnivore	a	Diets varying from berries to insects, worms, fish, and small rodents
	Granivore	b	Feeds on the seeds of plants
	Insectivore	c	Feeds on insects
	Carnivore	d	Feeds on animal tissues like worms, small rodents or small birds
Migratory behaviour	Resident	a	Non-migratory species which remain in the breeding area during the winter
	Short-distance migrant	b	Species that migrate only short distances in winter or where only part of the population migrates
	Long-distance migrant	c	Species that migrate across the Mediterranean or the Sahara in winter
Nesting site	Ground nester	a	Nests at the ground or in the herb layer
	Tree or shrub breeder	b	Nests in shrubs or trees
	Tree-cavity nester	c	Nests in tree-cavities
	Brood parasitism	d	Eggs are laid in the nest of other species
	Earth-cavity breeder	e	Nests in earth-cavities

Appendix 3: Information about the survey plots.

Plot ID	Forest management	Forest division	Forest age	Beech proportion [%]	Exposition	Slope	Area [ha]	ID of the forest patch	Municipality
INSEL1	Non-core zone	1	151	95	NW	27	0.62	FR1_511_F1	Klosterneuburg
INSEL10	Non-core zone	1	136	90	NO	18	1.89	FR1_729_B1	Mauerbach
INSEL11	Non-core zone	1	151	95	NW	27	2.95	FR1_511_F1	Klosterneuburg
INSEL12	Non-core zone	1	136	90	NO	18	3.82	FR1_729_B1	Mauerbach
INSEL14	Non-core zone	2	136	95	NW	36	5.35	FR2_634_B1	Wien
INSEL15	Non-core zone	2	156	100	NW	36	2.63	FR2_634_A1	Wien
INSEL16	Non-core zone	2	136	100	NW	9	5.95	FR2_601_C1	Klosterneuburg
INSEL18	Non-core zone	2	116	95	N	27	20.09	FR2_532_A1	Klosterneuburg
INSEL19	Non-core zone	2	151	90	S	18	2.72	FR2_642_D0	Wien
INSEL2	Non-core zone	1	141	95	SO	9	3.73	FR1_726_A1	Mauerbach
INSEL21	Non-core zone	2	161	100	SO	27	5.18	FR2_525_A1	Klosterneuburg
INSEL22	Non-core zone	2	131	95	SW	18	9.13	FR2_641_B1	Wien
INSEL23	Non-core zone	2	131	100	O	27	3.85	FR2_620_A1	Wien
INSEL24	Non-core zone	2	131	100	O	27	10.56	FR2_620_A1	Wien
INSEL28	Non-core zone	4	151	95	NO	18	10.56	FR4_575_C1	Gablitz
INSEL3	Non-core zone	1	136	80	NW	27	7.13	FR1_517_D1	Klosterneuburg
INSEL30	Non-core zone	4	131	95	NO	18	10.83	FR4_333_C1	Pressbaum
INSEL31	Non-core zone	4	136	100	N	27	4.06	FR4_332_B1	Pressbaum
INSEL33	Non-core zone	4	141	91	N	18	6.1	FR4_340_A1	Pressbaum
INSEL4	Non-core zone	1	136	100	N	18	7.68	FR1_536_A1	St. Andrä-Wördern

Appendix 3, Continued: Information about the survey plots.

Plot ID	Forest management	Forest division	Forest age	Beech proportion [%]	Exposition	Slope	Area [ha]	ID of the forest patch	Municipality
INSEL5	Non-core zone	1	131	95	NO	18	8.55	FR1_516_C0	Klosterneuburg
INSEL6	Non-core zone	1	156	80	W	27	3.65	FR1_515_D0	Klosterneuburg
INSEL7	Non-core zone	1	146	90	W	18	2.24	FR1_655_D1	Mauerbach
INSEL8	Non-core zone	1	161	85	N	27	4.57	FR1_538_G1	St. Andrä-Wördern
INSEL9	Non-core zone	1	136	90	NO	18	5.94	FR1_729_B1	Mauerbach
KZO1	Core zone	1	111	85	SW	25	8.57	1653A0	Klosterneuburg
KZO100	Core zone	4	141	98	NW	25	2.91	461B0	Gablitz
KZO101	Core zone	4	111	80	N	20	9.26	461A1	Gablitz
KZO110	Core zone	4	136	80	NO	30	3.06	456E1	Gablitz
KZO12	Core zone	1	136	100	NW	20	14.6	1653G1	Klosterneuburg
KZO2	Core zone	1	116	100	NW	30	6.4	1653C1	Klosterneuburg
KZO20	Core zone	1	106	95	S	15	12.16	1659D0	Mauerbach
KZO24	Core zone	1	121	95	N	15	12.63	1659E0	Mauerbach
KZO3	Core zone	1	151	85	SW	25	15.32	1651C2	Mauerbach
KZO33	Core zone	2	146	90	NW	45	14.52	2612A0	Klosterneuburg
KZO42	Core zone	2	116	100	N	50	2.65	2611D0	Klosterneuburg
KZO43	Core zone	2	156	94	W	35	7.74	2611C0	Klosterneuburg
KZO52	Core zone	4	126	92	SW	20	2.94	4321A0	Tullnerbach
KZO59	Core zone	4	131	85	N	15	6.29	4661B1	Tulbing
KZO60	Core zone	4	131	95	NO	20	2.49	4661B2	Tulbing
KZO70	Core zone	4	136	90	NO	30	3.64	4661G1	Tubling
KZO84	Core zone	4	146	90	SO	30	4.29	456C0	Gablitz
KZO85	Core zone	4	141	93	S	35	3.75	456B0	Gablitz
KZO90	Core zone	4	161	80	NW	25	3.14	461E1	Gablitz
KZO91	Core zone	4	136	95	N	25	1.59	461D0	Gablitz
KZO92	Core zone	4	141	98	NO	20	5.38	462B2	Gablitz
KZO93	Core zone	4	111	92	NW	30	3.79	461C1	Gablitz
KZO94	Core zone	4	111	80	N	20	9.26	461A1	Gablitz
KZO96	Core zone	4	126	80	W	25	14.35	4327B1	Tullnerbach
KZO97	Core zone	4	126	80	W	25	14.35	4327B1	Tullnerbach

Appendix 4: Calculated habitat parameters for each survey point.

Point ID	DBH mean	DBH SD	Canopy cover mean	Canopy cover SD	Cover herbs mean	Cover shrubs mean
INSEL1_1	24.2	23.61	99.74	0.40	1.5	45
INSEL1_2	37.2	27.90	98.70	1.08	20	50
INSEL1_3	41	15.13	98.65	0.60	28	30
INSEL10_1	51.6	5.00	97.30	2.46	20	70
INSEL10_2	47.6	10.69	97.45	0.92	22	65
INSEL10_3	46.6	7.74	94.18	2.75	80	35
INSEL11_1	39.8	20.68	99.38	0.35	28	10
INSEL11_2	46.4	13.98	98.60	1.28	40	15
INSEL11_3	40.8	8.42	99.22	0.68	6	6
INSEL12_1	51	12.38	98.60	1.09	50	40
INSEL12_2	51.4	8.04	90.07	7.34	45	70
INSEL12_3	45.2	1.94	98.08	1.62	80	20
INSEL14_1	30.4	23.98	97.45	1.11	15	70
INSEL14_2	46.2	4.96	91.37	2.57	50	70
INSEL14_3	36.8	10.83	98.28	1.26	30	27
INSEL15_1	36.4	12.61	96.20	3.22	35	35
INSEL15_2	28.4	18.35	98.28	1.30	30	65
INSEL15_3	34	18.38	98.02	1.73	35	45
INSEL16_1	37	22.19	97.56	1.51	65	43
INSEL16_2	45.4	6.97	99.74	0.00	68	15
INSEL16_3	44.6	5.49	99.22	0.40	80	35
INSEL18_1	28.4	18.85	99.79	0.30	0.5	97
INSEL18_2	50.6	6.83	94.80	1.59	0.5	97
INSEL18_3	55.6	8.45	96.83	0.65	0.5	95
INSEL19_1	55.8	9.56	99.01	0.38	95	30
INSEL19_2	57.6	6.74	98.44	1.79	86	40
INSEL19_3	55.4	11.07	98.70	1.62	35	70
INSEL2_1	57.4	10.27	84.82	6.16	80	30
INSEL2_2	49.2	13.99	91.58	4.71	92	20
INSEL2_3	58.4	7.42	81.80	4.20	92	40
INSEL21_1	27.2	17.29	97.14	3.09	8	50
INSEL21_2	15.6	19.33	99.74	0.52	4	75
INSEL21_3	16.2	20.05	99.32	1.11	1	75
INSEL22_1	57.8	12.72	99.27	0.25	90	75
INSEL22_2	46.8	7.36	99.27	0.45	78	80
INSEL22_3	38.4	18.33	97.14	2.01	70	78
INSEL23_1	28.4	21.76	98.80	1.59	3	40
INSEL23_2	22.8	14.50	96.26	4.57	3	40
INSEL23_3	33.8	15.04	99.90	0.21	3	40
INSEL24_1	16.6	21.38	99.95	0.10	3	80
INSEL24_2	48.6	10.44	99.74	0.23	3	40
INSEL24_3	42.2	3.97	99.27	0.95	6	25
INSEL28_1	40.2	22.64	99.38	0.75	50	50
INSEL28_2	41.6	16.56	97.45	1.97	60	50
INSEL28_3	45.8	4.62	97.82	0.56	70	40
INSEL3_1	56.4	8.59	79.25	5.04	0.5	0.5
INSEL3_2	47.2	4.31	79.88	2.67	1	1
INSEL3_3	28	17.91	99.01	0.80	20	25
INSEL30_1	47.4	3.07	95.22	1.71	65	15
INSEL30_2	46.8	4.60	92.56	2.52	65	35
INSEL30_3	39	10.10	96.62	2.37	35	50
INSEL31_1	24.8	24.78	97.56	1.54	20	70
INSEL31_2	52.4	7.31	95.22	2.00	35	55
INSEL31_3	37.4	12.82	95.74	1.32	50	35
INSEL33_1	50.6	12.53	96.62	3.22	60	25
INSEL33_2	46	6.78	96.05	4.57	35	25
INSEL33_3	43.2	19.90	99.12	0.69	8	50
INSEL4_1	51.8	6.43	87.16	2.56	75	55
INSEL4_2	57.2	6.41	81.90	6.01	75	60
INSEL4_3	55	6.11	82.42	4.32	90	30
INSEL5_1	47.8	4.66	87.05	2.59	95	3
INSEL5_2	51	3.22	77.28	5.79	95	4
INSEL5_3	43.2	2.79	95.01	3.42	95	12
INSEL6_1	54.4	26.40	91.78	4.57	10	80
INSEL6_2	51.8	18.35	99.69	0.19	8	75
INSEL6_3	33.8	16.47	98.70	0.47	45	65

Appendix 4, Continued: Calculated habitat parameters for each survey point.

Point ID	DBH mean	DBH SD	Canopy cover mean	Canopy cover SD	Cover herbs mean	Cover shrubs mean
INSEL7_1	53.6	8.78	98.80	1.05	80	70
INSEL7_2	46	19.83	99.32	0.67	20	70
INSEL7_3	33.8	19.56	98.96	0.92	8	20
INSEL8_1	42.2	5.11	99.01	0.80	40	20
INSEL8_2	40.6	3.38	98.60	0.51	4	4
INSEL8_3	37	7.95	99.32	1.10	1	1
INSEL9_1	49.2	6.11	96.57	3.36	80	40
INSEL9_2	28.2	20.36	99.27	0.30	10	45
INSEL9_3	48	3.16	99.53	0.19	65	18
KZO1_1	43.4	9.67	99.90	0.13	70	1.5
KZO1_2	54.2	9.52	98.18	1.46	70	6
KZO1_3	47.2	11.20	98.02	1.78	75	15
KZO100_1	47.2	8.45	96.20	3.28	10	50
KZO100_2	30.6	23.37	98.34	1.76	10	65
KZO100_3	52	5.06	98.80	0.54	17	45
KZO101_1	42.6	11.39	98.28	1.46	20	20
KZO101_2	27.8	13.70	98.54	1.75	30	40
KZO101_3	31	20.28	98.34	2.08	35	40
KZO110_1	46.6	6.18	99.48	0.28	15	10
KZO110_2	40.2	3.06	98.49	1.20	10	13
KZO110_3	32.4	18.10	99.43	0.69	0.5	1
KZO12_1	43.4	4.45	99.69	0.25	70	5
KZO12_2	43.8	8.75	99.69	0.19	70	0.5
KZO12_3	43.8	5.04	99.84	0.21	30	0.5
KZO2_1	49	12.85	98.91	1.21	65	30
KZO2_2	40.8	25.95	98.18	1.67	40	45
KZO2_3	43.8	4.79	98.18	2.28	60	15
KZO20_1	44.4	8.16	99.17	0.92	83	5
KZO20_2	45.4	8.48	99.69	0.19	83	5
KZO20_3	48	8.88	99.53	0.81	85	5
KZO24_1	39.8	4.10	96.46	3.88	60	50
KZO24_2	43.6	7.17	99.69	0.30	30	25
KZO24_3	46.6	24.31	98.23	2.76	70	70
KZO3_1	45.4	22.39	99.64	0.27	8	70
KZO3_2	52.2	21.98	99.64	0.35	10	72
KZO3_3	50.2	8.26	99.43	0.25	55	50
KZO33_1	38.6	20.44	98.80	1.40	4	85
KZO33_2	42.6	9.60	98.86	0.85	10	75
KZO33_3	42	7.01	98.13	1.27	40	40
KZO42_1	18	16.63	99.90	0.21	0.5	90
KZO42_2	14	8.90	99.95	0.10	15	35
KZO42_3	40.4	21.88	97.19	1.29	30	30
KZO43_1	36.8	11.09	98.44	0.64	5	10
KZO43_2	54.4	9.39	97.50	1.66	8	30
KZO43_3	46.4	17.84	95.16	1.65	8	30
KZO52_1	40.2	4.12	98.70	0.33	15	10
KZO52_2	37	7.80	98.60	0.69	20	3
KZO52_3	47	9.01	98.54	0.78	25	30
KZO59_1	32	19.67	96.57	5.05	10	80
KZO59_2	43.8	10.17	99.38	0.58	8	90
KZO59_3	39.8	10.50	99.43	0.53	13	80
KZO60_1	25	20.52	99.79	0.19	8	40
KZO60_2	10.8	10.80	100.00	0.00	8	70
KZO60_3	14.6	13.51	99.90	0.13	15	65
KZO70_1	52	8.22	97.92	0.57	8	35
KZO70_2	37.6	8.82	96.41	4.10	15	40
KZO70_3	46.2	6.11	95.74	5.48	25	65
KZO84_1	37.4	25.66	93.19	4.70	80	50
KZO84_2	41.6	24.16	97.14	3.07	80	50
KZO84_3	19.8	15.04	99.74	0.16	20	85
KZO85_1	45.8	11.09	98.65	0.96	10	20
KZO85_2	40.6	10.38	96.93	1.52	5	5
KZO85_3	37.4	13.84	99.22	0.59	1	3
KZO90_1	20.8	11.96	99.48	0.47	0.5	20
KZO90_2	44.8	21.28	95.06	1.77	20	15
KZO90_3	29.2	18.02	98.39	0.83	25	15
KZO91_1	42.2	8.30	96.88	1.72	15	35

Appendix 4, Continued: Calculated habitat parameters for each survey point.

Point ID	DBH mean	DBH SD	Canopy cover mean	Canopy cover SD	Cover herbs mean	Cover shrubs mean
KZO91_2	37.4	4.32	91.42	5.32	15	35
KZO91_3	38.4	6.62	99.01	0.34	8	10
KZO92_1	21.8	15.94	99.01	0.53	25	45
KZO92_2	13.4	17.96	98.91	0.69	30	35
KZO92_3	8.8	5.64	99.79	0.19	6	20
KZO93_1	34.8	7.86	96.41	4.82	10	20
KZO93_2	46	6.39	95.89	4.08	15	8
KZO93_3	36.8	9.30	98.44	1.08	8	4
KZO94_1	38.2	7.36	98.23	1.62	25	15
KZO94_2	42.8	10.70	98.60	1.17	20	10
KZO94_3	43.4	11.84	96.93	1.38	17	3
KZO96_1	40.6	2.87	96.78	1.66	35	50
KZO96_2	36	9.44	96.62	1.40	13	15
KZO96_3	36.2	12.11	97.61	1.70	15	15
KZO97_1	14.8	8.66	98.54	0.76	3	80
KZO97_2	21.2	12.75	98.39	0.19	20	40
KZO97_3	15.4	19.40	98.44	1.10	10	70

Appendix 5: Correlogram showing Pearson's correlation coefficient between pairs of predictor variables measured. Coefficients in bold shows pairs highly correlated variable.

	Predictor Variables	1	2	3	4	5	6	7	8	9	10
1	Forestry management	1.00									
2	DBH mean	0.21	1.00								
3	DBH SD	0.01	-0.39	1.00							
4	Canopy Cover mean	-0.28	-0.40	0.24	1.00						
5	Canopy Cover SD	0.16	0.31	-0.12	-0.73	1.00					
6	Cover herbs mean	0.23	0.48	-0.25	-0.32	0.27	1.00				
7	Cover shrubs mean	0.18	-0.17	0.38	0.10	0.01	-0.15	1.00			
8	Forest age	0.36	-0.01	0.21	-0.02	-0.02	-0.12	0.12	1.00		
9	Beech proportion in %	0.27	-0.07	0.02	-0.02	0.03	0.19	0.14	0.03	1.00	
10	Slope	-0.23	-0.27	0.19	0.17	-0.14	-0.48	0.06	0.12	0.03	1.00

Appendix 6: Results of the GLM testing the effect of the habitat parameters on the forest management method. Variables with a significant effect are highlighted in bold.

Model	Response variable	Explanatory variable	Estimate	SE	z-value	p-value
Model	Forest management	DBH mean	0.036	0.021	1.669	0.095
		Canopy cover mean	-0.388	0.148	-2.613	**< 0.009**
		Canopy cover SD	-0.390	0.234	-1.667	0.096
		Cover shrubs mean	0.024	0.009	2.763	**< 0.006**
		Forest age	0.094	0.022	4.347	**< 0.001**
		Beech proportion	0.159	0.044	3.620	**< 0.001**
		Slope	-0.120	0.036	-3.360	**< 0.001**
Full model	Forest management	DBH mean	0.032	0.024	1.331	0.183
		DBH SD	0.004	0.038	0.117	0.907
		Canopy cover mean	-0.393	0.147	-2.680	**0.007**
		Canopy cover SD	-0.421	0.240	-1.753	0.080
		Cover shrubs mean	0.025	0.010	2.540	**0.011**
		Cover herbs mean	0.006	0.010	0.646	0.518
		Forest age	0.093	0.022	4.248	**< 0.001**
		Beech proportion	0.154	0.044	3.490	**< 0.001**
		Slope	-0.111	0.038	-2.939	**0.003**

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 7: Total abundance of species detected within the different strata (for auditive and visual observations).

	Auditive			Visual				
	A	**B**	**nA**	**A**	**B**	**C**	**nA**	**Total**
Accipiter nisus	NA	NA	NA	NA	NA	2	NA	2
Aegithalos caudatus	NA	NA	10	NA	NA	NA	NA	10
Buteo buteo	NA	NA	4	NA	1	3	NA	8
Certhia brachydactyla	NA	NA	1	NA	NA	NA	NA	1
Chloris chloris	NA	NA	3	NA	NA	NA	NA	3
Coccothraustes coccothraustes	NA	3	19	NA	2	2	NA	26
Columba oenas	NA	9	109	NA	10	23	NA	151
Columba palumbus	NA	16	101	NA	2	15	NA	134
Corvus corax	NA	NA	7	NA	NA	NA	NA	7
Corvus corone	NA	13	40	NA	3	13	NA	69
Corvus monedula	NA	1	NA	NA	NA	NA	NA	1
Cuculus canorus	NA	NA	22	NA	NA	NA	NA	22
Cyanistes caeruleus	3	37	167	2	19	6	NA	234
Dendrocopos major	NA	29	108	NA	32	8	NA	177
Dendrocopos syriacus	NA	2	NA	NA	2	NA	NA	4
Dryobates minor	NA	NA	3	NA	NA	1	NA	4
Dryocopus martius	NA	4	28	NA	3	1	NA	36
Emberiza citrinella	NA	1	8	NA	1	NA	NA	10
Erithacus rubecula	18	10	240	5	1	NA	NA	274
Ficedula albicollis	NA	1	161	1	11	5	NA	179
Fringilla coelebs	1	85	421	3	18	7	NA	535
Garrulus glandarius	NA	2	19	NA	2	5	NA	28
Leiopicus medius	NA	4	15	1	NA	1	NA	21
Lophophanes cristatus	NA	1	NA	NA	NA	NA	NA	1
Merops apiaster	NA	NA	1	NA	NA	NA	NA	1
Oriolus oriolus	NA	NA	9	NA	NA	NA	NA	9
Parus major	3	74	339	13	35	13	1	478
Phylloscopus trochilus	NA	NA	1	NA	NA	NA	NA	1
Picus canus	NA	NA	15	NA	1	NA	NA	16
Picus viridis	NA	5	22	NA	1	1	NA	29
Pyrrhula pyrrhula	NA	2	NA	NA	NA	NA	NA	2
Regulus ignicapilla	NA	5	26	NA	NA	NA	NA	31
Sitta europaea	NA	38	141	NA	9	11	NA	199
Spinus spinus	NA	10	NA	NA	NA	1	NA	11
Sturnus vulgaris	27	232	1046	18	64	73	NA	1460
Sylvia atricapilla	13	1	188	1	2	NA	NA	205
Turdus merula	18	17	201	20	16	2	NA	274
Turdus philomelos	NA	22	156	NA	NA	1	NA	179
Turdus viscivorus	NA	5	28	NA	1	1	NA	35
All species	**83**	**629**	**3659**	**64**	**236**	**195**	**1**	**4867**

Appendix 8: Results of the ANOVA performed on the GLMMs with a ΔAICc < 2 and on the full model for the auditive data. Variables with a significant effect are highlighted in bold.

Model	**Response variable**	**Explanatory variable**	χ^2	**df**	**p-value**
Model16	Species richness	DBH mean	0.478	1	0.489
		DBH SD	2.696	1	0.101
		Canopy cover mean	6.479	1	**0.011**
		Canopy cover SD	2.704	1	0.100
		Cover herbs mean	3.907	1	**0.048**
Model13	Species richness	DBH mean	1.004	1	0.316
		DBH SD	2.220	1	0.136
		Canopy cover mean	3.830	1	0.050
		Canopy cover SD	1.392	1	0.238
		Cover shrubs mean	1.296	1	0.255
		Cover herbs mean	**3.851**	**1**	**< 0.050**
		Beech proportion	3.195	1	0.074
Model14	Species richness	DBH mean	0.642	1	0.423
		DBH SD	1.532	1	0.216
		Canopy cover mean	5.024	1	**0.025**
		Canopy cover SD	2.164	1	0.141
		Cover shrubs mean	1.611	1	0.204
		Cover herbs mean	4.281	1	**0.039**
Model17	Species richness	DBH mean	2.602	1	0.107
		DBH SD	2.892	1	0.089
		Canopy cover mean	6.482	1	**0.011**
		Canopy cover SD	3.075	1	0.079
Model19	Species richness	DBH mean	1.291	1	0.256
		Canopy cover mean	8.190	1	**0.004**
		Canopy cover SD	3.432	1	0.064
Model1	Species richness	DBH mean	1.228	1	0.268
		DBH SD	3.060	1	0.080
		Canopy cover mean	3.364	1	0.067
		Canopy cover SD	1.192	1	0.275
		Cover shrubs mean	1.016	1	0.314
		Cover herbs mean	1.537	1	0.215
		Forest age	0.571	1	0.450
		Beech proportion	3.581	1	0.058
		Slope	0.254	1	0.614
Model38	Total abundance	DBH mean	0.151	1	0.698
		DBH SD	1.448	1	0.229
		Canopy cover mean	0.346	1	0.556
Model39	Total abundance	DBH mean	0.679	1	0.410
		DBH SD	1.995	1	0.158
		Canopy cover mean	1.319	1	0.251
Model37	Total abundance	DBH mean	0.201	1	0.654
		DBH SD	1.279	1	0.258
		Canopy cover mean	1.421	1	0.233
		Canopy cover SD	1.151	1	0.283
Model21	Total abundance	DBH mean	0.339	1	0.560
		DBH SD	1.928	1	0.165
		Canopy cover mean	0.479	1	0.489
		Canopy cover SD	0.163	1	0.686
		Cover shrubs mean	0.066	1	0.797
		Cover herbs mean	0.492	1	0.483
		Forest age	2.953	1	0.086
		Beech proportion	0.958	1	0.328
		Slope	0.677	1	0.411

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 9: Results of the ANOVA performed on the GLMMs with a ΔAICc < 2 and on the full model for the visual data. Variables with a significant effect are highlighted in bold.

Model	**Response variable**	**Explanatory variable**	χ^2	**Df**	**p-value**
Model19	Species richness	DBH mean	3.492	1	0.062
		Canopy cover mean	0.422	1	0.516
		Canopy cover SD	3.155	1	0.076
Model20	Species richness	DBH mean	3.078	1	0.079
		Canopy cover mean	7.806	1	**0.005**
Model1	Species richness	DBH mean	2.449	1	0.118
		DBH SD	0.022	1	0.883
		Canopy cover mean	0.518	1	0.472
		Canopy cover SD	2.583	1	0.108
		Cover shrubs mean	0.010	1	0.921
		Cover herbs mean	0.060	1	0.807
		Forest age	0.075	1	0.784
		Beech proportion	1.644	1	0.200
		Slope	0.098	1	0.754
Model39	Total abundance	DBH mean	3.414	1	0.065
		Canopy cover mean	0.000	1	0.985
		Canopy cover SD	1.390	1	0.238
Model38	Total abundance	DBH mean	3.830	1	0.050
		DBH SD	0.672	1	0.412
		Canopy cover mean	1.655	1	0.198
Model37	Total abundance	**DBH mean**	3.890	1	**0.049**
		DBH SD	0.466	1	0.495
		Canopy cover mean	0.009	1	0.925
		Canopy cover SD	1.183	1	0.277
Model21	Total abundance	**DBH mean**	4.404	1	**0.036**
		DBH SD	0.505	1	0.477
		Canopy cover mean	0.019	1	0.890
		Canopy cover SD	1.144	1	0.285
		Cover shrubs mean	0.005	1	0.945
		Cover herbs mean	0.844	1	0.358
		Forest age	0.072	1	0.788
		Beech proportion	0.046	1	0.830
		Slope	0.323	1	0.570

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 10: Results of the ANOVA performed on the GLMs. Variables with a significant effect are highlighted in bold.

Method	Response variable	Explanatory variable	χ^2	df	p-value
Auditive	Species richness	Stratum	176.33	1	**< 0.001**
		Forest management method	3.72	1	0.054
Auditive	Number of indivudals detected	Stratum	352.41	1	**< 0.001**
		Forest management method	6.70	1	**0.010**
Visual	Species richness	Stratum	9.09	2	**0.011**
		Forest management method	2.97	1	0.084
Visual	Number of individuals detected	Stratum	15.97	2	**< 0.001**
		Forest management method	6.93	1	**0.008**

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 11: Post hoc comparisons of interactions between stratum and forest management methods. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Response variable	Comparison of parameter interactions	Estimate	SE	z-value	p-value
Auditive	Species richness	A core – B core	-1.553	0.170	-9.117	**< 0.001**
		A core – A noncore	-0.306	0.243	-1.258	0.284
		A noncore – Stratum- B noncore	-1.421	0.209	-6.844	**< 0.001**
		B core – B noncore	-0.173	0.118	-1.563	0.284
Auditive	Total abundance	A core – B core	-1.911	0.158	-12.130	**< 0.001**
		A core – A noncore	-0.447	0.220	-2.034	0.0839
		A noncore – Stratum- B noncore	-1.635	0.179	-9.200	**< 0.001**
		B core – B noncore	-0.171	0.093	-1.992	0.0839
Visual	Species richness	A – B	-0.445	0.163	-2.738	**0.019**
		A – C	-0.216	0.167	-1.291	0.197
		B – C	0.229	0.117	1.965	0.099
Visual	Species richness	A core – B core	-0.411	0.255	-1.611	0.858
		A core – C core	-0.170	0.262	-0.650	1.000
		B core – C core	0.240	0.183	1.315	1.000
		A core – A noncore	-0.126	0.291	-0.435	1.000
		B core – B noncore	-0.188	0.158	-1.185	1.000
		C core – C noncore	-0.210	0.177	-1.187	1.000
		A noncore – Stratum- B noncore	-0.472	0.211	-2.233	0.230
		A noncore – C noncore	-0.254	0.218	-1.167	1.000
		B noncore – C noncore	0.218	0.151	1.439	1.000
Visual	Total abundance	A – B	-0.530	0.141	-3.760	**< 0.001**
		A – C	-0.339	0.144	-2.354	**0.037**
		B – C	0.191	0.097	1.972	**0.049**
Visual	Total abundance	A core – B core	-0.356	0.213	-1.672	0.473
		A core – C core	-0.114	0.219	-0.518	1.000
		B core – C core	0.242	0.156	1.552	0.482
		A core – A noncore	0.057	0.251	0.227	1.000
		B core – B noncore	-0.245	0.133	-1.836	0.398
		C core – C noncore	-0.334	0.148	-2.264	0.165
		A noncore – Stratum- B noncore	-0.658	0.188	-3.492	**0.004**
		A noncore – C noncore	-0.505	0.192	-2.630	0.068
		B noncore – C noncore	0.153	0.123	1.244	0.641

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 12: Results of the ANOVA performed on the GLMs for dietary groups. Variables with a significant effect are highlighted in bold.

Method	Response variable	Explanatory variable	χ^2	df	p-value
Auditive	Species richness	Stratum * Diet	135.37	5	**< 0.001**
		Forest management method * Diet	5.68	3	0.128
Auditive	Number of individuals detected	Stratum * Diet	209.58	5	**< 0.001**
		Forest management method * Diet	12,52	3	**0.006**
Visual	Species richness	Stratum * Diet	8.08	9	0.526
		Forest management method * Diet	0.92	4	0.921
Visual	Number of individuals detected	Stratum * Diet	16.72	9	0.053
		Forest management method * Diet	4.85	4	0.303

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 13: Results of post hoc comparisons of interactions within the dietary groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Response variable	Comparison of parameter interactions	Estimate	SE	z-value	p-value
Auditive	Species richness	A/granivores – B/granivores	-0.560	1.005	-0.557	1
		A/insectivores – B/insectivores	-1.157	0.135	-8.544	**< 0.001**
		A/granivores– A/insectivores	-0.369	1.007	-0.367	1
		B/omnivores– B/granivores	-0.495	0.270	-1.836	0.398
		B/omnivores – B/insectivores	-1.462	0.257	-5.684	**< 0.001**
		B/omnivores – B/carnivores	0.065	1.031	0.063	1
		B/granivores – B/insectivores	-0.966	0.118	-8.219	**< 0.001**
		B/granivores – B/carnivores	0.560	1.005	0.557	1
		B/insectivores – B/carnivores	1.526	1.002	1.523	0.638
Auditive	Species richness	Core/B/omnivores – Noncore/B omnivores	-0.223	0.539	-0.414	1
		Core/A/granivores – Core/B/granivores	-0.507	1.006	-0.503	1
		Core/B/granivores – Noncore/B/granivores	-0.292	0.251	-1.165	0.732
		Core/A/insectivores – Core/B/insectivores	-1.237	0.177	-7.001	**< 0.001**
		Noncore/A/insectivores – Noncore/B/insectivores	-1.130	0.218	-5.188	**< 0.001**
		Core/A/insectivores – Noncore/A/insectivores	-0.332	0.244	-1.358	0.698
		Core/B/insectivores – Noncore/B/insectivores	-0.225	0.138	-1.633	0.512
Auditive	Total abundance	A/granivores – B/granivores	-1.317	1.002	-1.314	0.756
		A/insectivores – B/insecitvores	-1.348	0.121	-11.127	**< 0.001**
		A/granivores– A/insectivores	-0.557	1.006	-0.553	1
		B/omnivores– B/granivores	-1.135	0.246	-4.619	**< 0.001**
		B/omnivores – B/insectivores	-1.722	0.241	-7.149	**< 0.001**
		B/omnivores – B/carnivores	0.182	1.027	0.177	1
		B/granivores – B/insectivores	-0.588	0.085	-6.894	**< 0.001**
		B/granivores – B/carnivores	1.317	1.002	1.314	0.756
		B/insectivores – B/carnivores	1.905	1.001	1.902	0.286
Auditive	Total abundance	Core/B/omnivores – Noncore/B omnivores	-0.056	0.526	-0.107	0.915
		Core/A/granivores – Core/B/granivores	-1.280	1.003	-1.276	0.606
		Core/B/granivores – Noncore/B/granivores	-0.212	0.176	-1.205	0.606
		Core/A/insectivores – Core/B/insectivores	-1.470	0.163	-9.002	**< 0.001**
		Noncore/A/insectivores – Noncore/B/insectivores	-1.305	0.186	-7.003	**< 0.001**
		Core/A/insectivores – Noncore/A/insectivores	-0.470	0.221	-2.127	0.134
		Core/B/insectivores – Noncore/B/insectivores	-0.306	0.112	-2.732	**0.032**
Visual	Species richness	A/granivores – B/granivores	-0.032	0.604	-0.053	1.000
		A/granivores – C/granivores	-0.022	0.596	-0.036	1.000
		B/granivores – C/granivores	0.010	0.229	0.045	1.000
		A/insectivores – B/insectivores	-0.369	0.172	-2.143	0.642
		A/insectivores – C/insectivores	-0.116	0.195	-0.597	1.000
		B/insectivores – C/insectivores	0.252	0.155	1.631	1.000
		B/omnivores – C/omnivores	-0.118	0.506	-0.233	1.000
		B/carnivores – C/carnivores	0.000	1.095	0.000	1.000
		A/granivores – A/insectivores	-0.140	0.596	-0.235	1.000
		B/omnivores – B/granivores	-0.032	0.481	-0.066	1.000
		B/omnivores – B/insectivores	-0.508	0.456	-1.115	1.000
		B/omnivores – B/carnivores	0.000	1.095	0.000	1.000
		B/granivores – B/insectivores	-0.477	0.198	-2.411	0.334

Appendix 13, continued: Results of post hoc comparisons of interactions within the dietary groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Response variable	Comparison of parameter interactions	Estimate	SE	z-value	p-value
		B/granivores – B/carnivores	0.032	1.016	0.031	1.000
		B/insectivores – B/carnivores	0.508	1.004	0.506	1.000
		C/omnivores – C/granivores	0.096	0.277	0.347	1.000
		C/omnivores – C/insectivores	-0.138	0.268	-0.516	1.000
		C/omnivores – C/carnivores	0.118	0.506	0.233	1.000
		C/granivores– C/insectivores	-0.234	0.193	-1.212	1.000
		C/granivores– C/carnivores	0.022	0.470	0.046	1.000
		C/insectivores – C/carnivores	0.256	0.465	0.551	1.000
Visual	Species richness	Core/A/insectivores – Noncore/A/ insectivores	-0.062	0.297	-0.207	1.000
		Core/B/omnivores – Noncore/B/omnivores	0.000	1.118	0.000	1.000
		Core/B/insectivores – Noncore/B/ insectivores	-0.177	0.181	-0.981	1.000
		Core/C/omnivores – Noncore/C/omnivores	-0.154	0.567	-0.272	1.000
		Core/C/granivores – Noncore/C/granivores	-0.044	0.292	-0.152	1.000
		Core/C/insectivores – Noncore/C/insectivores	-0.056	0.259	-0.215	1.000
		Core/C/carnivores – Noncore/C/carnivores	0.000	1.118	0.000	1.000
		Core/A/insectivores – Core/B/insectivores	-0.300	0.264	-1.137	1.000
		Core/A/insectivores – Core/C/insectivores	-0.118	0.300	-0.393	1.000
		Core/B/insectivores – Core/C/insectivores	0.182	0.244	0.747	1.000
		Noncore/A/insectivores – Noncore/B/insectivores	-0.416	0.227	-1.832	1.000
		Noncore/A/insectivores – Noncore/C/insectivores	-0.112	0.256	-0.436	1.000
		Noncore/B/insectivores – Noncore/C/insectivores	0.304	0.200	1.519	1.000
		Core/B/omnivores – Core/C/omnivores	0.000	1.118	0.000	1.000
		Core/B/granivores – Core/C/granivores	0.069	0.329	0.210	1.000
		Noncore/B/omnivores – Noncore/C/omnivores	-0.154	0.567	-0.272	1.000
		Noncore/B/granivores – Noncore/C/granivores	-0.044	0.320	-0.139	1.000
		Noncore/B/carnivores – Noncore/C/carnivores	0.000	1.118	0.000	1.000
Visual	Total abundance	A/granivores – B/granivores	-0.280	0.598	-0.467	1.000
		A/granivores – C/granivores	-0.515	0.589	-0.875	1.000
		B/granivores – C/granivores	-0.236	0.193	-1.219	1.000
		A/insectivores – B/insectivores	-0.455	0.148	-3.079	**0.023**
		A/insectivores – C/insectivores	-0.173	0.167	-1.034	1.000
		B/insectivores – C/insectivores	0.282	0.130	2.168	0.302
		B/omnivores – B/granivores	0.308	0.368	0.837	1.000
		B/omnivores – B/insectivores	-0.289	0.341	-0.846	1.000
		B/omnivores – B/carnivores	0.588	1.054	0.558	1.000
		B/granivores – B/insectivores	-0.597	0.173	-3.458	**0.007**
		B/granivores – B/carnivores	0.280	1.012	0.276	1.000
		B/insectivores – B/carnivores	0.877	1.003	0.874	1.000
Visual	Total abundance	Core/A/insectivores– Noncore/A/insectivores	0.102	0.256	0.399	1.000
		Core/B/omnivores – Noncore/B/omnivores	-0.693	1.061	-0.654	1.000
		Core/B/insectivores– Noncore/B/insectivores	-0.262	0.152	-1.726	1.000
		Core/C/omnivores – Noncore/C/omnivores	-0.606	0.544	-1.115	1.000
		Core/C/granivores – Noncore/C/granivores	-0.113	0.228	-0.496	1.000
		Core/C/insectivores– Noncore/C/insectivores	-0.255	0.224	-1.139	1.000
		Core/C/carnivores – Noncore/C/carnivores	0.000	1.118	0.000	1.000
		Core/A/insectivores– Core/B/insectivores	-0.245	0.221	-1.110	1.000
		Core/A/insectivores– Core/C/insectivores	0.039	0.258	0.150	1.000
		Core/B/insectivores– Core/C/insectivores	0.284	0.216	1.316	1.000
		Noncore/A/insectivores– Noncore/B/insectivores	-0.609	0.200	-3.047	**0.042**
		Noncore/A/insectivores– Noncore/C/insectivores	-0.319	0.222	-1.437	1.000
		Noncore/B/insectivores– Noncore/C/insectivores	0.291	0.163	1.783	1.000
		Core/B/omnivores – Core/C/omnivores	0.000	1.118	0.000	1.000
		Core/B/granivores – Core/C/granivores	-0.054	0.272	-0.199	1.000
		Noncore/B/omnivores – Noncore/C/omnivores	0.087	0.413	0.211	1.000
		Noncore/B/granivores – Noncore/C/granivores	-0.410	0.275	-1.491	1.000
		Noncore/B/carnivores – Noncore/C/carnivores	0.000	1.118	0.000	1.000

Appendix 14: Results of the ANOVA performed on the GLMs for migratory behaviour groups. Variables with a significant effect are highlighted in bold.

Method	Response variable	Explanatory variable	χ^2	df	p-value
Auditive	Species richness	Stratum * Migratory behaviour group	53.63	5	**< 0.001**
		Forest management method * Migratory behaviour group	5.35	3	0.148
Auditive	Total abundance	Stratum * Migratory behaviour group	139.29	6	**< 0.001**
		Forest management method * Migratory behaviour group	10.65	3	**0.014**
Visual	Species richness	Stratum * Migratory behaviour group	2.75	8	0.949
		Forest management method * Migratory behaviour group	1.10	3	0.777
Visual	Total abundance	Stratum * Migratory behaviour group	5.69	8	0.682
		Forest management method * Migratory behaviour group	3.18	3	0.365

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 15: Results of post hoc comparisons of interactions within the migratory behaviour groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Response variable	Comparison of parameter interactions	Estimate	SE	z-value	p-value
Auditive	Species richness	A/residents – B/residents	-1.200	0.582	-2.055	0.319
		A/short-distance– B/short-distance	-0.861	0.143	-6.003	**< 0.001**
		A/long-distance – B/long-distance	< 0.001	1.160	0	1
		A/residents– A/short-distance	-0.324	0.591	-0.549	1
		A/residents – A/long-distance	< 0.001	1.160	0	1
		A/short-distance – A/long-distance	-0.324	1.010	0.322	1
		B/residents– B/short-distance	-0.010	0.102	0.102	1
		B/residents – B/long-distance	1.200	0.582	2.055	0.319
		B/short-distance – B/long-distance	1.900	0.582	2.037	0.319
Auditive	Species richness	Core/A/residents–Noncore/A/residents	< 0.001	1.225	0	1
		Core/B/residents – Noncore/B/ residents	-0.355	0.158	-2.24	0.201
		Core/A/short-distance – Noncore/A/short-distance	-0.226	0.252	-0.899	1
		Core/B/short-distance – Noncore/B/short-distance	-0.067	0.181	-0.373	1
		Core/B/long-distance – Noncore/B/long-distance	< 0.001	1.225	0	1
		Noncore/A/long-distance – Noncore/B/long-distance	< 0.001	1.225	0	1
		Core/A/residents –Core/B/residents	-1.106	1.004	-1.102	1
		Noncore/A/residents – Noncore/B/residents	-1.46	0.72	-2.029	0.297
		Core/A/short-distance –Core/B/short-distance	-0.936	0.181	-5.17	**< 0.001**
		Noncore/A/short-distance – Noncore/B/short-distance	-0.777	0.252	-3.087	**0.0182**
Auditive	Total abundance	A/residents – B/residents	-1.606	0.580	-2.768	**0.040**
		A/short-distance– B/short-distance	-1.211	0.125	-9.679	**< 0.001**
		A/long-distance – B/long-distance	-0.288	1.118	-0.257	1
		A/residents– A/short-distance	-0.519	0.588	-0.883	1
		A/residents – A/long-distance	< 0.001	1.155	0.000	1
		A/short-distance – A/long-distance	0.519	1.006	0.516	1
		B/residents– B/short-distance	-0.125	0.080	-1.557	0.598
		B/residents – B/long-distance	1.318	0.503	2.619	0.053
		B/short-distance – B/long-distance	1.443	0.503	2.869	**0.033**
Auditive	Total abundance	Core/A/residents–Noncore/A/residents	< 0.001	1.225	0	1.000
		Core/B/residents – Noncore/B/ residents	-0.397	0.128	-3.106	**0.015**
		Core/A/short-distance – Noncore/A/short-distance	-0.390	0.226	-1.728	0.504
		Core/B/short-distance – Noncore/B/short-distance	-0.057	0.138	-0.410	1.000
		Core/B/long-distance – Noncore/B/long-distance	-0.406	1.155	-0.351	1.000
		Noncore/A/long-distance – Noncore/B/long-distance	-0.406	1.155	-0.351	1.000

Appendix 15, Continued: Results of post hoc comparisons of interactions within the migratory behaviour groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Response variable	Comparison of parameter interactions	Estimate	SE	z-value	p-value
		Core/A/residents –Core/B/residents	-1.504	1.002	-1.500	0.668
		Noncore/A/residents – Noncore/B/residents	-1.901	0.715	-2.658	0.055
		Core/A/short-distance –Core/B/short-distance	-1.360	0.164	-8.277	**< 0.001**
		Noncore/A/short-distance – Noncore/B/short-distance	-1.026	0.208	-4.939	**< 0.001**
Visual	Species richness	A/residents – B/residents	-0.274	0.288	-0.951	1.000
		A/residents – C/residents	-0.219	0.296	-0.741	1.000
		B/residents – C/residents	0.055	0.166	0.333	1.000
		A/short–distance – B/short–distance	-0.143	0.210	-0.681	1.000
		A/short–distance – C/short–distance	0.009	0.212	0.044	1.000
		B/short–distance – C/short–distance	0.152	0.174	0.875	1.000
		A/long–distance– B/long–distance	-0.080	1.038	-0.077	1.000
		A/long–distance– C/long–distance	0.000	1.095	0.000	1.000
		B/long–distance– C/long–distance	0.080	0.526	0.152	1.000
		A/residents – A/short–distance	-0.051	0.318	-0.161	1.000
		A/short–distance – A/long–distance	0.125	1.015	0.123	1.000
		B/residents – B/short–distance	0.080	0.163	0.492	1.000
		B/residents – B/long–distance	0.268	0.298	0.901	1.000
		B/short–distance – B/long–distance	0.188	0.303	0.622	1.000
		C/residents – C/short–distance	0.177	0.178	0.998	1.000
		C/residents – C/long–distance	0.293	0.465	0.631	1.000
		C/short–distance – C/long–distance	0.116	0.464	0.249	1.000
Visual	Species richness	Core/A/residents – Noncore/A/residents	-0.134	0.540	-0.247	1.000
		Core/A/short–distance – Noncore/A/short–distance	-0.223	0.349	-0.640	1.000
		Core/B/residents – Noncore/B/residents	-0.118	0.223	-0.531	1.000
		Core/B/short–distance – Noncore/B/short–distance	-0.108	0.248	-0.434	1.000
		Core/B/long–distance – Noncore/B/long–distance	0.154	0.556	0.277	1.000
		Core/C/residents – Noncore/C/residents	0.039	0.264	0.147	1.000
		Core/C/short–distance – Noncore/C/short–distance	-0.153	0.251	-0.609	1.000
		Core/C/long–distance – Noncore/C/long–distance	0.000	0.913	0.000	1.000
		Core/A/residents – Core/B/residents	-0.278	0.444	-0.626	1.000
		Core/A/residents – Core/C/residents	-0.319	0.461	-0.691	1.000
		Core/B/residents – Core/C/residents	-0.041	0.275	-0.148	1.000
		Core/A/short–distance – Core/B/short–distance	-0.205	0.329	-0.622	1.000
		Core/A/short–distance – Core/C/short–distance	-0.035	0.325	-0.108	1.000
		Core/B/short–distance – Core/C/short–distance	0.170	0.267	0.635	1.000
		Core/B/long–distance – Core/C/long–distance	0.154	0.690	0.223	1.000
		Noncore/A/residents – Noncore/B/residents	-0.262	0.380	-0.691	1.000
		Noncore/A/residents – Noncore/C/residents	-0.146	0.387	-0.378	1.000
		Noncore/B/residents – Noncore/C/residents	0.116	0.209	0.557	1.000
		Noncore/A/short–distance – Noncore/B/short–distance	-0.089	0.273	-0.327	1.000
		Noncore/A/short–distance – Noncore/C/short–distance	0.035	0.280	0.125	1.000
		Noncore/B/short–distance – Noncore/C/short–distance	0.124	0.230	0.540	1.000
		Noncore/B/long–distance – Noncore/C/long–distance	0.000	0.817	0.000	1.000
Visual	Total abundance	A/residents – B/residents	-0.362	0.246	-1.473	1.000
		A/residents – C/residents	-0.225	0.254	-0.886	1.000
		B/residents – C/residents	0.138	0.140	0.985	1.000
		A/short–distance – B/short–distance	-0.198	0.183	-1.084	1.000
		A/short–distance – C/short–distance	-0.218	0.180	-1.214	1.000
		B/short–distance – C/short–distance	-0.020	0.143	-0.140	1.000
		A/long–distance– B/long–distance	-0.348	1.029	-0.338	1.000
		A/long–distance– C/long–distance	0.000	1.095	0.000	1.000
		B/long–distance– C/long–distance	0.348	0.509	0.685	1.000

Appendix 15, Continued: Results of post hoc comparisons of interactions within the migratory behaviour groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	**Response variable**	**Comparison of parameter interactions**	**Estimate**	**SE**	**z-value**	**p-value**
		A/residents – A/short–distance	-0.004	0.275	-0.013	1.000
		A/short–distance – A/long–distance	0.383	1.011	0.379	1.000
		B/residents – B/short–distance	0.161	0.137	1.175	1.000
		B/residents – B/long–distance	0.394	0.258	1.523	1.000
		B/short–distance – B/long–distance	0.233	0.264	0.884	1.000
		C/residents – C/short–distance	0.003	0.146	0.020	1.000
		C/residents – C/long–distance	0.604	0.460	1.313	1.000
		C/short–distance – C/long–distance	0.601	0.458	1.313	1.000
Visual	Total abundance	Core/A/residents – Noncore/A/residents	0.260	0.460	0.565	1.000
		Core/A/short–distance – Noncore/A/short–distance	-0.141	0.304	-0.463	1.000
		Core/B/residents – Noncore/B/residents	-0.286	0.187	-1.531	1.000
		Core/B/short–distance – Noncore/B/short–distance	-0.015	0.210	-0.073	1.000
		Core/B/long–distance – Noncore/B/long–distance	0.118	0.486	0.242	1.000
		Core/C/residents – Noncore/C/residents	-0.175	0.235	-0.745	1.000
		Core/C/short–distance – Noncore/C/short–distance	-0.236	0.198	-1.191	1.000
		Core/C/long–distance – Noncore/C/long–distance	0.000	0.913	0.000	1.000
		Core/A/residents – Core/B/residents	-0.054	0.350	-0.156	1.000
		Core/A/residents – Core/C/residents	0.025	0.372	0.068	1.000
		Core/B/residents – Core/C/residents	0.080	0.247	0.323	1.000
		Core/A/short–distance – Core/B/short–distance	-0.267	0.280	-0.955	1.000
		Core/A/short–distance – Core/C/short–distance	-0.169	0.274	-0.618	1.000
		Core/B/short–distance – Core/C/short–distance	0.098	0.219	0.448	1.000
		Core/B/long–distance – Core/C/long–distance	0.406	0.667	0.608	1.000
		Noncore/A/residents – Noncore/B/residents	-0.600	0.351	-1.709	1.000
		Noncore/A/residents – Noncore/C/residents	-0.409	0.358	-1.144	1.000
		Noncore/B/residents – Noncore/C/residents	0.191	0.170	1.124	1.000
		Noncore/A/short–distance – Noncore/B/short–distance	-0.142	0.242	-0.585	1.000
		Noncore/A/short–distance – Noncore/C/short–distance	-0.264	0.239	-1.106	1.000
		Noncore/B/short–distance – Noncore/C/short–distance	-0.123	0.188	-0.650	1.000
		Noncore/B/long–distance – Noncore/C/long–distance	0.288	0.791	0.364	1.000

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 16: Results of the ANOVA performed on the GLMs for the nesting site groups. Variables with a significant effect are highlighted in bold.

Method	Response variable	Explanatory variable	χ^2	df	p-value
Auditive	Species richness	Stratum * Nesting site	75.59	5	**< 0.001**
		Forest management method * Nesting site	9.86	3	**0.020**
Auditive	Total abundance	Stratum * Nesting site	187.60	5	**< 0.001**
		Forest management method * Nesting site	16.27	3	**< 0.001**
Visual	Species richness	Stratum * Nesting site	4.27	7	0.748
		Forest management method * Nesting site	1.29	3	0.733
Visual	Total abundance	Stratum * Nesting site	10.59	7	0.158
		Forest management method * Nesting site	4.40	3	0.222

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

Appendix 17: Results of post hoc comparisons of interactions within the nesting site groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Response variable	Comparison of parameter interactions	Estimate	SE	z-value	p-value
Auditive	Species richness	A/ground – B/ground	0.079	0.274	0.287	1
		A/tree-shrub– B/tree-shrub	-0.975	0.201	-4.849	**< 0.001**
		A/tree-cavity – B tree-cavity	-0.815	0.414	-1.968	0.393
		A/ground– A/tree-shrub	0.054	0.253	0.212	1
		A/ground – A/tree-cavity	-0.280	0.443	-0.633	1
		A/tree-shrub – A/tree-cavity	-0.334	0.449	-0.745	1
		B/ground – B/tree-shrub	-1.000	0.227	-4.410	**< 0.001**
		B/ground – B/tree-cavity	-1.174	0.225	-5.228	**< 0.001**
		B/ground – B/earth-cavity	0.047	1.022	0.045	1
		B/tree-shrub – B/earth-cavity	1.046	1.003	1.043	1
		B/tree-cavity – B/earth-cavity	1.221	1.003	1.218	1
Auditive	Species richness	Core/A/ground – Non-core/A/ground	-0.310	0.345	-0.898	1.000
		Core/A/tree-shrub – Non-core/A/tree-shrub	-0.026	0.377	-0.070	1.000
		Core/B/ground – Non-core/B/ground	0.051	0.742	0.069	1.000
		Core/B/tree-shrub – Non-core/B/tree-shrub	0.053	0.201	0.262	1.000
		Core/A/tree-cavity – Non-core/A/tree-cavity	< 0.001	0.817	0.000	1.000
		Core/B/tree-cavity – Non-core/B/tree-cavity	-0.487	0.152	-3.198	**0.015**
		Core/A/ground – Core/B/ground	-0.051	0.320	-0.160	1.000
		Non-core/A/ground – Non-core/B/ground	0.310	0.753	0.412	1.000
		Core/A/tree-shrub – Core/B/tree-shrub	-0.995	0.257	-3.873	**0.001**
		Non-core/A/tree-shrub – Non-core/B/tree-shrub	-0.916	0.342	-2.683	0.073
		Core/A/tree-cavity – Core/B/tree-cavity	-0.686	0.584	-1.175	1.000
		Non-core/A/tree-cavity – Non-core/B/tree-cavity	-1.173	0.591	-1.985	0.425
Auditive	Total abundance	A/ground – B/ground	0.062	0.258	0.241	1
		A/tree-shrub– B/tree-shrub	-1.242	0.170	-7.288	**< 0.001**
		A/tree-cavity – B tree-cavity	-1.250	0.412	-3.033	**0.019**
		A/ground– A/tree-shrub	-0.131	0.228	-0.576	1
		A/ground – A/tree-cavity	-0.169	0.439	-0.385	1
		A/tree-shrub – A/tree-cavity	-0.038	0.439	-0.086	1
		B/ground – B/tree-shrub	-1.435	0.208	-6.889	**< 0.001**
		B/ground – B/tree-cavity	-1.481	0.208	-7.125	**< 0.001**
		B/ground – B/earth-cavity	-0.519	0.735	-0.706	1
		B/tree-shrub – B/earth-cavity	0.916	0.710	1.291	1
		B/tree-cavity – B/earth-cavity	0.963	0.709	1.357	1
Auditive	Total abundance	Core/A/ground – Non-core/A/ground	-0.335	0.326	-1.028	1
		Core/A/tree-shrub – Non-core/A/tree-shrub	-0.323	0.320	-1.010	1
		Core/B/ground – Non-core/B/ground	-0.259	0.616	-0.421	1
		Core/B/tree-shrub – Non-core/B/tree-shrub	0.069	0.153	0.448	1
		Core/A/tree-cavity – Non-core/A/tree-cavity	0.000	0.817	0.000	1
		Core/B/tree-cavity – Non-core/B/tree-cavity	-0.497	0.122	-4.064	**< 0.001**
		Core/A/ground – Core/B/ground	-0.047	0.305	-0.152	1

Appendix 17, Continued: Results of post hoc comparisons of interactions within the nesting site groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	Response variable	Comparison of parameter interactions	Estimate	SE	z-value	p-value
		Non-core/A/ground – Non-core/B/ground	0.030	0.626	0.048	1
		Core/A/tree-shrub – Core/B/tree-shrub	-1.399	0.233	-6.013	**< 0.001**
		Non-core/A/tree-shrub – Non-core/B/tree-shrub	-1.007	0.268	-3.756	**0.002**
		Core/A/tree-cavity – Core/B/tree-cavity	-1.118	0.581	-1.922	0.436
		Non-core/A/tree-cavity – Non-core/B/tree-cavity	-1.615	0.586	-2.755	0.053
Visual	Species richness	A/ground–B/ground	-0.182	0.508	-0.359	1.000
		A/tree–shrub–B/tree–shrub	-0.061	0.257	-0.238	1.000
		A/tree–shrub–C/tree–shrub	-0.029	0.252	-0.115	1.000
		B/tree–shrub–C/tree–shrub	0.032	0.196	0.164	1.000
		A/tree–cavity–B/tree–cavity	-0.397	0.267	-1.483	1.000
		A/tree–cavity–C/tree–cavity	-0.254	0.275	-0.924	1.000
		B/tree–cavity–C/tree–cavity	0.143	0.148	0.961	1.000
		A/ground–A/tree–shrub	-0.047	0.369	-0.126	1.000
		A/tree–shrub–A/tree–cavity	-0.018	0.329	-0.055	1.000
		B/ground–B/tree–shrub	0.075	0.433	0.173	1.000
		B/ground–B/tree–cavity	-0.279	0.419	-0.665	1.000
		B/tree–shrub–B/tree–cavity	-0.353	0.172	-2.061	0.512
		C/tree–shrub–C/tree–cavity	-0.243	0.177	-1.376	1.000
Visual	Species richness	Core/A/ground – Noncore/A/ground	< 0.001	0.627	0.000	1.000
		Core/A/tree–shrub – Noncore/A/tree–shrub	-0.080	0.434	-0.185	1.000
		Core/A/tree–cavity – Noncore/A/tree–cavity	-0.118	0.504	-0.234	1.000
		Core/B/ground – Noncore/B/ground	-0.288	0.866	-0.332	1.000
		Core/B/tree–shrub – Noncore/B/tree–shrub	0.105	0.289	0.365	1.000
		Core/B/tree–cavity – Noncore/B/tree–cavity	-0.288	0.201	-1.429	1.000
		Core/C/tree–shrub – Noncore/C/tree–shrub	-0.088	0.270	-0.324	1.000
		Core/C/tree–cavity – Noncore/C/tree–cavity	0.015	0.243	0.061	1.000
		Core/A/ground – Core/B/ground	< 0.001	0.866	0.000	1.000
		Core/A/tree–shrub – Core/B/tree–shrub	-0.154	0.383	-0.402	1.000
		Core/A/tree–shrub – Core/C/tree–shrub	-0.035	0.382	-0.092	1.000
		Core/A/tree–cavity – Core/C/tree–cavity	-0.329	0.428	-0.768	1.000
		Core/B/tree–shrub – Core/C/tree–shrub	0.119	0.265	0.449	1.000
		Core/B/tree–cavity – Core/C/tree–cavity	-0.050	0.259	-0.192	1.000
		Noncore/A/ground – Noncore/B/ground	-0.288	0.627	-0.459	1.000
		Noncore/A/tree–shrub – Noncore/B/tree–shrub	0.031	0.353	0.089	1.000
		Noncore/A/tree–shrub – Noncore/C/tree–shrub	-0.043	0.340	-0.125	1.000
		Noncore/B/tree–shrub – Noncore/C/tree–shrub	-0.074	0.293	-0.252	1.000
		Noncore/A/tree–cavity – Noncore/C/tree–cavity	-0.196	0.361	-0.543	1.000
		Noncore/B/tree–cavity – Noncore/C/tree–cavity	0.253	0.181	1.397	1.000
Visual	Total abundance	A/ground–B/ground	-0.015	0.494	-0.031	1.000
		A/tree–shrub–B/tree–shrub	-0.034	0.221	-0.152	1.000
		A/tree–shrub–C/tree–shrub	-0.177	0.212	-0.838	1.000
		B/tree–shrub–C/tree–shrub	-0.144	0.164	-0.878	1.000
		A/tree–cavity–B/tree–cavity	-0.521	0.232	-2.249	0.294
		A/tree–cavity–C/tree–cavity	-0.320	0.238	-1.343	1.000
		B/tree–cavity–C/tree–cavity	0.201	0.124	1.621	1.000
		A/ground–A/tree–shrub	-0.190	0.332	-0.571	1.000
		A/tree–shrub–A/tree–cavity	0.020	0.285	0.071	1.000
		B/ground–B/tree–shrub	-0.208	0.427	-0.487	1.000
		B/ground–B/tree–cavity	-0.675	0.416	-1.624	1.000
		B/tree–shrub–B/tree–cavity	-0.467	0.146	-3.191	**0.019**
		C/tree–shrub–C/tree–cavity	-0.123	0.144	-0.852	1.000
Visual	Total abundance	Core/A/ground – Noncore/A/ground	-0.251	0.601	-0.418	1.000
		Core/A/tree–shrub – Noncore/A/tree–shrub	0.154	0.366	0.421	1.000
		Core/A/tree–cavity – Noncore/A/tree–cavity	0.229	0.437	0.524	1.000
		Core/B/ground – Noncore/B/ground	-0.288	0.866	-0.332	1.000
		Core/B/tree–shrub – Noncore/B/tree–shrub	0.159	0.252	0.633	1.000
		Core/B/tree–cavity – Noncore/B/tree–cavity	-0.371	0.168	-2.212	0.539
		Core/C/tree–shrub – Noncore/C/tree–shrub	-0.220	0.214	-1.025	1.000
		Core/C/tree–cavity – Noncore/C/tree–cavity	-0.163	0.213	-0.764	1.000
		Core/A/ground – Core/B/ground	0.000	0.866	0.000	1.000
		Core/A/tree–shrub – Core/B/tree–shrub	-0.018	0.313	-0.057	1.000
		Core/A/tree–shrub – Core/C/tree–shrub	0.013	0.308	0.042	1.000

Appendix 17, Continued: Results of post hoc comparisons of interactions within the nesting site groups. Interactions with a significant difference are highlighted in bold. A indicates for the ground and herb layer (0-10 m), and B for the shrub and tree layer (> 10 m) for the auditive data. A indicates for the ground and herb layer (0-1 m), B for the shrub layer (1-10 m), and C for the tree layer (> 10m) for the visual data.

Method	**Response variable**	**Comparison of parameter interactions**	**Estimate**	**SE**	**z-value**	**p-value**
		Core/A/tree–cavity – Core/C/tree–cavity	-0.092	0.351	-0.261	1.000
		Core/B/tree–shrub – Core/C/tree–shrub	0.031	0.223	0.137	1.000
		Core/B/tree–cavity – Core/C/tree–cavity	0.075	0.227	0.332	1.000
		Noncore/A/ground – Noncore/B/ground	-0.036	0.601	-0.061	1.000
		Noncore/A/tree–shrub – Noncore/B/tree–shrub	-0.012	0.316	-0.039	1.000
		Noncore/A/tree–shrub – Noncore/C/tree–shrub	-0.361	0.292	-1.237	1.000
		Noncore/B/tree–shrub – Noncore/C/tree–shrub	-0.349	0.245	-1.426	1.000
		Noncore/A/tree–cavity – Noncore/C/tree–cavity	-0.483	0.336	-1.437	1.000
		Noncore/B/tree–cavity – Noncore/C/tree–cavity	0.284	0.148	1.918	1.000

Significance codes: * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.