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Species -diversity and -dominance among secondary hole nesting birds depending on human presence

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Abstract

Myriad different factors influence the breeding ecology of secondary hole nesting birds. Examples include, but are not limited to, the presence/influence of humans (urbanisation), the nesting material, availability of food sources and familiarity with the nesting site. In general, bird species diversity decreases in proximity to humans and their settlements, while more generalist species become more dominant. This study investigates the influence of human presence on the breeding ecology and species diversity/dominance of secondary hole nesting birds in three specific localities, using artificial nest boxes. The study locations are three adjacent forests at the Konrad Lorenz Forschungstelle (KLF) in Grünau, Upper Austria. These areas mainly differ in the degree of human presence (i.e., high-/low levels) and the type of woodland (i.e., coniferous or mixed). In total, n=154 nest boxes dispersed across the three study areas were the basis of the monitoring project. The influence of humans on the breeding ecology and species diversity/-dominance was measured with parameters such as occupation rate, clutch size, date of first laid egg and overall reproductive success. The great tit *(Parus major)* was found to be significantly more prevalent in the nest boxes of the three study areas then the other study species coal tit *(Periparus ater)*, marsh tit *(Poecile palustris)*, blue tit *(Cyanistes ceruleus)*, nuthatches *(Sitta europaea)* and collared flycatchers *(Ficedula albicollis)*. A range of factors, such as their ecological niche and larger body weight, might explain the great tits *(Parus major)* dominance. Additionally, a significant nesting preference for the area with high levels of human presence was found among the study species. This study represents the second instance of the proposed continuous monitoring program of the cavity nesting birds of the Grünau area. The project might supply valuable information to aid in the identification of species that may benefit from conservation efforts, while also delivering the necessary data for the "Höhlenbrüter Monitoring" project of the Austrian ornithological centre (AOC).

Kurzfassung

Eine Vielzahl an Faktoren beeinflussen die Brutökologie von sekundären Höhlenbrütern. Beispiele hierfür sind unter anderem der Einfluss/die Präsenz von Menschen und die resultierende Urbanisierung, das Nistmaterial, die verfügbaren Nahrungsressourcen sowie die Vertrautheit der Tiere mit den Nistplätzen. Generell wird eine Verringerung der Artenzahl von Vögeln in menschlicher Nähe sichtbar, wobei generalistische Arten dominanter werden. Diese Studie untersucht den Einfluss des Menschen auf das Brutverhalten und die Artenvielfalt von sekundären Höhlenbrütern in drei verschieden Studiengebieten, mithilfe dort platzierter Nistboxen. Die aneinandergrenzenden Studienareale liegen an und um der Konrad Lorenz Forschungsstelle (KLF) in Grünau, Oberösterreich. Sie unterscheiden sich vor allem im Level der menschlichen Präsenz (hohe/niedrige Levels an Präsenz), sowie im Waldtyp (Nadel- oder Mischwald). 154 über die Studiengebiete verteilte Nistboxen waren die Grundlage für das Monitoring Projekt. Der menschliche Einfluss auf die Studienarten wurde anhand von parametern wie der Belegungsrate, der Gelegegröße, dem Zeitpunkt der ersten Eiablage und dem Bruterfolg gemessen. Die Kohlmeise *(Parus major)* wurde signifikant öfter in den Nistboxen vorgefunden als die anderen Studienarten Tannenmeise *(Periparus ater)*, Sumpfmeise *(Poecile palustris)*, Blaumeise *(Cyanistes ceruleus)*, Kleiber *(Sitta europaea)* und Halsbandschnäpper *(Ficedula albicolis)*. Mehrere Faktoren, wie ihre ökologische Nische und hohe Körpermasse, könnten die Dominanz der Kohlmeise *(Parus major)* erklären. Auch wurde eine signifikante Nistpräferenz für das Studiengebiet mit hohem Level an menschlicher Präsenz gefunden. Diese Studie representiert die zweite Instanz des geplanten langfristigen Monitoring-Programms der sekundären Höhlenbrüter in der Gegend um Grünau, Oberösterreich. Zusätzlich könnten die gewonnenen Informationen bei der Identifikation von Vogelarten helfen, die von einem Schutzprogramm profitieren würden, und liefern die nötigen Daten für das "Höhlenbrüter Monitoring" der Österreichischen Vogelwarte (AOC).

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This study complies with all current Austrian laws and regulations concerning the work with wildlife. Observing the animals and controlling their nests were performed under Animal Experiment Licence Number 66.006/0026-WF/V/3b/2014 by the Austrian Federal Ministry for Science and Research (EU Standard, equivalent to the Animal Ethics Board).

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The question of the breeding ecology of secondary hole nesting birds breeding in artificial nest boxes is a topic of scientific interest for many years now (Serrano *et al.*, 2017; Lambrechts *et al.*, 2010). The breeding ecology of these birds can be influenced by various different factors, such as the availability of food (Branston *et al.*, 2021; Vaugoyeau *et al.*, 2016; Chamberlain *et al.*, 2009; Solonen, 2001; Perrins and McCleery, 1989), familiarity with the nesting site (De León and Mínguez, 2003), the degree of urbanisation (Remacha and Delgado, 2009; Clergeau *et al.*, 2006; Van der Zande *et al.*, 1984), the type of forest (Zárybnická *et al.*, 2017; Mänd *et al.*, 2005), level of disturbances (Lalrosangpuii *et al.*, 2014), the orientation of the nest opening (Rodriguez *et al.*, 2011; Goodenough *et al.*, 2008; Ardia *et al.*, 2006), exposure to sunlight and radiation (Monti *et al.*, 2019), illumination (Podkowa and Surmacki, 2017) and the openness of the adjacent area (Bohus, 2002). In the case of artificial nest sites, the material (Bueno-Enciso *et al.*, 2016; Lambrechts *et al.*, 2010; García-Navas *et al.*, 2008; Browne, 2006), dimensions (Møller *et al.*, 2014; Sorace and Carere, 1996), orientation (Rodriguez *et al.*, 2011; Goodenough *et al.*, 2008; Ardia *et al.*, 2006) and hanging height (Harper *et al.*, 2005) of the nest boxes might also affect the nest site choice of secondary cavity nesting birds. The adequate choice of nesting site therefore is critical for secondary hole nesting birds to ensure successful reproduction and healthy populations. The use of artificial nest boxes allows for easy access of the breeding efforts and therefore facilitates monitoring through a standardized setting when compared to natural nest cavities (Lambrechts *et al.*, 2010). Other advantages of artificial nest boxes are lower rates of predation compared to natural nest cavities and a lower risk of drowning after heavy rainfall (Llambias and Fernandez, 2009). According to a number of studies, such as by Kiss *et al.* (2017); Libois *et al.* (2012) and Lowther (2012), some bird species breeding in artificial nest sites can have larger clutches and a higher reproductive success than the same species nesting in natural cavities of the same area. Because of these factors, nest boxes are being used in a variety of avian studies across the globe since many years now (Newton, 1998). Long-term monitoring can be a vital tool in the investigation of the breeding ecology of birds, providing multi-year spanning data-banks that can be evaluated later and used as a basis for further studies. Additionally, potential long-term changes to populations and trends in the breeding ecology as well as reproductive success are more easily assessed when having a perennial data-bank at hand (Samplonius and Both, 2019; Sanz, 2002). Providing additional nesting grounds in the form of nest boxes can have positive effects on the population of various species, especially important for species that are vulnerable or endangered (Lambrechts *et al.*, 2010; De León and Mínguez, 2003). Furthermore, the number of natural nesting sites is thought to be at its lowest throughout recent history, further increasing the need for additional nesting sites that could be supplemented with the help of artificial nest boxes (Newton, 1998). Nest boxes (**Figure 1.1**) can help gain insight in the nesting preferences of different secondary hole nesting bird species. They allow for interchangeable nesting environments through variation in the nesting materials (i.e., wooden or concrete nest boxes), nest dimensions (Bueno-Enciso *et al.*, 2016; Møller *et al.*, 2014; García-Navas *et al.*, 2008; Summers and Taylor, 1996), as well as hanging height (Harper *et al.*, 2005) and nest box orientation (Ardia *et al.*, 2006). A science-backed approach in the placement and design of artificial nest settings, catering to variable nesting preferences among species is therefore vital when aiming to attract particular species and having species conservation in mind.

Figure 1.1: An example of a nesting tree (nr. 55 in the woodland north of KLF)

Human presence seems to affect the breeding ecology of birds.
The structure of bird communities seems to be affected by the size of towns, the location of the study site within the city as well as the local habitat structure and quality (Savard *et al.*, 2000; Blair and Launer, 1997; Dinetti, 1994). In general, bird species diversity seems to decline with high levels of human disturbances such as in cities and with high levels of urbanisation (Kang *et al.*, 2015). Furthermore, increased urbanisation seems to negatively affect the body mass of nestlings, as broods of the great tit *(Parus major)* or the common starling *(Sturnus vulgaris)* in more urban areas tend to be lighter (Mennechez and Clergeau, 2006, 2001; Hõrak *et al.*, 2000). Bird species from different regions seem to react similarly to urbanisation (Blair, 2001; Clergeau *et al.*, 2001, 1998). The general decrease in species diversity with urbanisation and the fact that similar species are present in urban centres across varying locations might suggest that urbanisation has a similar effect on local communities independent of geographic locations or ecoregions (Blair, 2001). However, urbanisation does not always necessarily decrease the diversity of communities. Suburban areas may in some cases present more varied environmental conditions and a range of habitats that might be richer than more natural areas (Blair, 1996). Therefore, when studying homogenisation of communities caused by urbanisation, the locations within the town is also to be considered. The respective ecological niche of a particular species seems to be an important factor. For example, Clergeau *et al.* (1998) and Jokimäki and Suhonen (1998) suggest that some life-history traits, such as omnivory, are more common in city centres than in more rural/natural areas. In addition, Lim and Sodhi (2004) raise the notion that insectivores and carnivores are negatively affected by increased urbanisation. More generalist species with a wider ecological niche such as the great tit *(Parus major)* and blue tit *(Cyanistes ceruleus)* seem to be less negatively affected by human disturbances. More specialist species with a more narrow ecological niche such as the coal tit *(Periparus ater)* and the marsh tit *(Poecile palustris)* however seem to be more negatively affected by human disturbances (Farina, 1983).

The occupation rate seems to be impacted by humans and urbanisation.
Previously conducted research has found the occupation rate of nest boxes by some passerine species like the great tit *(Parus major)* or tree- and house sparrows *(Passer montanus; Passer domesticus)* to be higher in the vicinity of humans and their settlements (Remacha and Delgado, 2009). The same seems to hold true for the western bluebird *(Sialia mexicana)* and mountain bluebird *(Sialia currucoides)*, with Dale *et al.* (2021) finding increased occupation rates for nest boxes in proximity to human infrastructure. Other research on passerines (great- and blue tit, Sparrow species) has not found clear preferences for urban, periurban or city centre areas. Some species favour more central areas in the cityscape while others are more often found near the city's edge (periurban) (Clergeau *et al.*, 2006). A couple of unsupportive studies by Sukopp *et al.* (1982) and Hounsome (1979) argue that the amount of bird species tends to increase with growing distance from the city centre in urban parks. A paper published by Nuorteva (1971) states that in a comparative study between a Finish city

centre, the surrounding agricultural area and an uninhabited forest habitat, bird communities were richest in terms of species in the rural area surrounding the city, and lowest in the city centre. This is supported by a study in Hamburg, also finding the highest number of species in the agricultural land (Mulsow, 1982). Another contrasting study by Sidemo-Holm *et al.* (2022) has found the numbers of other passerines such as the coal tit *(Periparus ater)* and marsh tit *(Poecile palustris)* to be lower in more urban areas compared to more rural habitats.

Proximity to humans may have an effect on the timing of egg laying.
Great tits *(Parus major)* and mountain chickadees *(Poecile gambeli)* seem to lay their eggs earlier in more urban areas compared to less urban locations (Branston *et al.*, 2021; Marini *et al.*, 2017; Chamberlain *et al.*, 2009). Similarly, a study by Perrins (1965) found that great tits *(Parus major)* and blue tits *(Cyanistes ceruleus)* lay their eggs earlier in gardens than in woodlands. Similar results were found by Dhondt *et al.* (1984) for Belgian great tits *(Parus major)* and blue tits *(Cyanistes ceruleus).* In contrast, a different study with blue tits *(Cyanistes ceruleus)* has not found any such time differences in the date of the first egg laying between an oak *(Quercus spp.)* forest and a park in the city centre (Branston *et al.*, 2021). On the other hand, Cole *et al.* (2015) as well as Wilkin *et al.* (2007) have found evidence for earlier egg laying by great tits *(Parus major)* and blue tits *(Cyanistes ceruleus)* in oak-rich compared to oak-poor habitats *(Quercus spp.).* Another contrasting study failed to detect any differences in the timing of egg laying in Mediterranean great tit *(Parus major)* and blue tit *(Cyanistes ceruleus)* populations across locations (Belda *et al.*, 1998).

The clutch size of some bird species might be affected by human presence.
The clutch size of birds seems to be larger in deciduous woodlands compared to evergreen woodlands or more urban environments such as parks and gardens (Branston *et al.*, 2021; Gladalski *et al.*, 2017; Lambrechts *et al.*, 2004; Blondel *et al.*, 1993; Gibb and Betts, 1963). A study with great tits *(Parus major)* conducted by Perrins (1965) in England supports this notion, as it found that clutches were larger in oak *(Quercus spp.)* forests compared to gardens and more open landscapes. Another supportive study states that great tits *(Parus major)* and blue tits *(Cyanistes ceruleus)* seem to have smaller clutch sizes in locations with higher levels of human activity and urbanisation than in more natural locations (Branston *et al.*, 2021; Chamberlain *et al.*, 2009; Solonen, 2001). This does not seem to hold true for other species such as the mountain chickadee *(Poecile gambeli)*, as no such anthropogenic influence on the clutch size of the species could be found (Marini *et al.*, 2017).

Urbanisation seems to affect the reproductive success.
For great tits *(Parus major)* and blue tits *(Cyanistes ceruleus)*, studies seem to find lower values for the reproductive success in areas with higher levels of human presence (Chamberlain *et al.*, 2009; Solonen, 2001; Horak, 1993). This seems to hold true for other species such as the common starling *(Sturnus vulgaris)* or the Eurasian Magpie *(Pica pica)* as well (Chamberlain *et al.*, 2009). For the mountain chickadee *(Poecile gambeli)*, no such differences were found (Marini *et al.*, 2017). Anthropogenic noise disturbance seems to have a negative effect on the reproductive success of the great tit *(Parus major)*, with a study by Halfwerk *et al.* (2011) finding lower values for the reproductive success in great tits *(Parus major)* breeding in proximity to a highway. However, human presence is not the only factor affecting the reproductive success. The weight of the chicks seems to decrease, while their mortality seems to increase, the later in the season the breeding efforts occur (Perrins, 1965). Additionally, the number of eggs (clutch size) seems to be smaller the later in the breeding season the eggs are laid (García-Navas *et al.*, 2008; Perrins and McCleery, 1989; Van Balen, 1973; Perrins, 1965).

The variance in the above-mentioned studies seems to suggest that at least some level of interspecific differences based on different levels of human presence arise when the breeding ecology, and more specifically the occupation rate, the date of the first egg laying, the clutch size and the overall reproductive success are concerned.

The Austrian entity concerned with monitoring the local bird species populations and their respective breeding efforts is the Austrian Ornithological centre, or AOC for short. A variety of ongoing and long-term monitoring projects are overseen by the AOC. An important example is the secondary hole nesting bird project, which is concerned with investigating the long-term breeding efforts of secondary hole nesting bird species across Austria. The project looks into changes in the breeding ecology, behavioural ecology, populations and occupational preferences over time among the study species. Generally, nest boxes are used in such projects to facilitate the long-term monitoring process, with their benefits having already been discussed above (see first paragraph of introduction). The process of long-term monitoring in itself is an important tool for the investigation of fluctuations across the populations of the study species over time. Monitoring therefore is critical for gaining an overview of the current state of bird populations and their habitat distributions. Long term monitoring can therefore provide an insight on the quality of a specific territory (Potti *et al.*, 2018). Additionally, long-term monitoring also facilitates the identification of species that might benefit from conservation efforts (Gameiro *et al.*, 2020; Nichols and Williams, 2006; Avilés and Parejo, 2004; Kéry and Schmid, 2004), and to assess a particular specie's extinction risk (following the guidelines set by the International Union for Conservation of Nature (IUCN)). Because of this, long term monitoring also aids in fulfilling the EU guidelines for the conservation of wild bird species, providing the underlying data for regulatory and protective efforts of wild bird species (Europäisches Parlament, 2010).

The here presented master's project is done in cooperation with the AOC as part of the "Höhlenbrüter Monitoring". This survey spans a variety of regions across Austria, with this master's project providing the monitoring data for the secondary hole nesting bird species of the area at and around the Konrad Lorenz Forschungstelle (KLF) in the Almtal region of Grünau, Upper Austria. The study area is quite remote and remains relatively near-natural. The landscape is shaped by limestone mountains and different types of forests (i.e., deciduous, coniferous or mixed) as well as wetlands such as lakes and rivers. The climate is quite humid with lots of precipitation year-round. An estimated 170 bird species inhabit and regularly breed in the area (Pühringer et al., 2020). Other than the species monitored in the authors project, the "Höhlenbrüter Monitoring" includes these secondary hole nesting bird species as well as all other Austrian song bird species (AOC/Österreichische Vogelwarte, 2016a). Directly adjacent to the KLF lies the Cumberland Wildpark, which is a well-known and well-visited tourist attraction in the area. In addition, it is an important study site for a variety of ethological studies. Together with two adjacent woodlands, Oberganslbach and the woodland north of the KLF building, it provides the study locations for the presented project. Oberganslbach is an important study area as well, with a part of the region's greylag geese *(Anser anser)* breeding there. The woodland north of the KLF has been established as a study site only this year. Some nest boxes in the Cumberland Wildpark relevant to this study have been hanging for over 20 years. In contrast, they have only been hung up in anticipation of last year's breeding season (2022) in the area Oberganslbach and only in anticipation of this year's breeding season (2023) in the new area north of the KLF building. Last year's monitoring project conducted by Tatjana Vogel for her master's thesis was the first year of consistent monitoring of the nest boxes in the Cumberland Wildpark as well as Oberganslbach, with the nest boxes in the area north of the KLF first being monitored this year. This research therefore represents the second year of ongoing monitoring, with the aim of establishing a long-term monitoring databank for the secondary hole nesting birds of the area. The hereby gathered data might shed light on the breeding ecology as well as population trends of the secondary hole nesting bird species breeding in the provided nest boxes (**Figure 1.2**), supplying the basis for further research and if needed, possible conservation efforts.

Figure 1.2: 2-3 day old nestlings in a nest box

Chapter 2

Aims and Predictions

The aim of this study is to investigate possible differences and preferences in the breeding ecology and species distribution of secondary hole nesting birds across the three study areas. The study is conducted on the basis of different levels of human presence and with the help of artificial nest boxes. Two areas, Oberganslbach and the forest north of KLF experience low levels of human presence. The third area, the Cumberland Wildpark, sees high levels of human presence due to it being open to the public year-round.

The variables measured to assess the effect of human presence are:

1) the occupation rate (number of occupied nest boxes per area).

2) the date of the first laid egg (per clutch).

3) the clutch size (maximum number of eggs in one nest before incubation).

4) the reproductive success (number of fledglings divided by number of eggs).

Based on the effects of human presence and last year's results (Vogel, 2022), the author predicts that:

• the occupation rate for the Cumberland Wildpark, the area with high levels of human presence, will be higher compared to the other two study areas.

• the clutch size will diminish regardless of species with the progression of the breeding season.

• the breeding season will start earlier and last longer in the Cumberland Wildpark compared to the other two study areas.

• the great tit *(Parus major)* will be the most dominant species in terms of numbers across the nest boxes of all three study areas.

While other secondary hole nesting bird species are found in the area, they do not or only seldom breed in the provided nest boxes. Examples thereof are crested tits *(Lophophanes cristatus)* and the collared flycatcher *(Ficedula albicollis)* (Pühringer *et al.*, 2020).

Chapter 3

Material and Methods

3.1 Study locations:

The localities of interest consist of three adjacent forest areas in close proximity to the KLF in Grünau, Upper Austria. Two of said areas, the Cumberland Wildpark (**Figure 3.1**) and Oberganslbach (**Figure 3.2**) are characterized by a mix of deciduous and coniferous trees, while the third area (just north of the KLF building) is a predominantly coniferous woodland (**Figure 3.3**). The Cumberland Wildpark is open to the public year-round and therefore sees the highest level/degree of human presence as well as urbanisation. A variety of buildings and other infrastructure such as paths and fences are to be found in the Cumberland Wildpark. The other two areas are predominantly used for forestry and hunting purposes, and are therefore much less frequented by humans. No or very little infrastructure like paths and buildings are located in the areas of Oberganslbach and the woodland north of the KLF. The nest-boxes in the Cumberland Wildpark are placed in close proximity to the paths, while the nest boxes in the latter two forests are dispersed along a linear profile across the areas and therefore are more secluded and hidden then the ones in the Cumberland Wildpark.

Figure 3.1: Map of the study area Cumberland Wildpark (stars represent placement of nest boxes) (Google-Maps, 2023b).

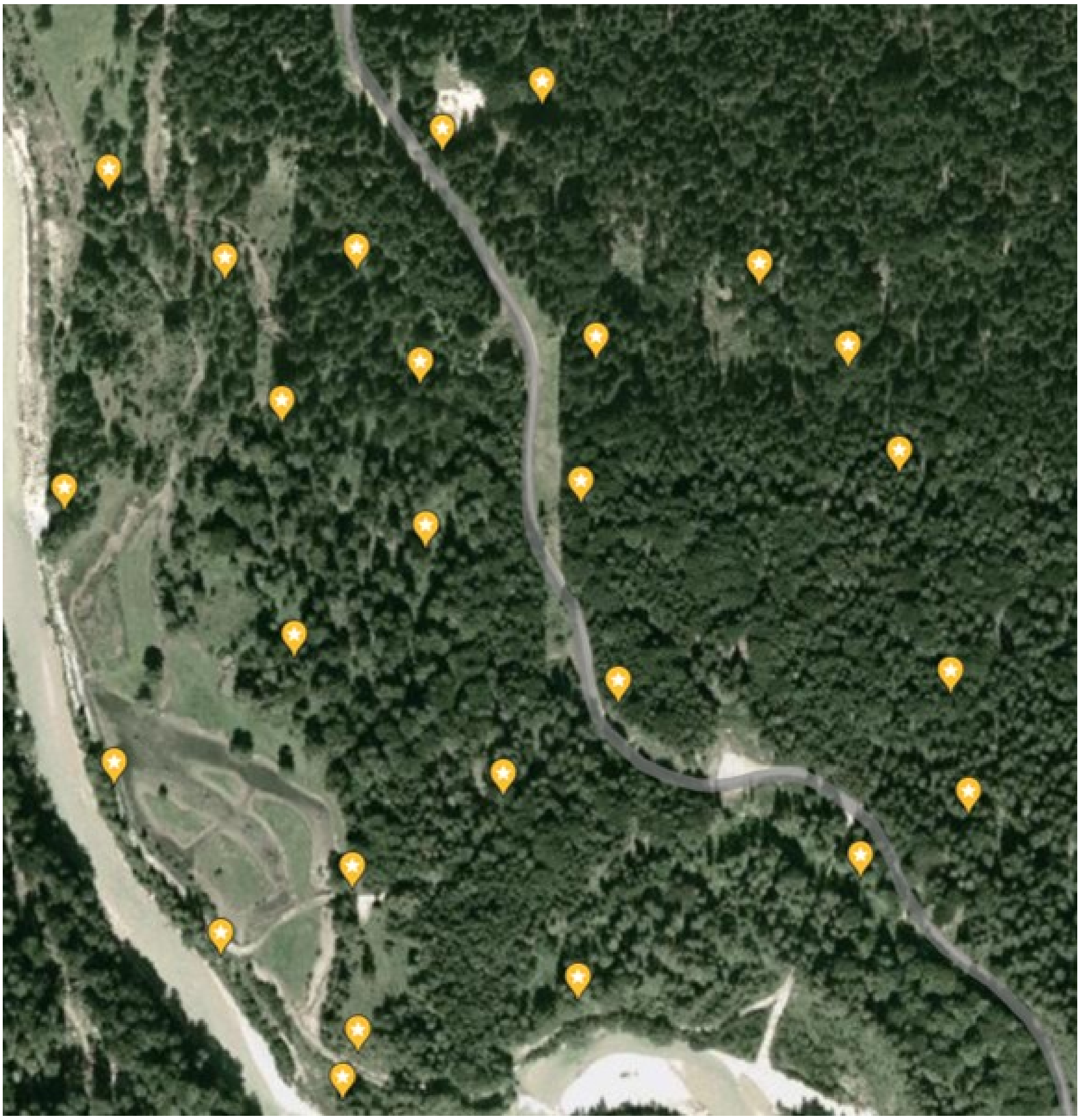


Figure 3.2: Map of the study area Oberganslbach (stars represent placement of nest boxes) (Google-Maps, 2023a).

Figure 3.3: Map of the study area woodland north of the KLF (stars represent placement of nest boxes) (Google-Maps, 2023c).

3.2 Nest boxes:

A total of n=154 nest boxes situated on n=77 trees dispersed across the three adjacent study areas were the basis for the monitoring. Two of the areas, the Cumberland Wildpark and Oberganslbach, house n=52 nest boxes on n=26 trees each, while the area north of the KLF houses n=50 nest boxes on n=25 trees. For the areas Oberganslbach and the woodland north of the KLF, the nesting trees were chosen randomly along a linear profile. In the Cumberland Wildpark the trees were also chosen randomly but are mostly situated close to the paths and therefore less secluded than in the other two areas that do not (or very few) have beaten paths. This randomization was done to avoid potential effects caused by the tree type (i.e., deciduous or coniferous). Every tree in question carries two nest boxes, with one box being made of concrete, while the second consists of wood. The boxes are secured to the tree with cordage and/or nails. Both boxes on the same nesting tree are labeled with the same corresponding number for the tree, ranging from 1 to 26 for every nesting tree in the Cumberland Wildpark, 27 to 52 for every nesting tree in Oberganslbach and 52 to 77 for every nesting tree in the area north of the KLF. This is done to keep track of the different nesting sites and to facilitate the monitoring process by creating a numeric layout of the tree location for every area. Generally, the boxes are hung up at a height of 1.5-3 meters and are situated one above the other in a randomized fashion. The order was randomized to avoid potential effect caused by the placement of the boxes. The height of the boxes was chosen specifically to favour the study species, as other species of secondary hole nesting birds seem to prefer cavities located higher up in the treeline (Zhang *et al.*, 2021). Additionally, the boxes were positioned so that the entry hole is always facing southward, which seems to be favoured by secondary hole nesting birds (Briggs and Mainwaring, 2021; Rendell and Robertson, 1994). The direction of the nest opening has an effect on the microclimate inside the nest box, most notably on the temperature (Maziarz *et al.*, 2017; Butler *et al.*, 2009; Goodenough *et al.*, 2008) and the illumination (Podkowa and Surmacki, 2017). This ties in to a potential shortcoming of artificial nest boxes, as compared to natural cavities, nest boxes seem to experience larger temperature fluctuations, increasing the risk for hyper- or hypothermia in case of high or low temperatures respectively (Salaberria *et al.*, 2014; Haftorn and Reinertsen, 1985). All nest boxes were cleaned prior to the start of the breeding season and old nests or other organic materials were removed. This is done to ensure a standardized setting across all nest boxes and to meet the spatial requirements of the different study specie's breeding efforts.

The concrete nest boxes (**Figure 3.4**) were made by the company Schwegler Germany, and constitute of a mixture of concrete and sawdust, often called woodcrete. The model used (named model 1b by the company) is cylindrical in form and has outside dimensions of 26 x 17 x 18cm, while the inside has a height of 17,5cm and a diameter of 12cm (Vogel, 2022). These standardized nest boxes are opened from the front via a latch on the bottom. Once the latch is open the entire front panel can be detached, allowing for easy access of the inside. They are closed by reinstating the front panel and closing the latch.

Figure 3.4: A concrete nest box (model 1b)

The wooden nest boxes (**Figure 3.5**) were sourced from a regional carpenter and are made of spruce wood *(Piceae spp.)*. These wooden nest boxes are rectangular in shape and have outside dimensions of 25 x 12,5 x 16cm, while the inside dimensions measure 23 x 8,8 x 12cm (Vogel, 2022). They are opened from above by lifting a hook situated on the top of the box from the corresponding eyelid situated at the upper right side of the box's body. The lid can then be folded to the side, revealing the inside of the box. To close it, the lid is folded back again and the hook is reinstated in the eyelid. For all nest boxes of both types, the entry hole has a diameter of 32mm.

Figure 3.5: A wooden nest box

3.3 Study species:

Artificial nest boxes mainly attract secondary hole nesting birds. 60 European bird species, amounting to 14 percent of all species, commonly use cavities as their nesting grounds (Newton, 1998). Secondary hole nesting birds naturally use pre-existing cavities like tree-hollows or cavities created by primary hole nesting birds such as woodpeckers *(Picidae)* as their nesting sites (Perrins, 1979). The most common secondary hole nesting birds of the area breeding in the provided nest boxes consist of different tit species *(Paridae)* such as the great tit *(Parus major)*, the coal tit *(Periparus ater)*, the marsh tit *(Poecile palustris)* and the blue tit *(Cyanistes ceruleus)*. Nuthatches *(Sitta europea)* are the only non-tit species that are known to regularly use the provided nest boxes. A novelty of this year's breeding season is the occupation of one of the nest boxes by a breeding pair of collared flycatchers *(Ficedula albicollis)*, which are not normally seen in the provided nest boxes. All the above-mentioned tit *(Paridae)* species have a very similar nest architecture. A completed tit nest (**Figure 3.6**) mainly consists of a bottom layer of moss and other plant matter such as grass that is topped with fluffy material like animal hair for insulation purposes and concealment of the eggs to avoid predation (Lambrechts *et al.*, 2012; Alabrudzińska *et al.*, 2003). The nuthatches *(Sitta europaea)* differ in their nest building, as their nests mainly consist of loose foliage and bark (Cantarero *et al.*, 2014). Notably, nuthatches *(Sitta europaea)* often create a seal for their nests or reduce the entrance hole diameter with a mixture of saliva and mud for further protection of the brood (Löhrl, 1964). The nests of collared flycatchers *(Ficedula albicollis)* generally consist of dry grass, leaves and branches. These migratory secondary hole nesting birds normally do not breed in the area, but are known to breed in areas in relative proximity to the east of Austria (BirdLife International, 2023). All study species may sometimes attempt secondary or replacement broods, i.e., second broods within the same breeding season or replacement clutches if the first breeding efforts failed (Verhulst *et al.*, 1997). All the above-mentioned study species, except for the collared flycatchers *(Ficedula albicollis)*, are residents and live in the area year-round. The diet of all the above-mentioned study species is similar, mainly consisting of invertebrates like insects, caterpillars and spiders, as well as fruits and nuts (Perrins and Snow, 1998).

Habitat wise, the great tit *(Parus major)* is a generalist species that can be found in various habitats such as different forest-types (mixed, coniferous and deciduous) and more urban areas such as parks and cities (BirdLife International, 2023). Coal tits *(Periparus ater)* are known to prefer coniferous forests over other forest types but can also be found in more urban areas such as parks and greenspaces if conifers are present (BirdLife International, 2023). Marsh tits *(Poecile palustris)* favour mature, deciduous forests with many old and rotting trees (BirdLife International, 2023). The species seems to avoid habitats such as hedgerows, gardens and low scrub (Cramp *et al.*, 1993). Blue tits *(Cyanistes ceruleus)* are like the great tit *(Parus major)* a more generalist species, that can be found in most different forest types as well as more urban areas such as the cityscape and parks (BirdLife International, 2023). Nuthatches *(Sitta europaea)* are most often found in deciduous and mixed forests with many old trees, but might also be found in larger greenspaces around cities. (BirdLife International, 2023). Collared flycatchers *(Ficedula albicollis)* are mostly found in deciduous forest with old trees but also in the parks of cities or orchards (BirdLife International, 2023).

Figure 3.6: A completed nest with 9 eggs inside a nest box

The breeding process of the study species is similar, with variations in the clutch size. Generally, the eggs are laid in April through to May, with secondary/replacement broods occurring up to the end of July or the beginning of August (Blondel, 1985). The average clutch size for the great tit *(Parus major)* ranges from 9-11 eggs (Van Balen, 1973; Perrins, 1965). The coal tit *(Periparus ater)* lays a mean of 5-13 eggs (BirdLife International, 2023). The marsh tit *(Poecile palustris)* is reported to have an average clutch size of 5-10 eggs (BirdLife International, 2023). For blue tits *(Cyanistes ceruleus)*, the mean number of eggs seems to be 7-13 (Perrins, 1979). Nuthatches *(Sitta europaea)* are known to have a clutch size of about 5-9 eggs (BirdLife International, 2023). The collared flycatcher *(Ficedula albicollis)* usually has a clutch of 5-7 eggs (BirdLife International, 2023). In all the above-mentioned species the adult female incubates the eggs for a period of 12-14 days (**Figure 3.7**), while the male is mainly concerned with food procurement (Perrins, 1979). After hatching, the chicks stay in the nest for about 20 days before fledging and leaving the nest (Löhrl, 1964).

Figure 3.7: An incubating coal tit *(Periparus ater)* in a wooden nest box

All the study species are listed as "least concern" globally, but their population trends across Austria seem to vary (BirdLife International, 2023). When the Austrian great tits *(Parus major)*, blue tits *(Cyanistes ceruleus)*, marsh tits *(Poecile palustris)* and collared flycatchers *(Ficedula albicollis)* are concerned, their populations seems to be stable across the period of 1998-2016. When looking at the populations of coal tits *(Periparus ater)* and nuthatches *(Sitta europaea)* for the same period, the numbers seem to be in decline (Teufelbauer *et al.*, 2017). The more recent study by Teufelbauer and Seaman (2021) on the populations of Austrian birds confirms an ongoing decline in the coal tits *(Periparus ater)* and a more stable decline for the nuthatches *(Sitta europaea)*, while the Austrian populations of great tits *(Parus major)*, blue tits *(Cyanistes ceruleus)* and collared flycatchers *(Ficedula albicollis)* remain stable. However, the more recent rendition of the study found an additional decrease for the populations of Austrian marsh tits *(Poecile palustris)* (Teufelbauer and Seaman, 2021). This trend seems to hold true for other places as well, with a study from Eaton *et al.* (2009) finding a long-term decrease of 66 percent to the populations of marsh tits *(Poecile palustris)* in Great Britain. Similarly, the "Woodland Bird Index" from the period of 1998-2012 found an annual decline of 1,3 percent for the Austrian marsh tits *(Poecile palustris)* (Teufelbauer and Seaman, 2021). Different factors might influence the decrease in marsh tit *(Poecile palustris)* numbers. Predation, disturbances, habitat destruction/fragmentation or strong competition for nesting grounds and/or food -which might hold true for the other declining species as well- are all examples thereof (Lalrosangpuii *et al.*, 2014; Broughton *et al.*, 2011; Fuller *et al.*, 2005).

3.4 Data collection:

The nest boxes are being monitored over the entire breeding season, from the end of March to the end of July or beginning of August, depending on the last breeding efforts. More specifically, the monitoring begun on the 23rd of march and ended on the 10th of July. The data was collected at least once a week for every calendar week of the breeding season. For most of the season the data was collected twice a week, once near the beginning of the week, done by Johanna Weber, and once near the end of the week, done by the author. It is critical to visit every nest box at least once a week to ensure all developments in the breeding efforts are catalogued. When visiting a nesting site, a ladder is used to reach the nest boxes. They are then opened from above in the case of the wooden nest boxes, and from the front in the case of concrete nest boxes. Opening the boxes reveals the (possible) breeding efforts in that particular box. When monitoring boxes that are not to be opened such as when nuthatches *(Sitta europaea)* are breeding in them or when they are hard to reach, the boxes are checked with the help of an endoscope camera (Depstech DS 450) that is inserted through the entry hole. The first signs of occupation are moss, leaves, bark or grassy material, depending on the nesting species. More advanced tit *(Paridae)* nests have a top layer of animal hair. Generally, eggs are laid only once this top layer is present. When incubation has not yet begun, the eggs are often hidden beneath the animal hair to conserve heat and to avoid predation (Lambrechts *et al.*, 2012; Alabrudzińska *et al.*, 2003). Therefore, if a finished tit *(Paridae)* nest is found, the animal hair is carefully pushed aside to look for eggs beneath. Said layer is put back in place when leaving the site. In the case of nuthatches *(Sitta europaea)* breeding, only leaves and bark will be present (Cantarero *et al.*, 2014). If collared flycatchers *(Ficedula albicollis)* are breeding, the nest mostly consists of grass, twigs and leaves (BirdLife International, 2023). If eggs are found, they are counted and the amount noted. The eggs are touched with the back of the hand. If warm, the incubation process has begun. In any case, it is noted whether the eggs are warm or not. During the incubation process, the female bird would often be present while collecting the data. Most of the time it would fly out when the nest box is opened. If not, the adult is carefully pushed aside to reveal what is underneath. If chicks are present, they are counted and their development stage (in days) is estimated following a development chart provided by the AOC. The age estimation is hereby based on the development of plumage and keels as well as the degree of openness of the eyes (example thereof provided in **Figure 3.8** and **Figure 3.9**). This is important to determine the appropriate date for later banding. Two weeks after banding, when the fledging phase is over, the nest is checked again to see if all birds have fledged. Possible carcasses or unhatched eggs are removed together with the nest. Any such findings are noted as well. Cleaning the nest boxes allows them to be available for further breeding efforts. The data collection is kept as short and unintrusive as possible, to limit the stress exposure for the birds to a minimum. In some cases, the provided nest boxes are occupied by other taxa not related to the study. Examples thereof are wasps *(Vespidae)*, such as yellow-jackets *(Vespula vulgaris)* and hornets *(Vespa crabro)*, bumblebees *(Apidae)*, ants *(Formicidae)*, dormice *(Gliridae)*, such as the European edible dormouse *(Glis glis)* and hazel dormouse *(Muscardinus avellanarius)*, spiders *(Araneae)* and the Aesculapian snake *(*Zamenis longissimus). In cases of animal nests, such as of dormice *(Gliridae)*, bumblebees *(Apidae)*, ants *(Formicidae)* or wasps *(Vespidae)*, the nest boxes in question are not checked again to avoid disturbing the animals and their respective breeding efforts.

Figure 3.8: The nuthatch nestlings *(Sitta europaea)* photographed on the 27/04/23 with the endoscope camera (Depstech DS 450)

Figure 3.9: The same, more developed nuthatch nestlings *(Sitta europaea)* photographed a week later, on the 04/05/23 with the endoscope camera (Depstech DS 450)

3.5 Variables:

When monitoring a nest box, various parameters are to be considered. First, it is checked for occupation. Subsequently, the species and its clutch are determined. Other parameters are: the day of the first laid egg, breeding start, clutch size, hatching day, number and age of hatchlings, number of fledglings and the reproductive success. The nests are also checked for occupation by other taxa. A particular nest box is considered occupied, if at least one egg has been laid by one of the six study species in said nest box (Zhang *et al.*, 2021). The study species is determined by observing the adults entering the nest or while incubating, based on their plumage characteristics. The day of the first laid egg is determined by backdating. This is achieved by counting back one day from the date of data collection for every one egg laid once incubation has commenced (Purcell *et al.*, 1997). This process is based on the assumption that one egg is laid per day (Perrins, 1979). Therefore, if the last egg was laid on the 10th day of the month, and there are 8 eggs in the clutch, the first egg was laid on the 3rd day of the same month (which would be day 0). The breeding start is defined as the day the last egg was laid, based on the assumption that incubation begins on the same day the last egg was laid (Haftorn, 1966). The clutch size is defined as the maximum number of eggs within a specific nest before the onset of incubation (Shackelford and Weekes-Shackelford, 2021). The expected hatching day is determined by adding 14 days to the day of incubation start, based on the assumption that chicks hatch after 14 days of continuous incubation (Bambini *et al.*, 2019). The number of hatchlings is defined as the number of chicks that hatched from the eggs. The age of hatchlings is determined by observing their developmental stage, following the development chart provided by the AOC. This allows for an age estimation in days with a range of ± 1 day. The number of fledglings is defined by the number of hatchlings that fledged, i.e., the number of birds that reached the ability to fly and left the nest (Vander Haegen, 2007). The reproductive success is calculated by dividing the number of fledglings by the number of eggs (see "egg success" in Murray, 2000). If all eggs hatched and all chicks fledged, the reproductive success is at its maximum with a value of 1. If some eggs didn't hatch, or some hatchlings died, the value would fall below 1. The lowest value possible is 0, if the whole clutch died. The so collected data during the monitoring process is the basis for the statistical analysis of the different study specie's breeding efforts and preferences. A novelty of this breeding season was that one nest box in the woodland north of the KLF, number 56c, was occupied by a breeding pair of collared flycatchers *(Ficedula albicollis)*, which are not usually seen in the provided nesting boxes of the area. Their breeding efforts have been taken up in the monitoring process as part of the study species.

3.6 Banding:

7 to 13 days after hatching, the chicks are to be banded. This is done in order to recognize the fledged adult birds if they are caught again in the future. Each ring is fitted with a specific number that is represented in a databank together with the species, the date of banding, the estimated age, weight, the sex (if possible), the catching status (i.e., "first catch" for hatchlings, for caught again adults "recatch"), the clutch size, the catching method and the tarsus length at banding. The corresponding nest box location, i.e., the Cumberland Wildpark, Oberganslbach or the woodland north of the KLF is also represented. During the banding process, the chicks are carefully removed from the nest and placed in a cloth bag that is used to transport them to the nearby banding station. The bag provides additional insulation and reduces the stress exposure to the chicks. The location of the banding station should be in proximity of the nest but not so close as to disturb the parent birds at the nest. It is also important to shelter the frail chicks from possible precipitation and low temperatures. The banding process is done in batches for every nest, generally banding half the number of hatchlings from a specific nest, returning them to the nest and then banding the other half. This is done to avoid fully disrupting the (possible) feeding process by the adults and to ensure that the parent birds never encounter an empty nest in order to minimize stress and avoid abandonment. Generally, the process is kept as short as possible to minimize stress to chicks and adults. Once the chicks are ringed, the specific nest box is not controlled again for two weeks. This pause is necessary to avoid premature fledging of the chicks. If the juveniles are disturbed in the critical fledging phase, they might try to leave the nest prematurely without yet having acquired the ability to fly. This results in the hatchlings falling to the ground, possibly sustaining an injury and making them easy prey. After the passing of two weeks, the nest is checked again to confirm whether or not all chicks had fledged and to recover potential carcasses and rings. The banding data as well as possible nestling casualties are then forwarded to the AOC for their long-term monitoring data bank.

3.7 Ethical basis:

Every step of the monitoring process as well as the bird banding is done with the welfare of the animals in mind. The handling of birds is kept as short and unintrusive as possible to limit the stress acting on the birds. At the beginning of the 2023 breeding season, before the start of the master's project, the author took part in the monitoring of the AOC at the Konrad-Lorenz-Institut für Vergleichende Verhaltensforschung (KLIVV) in Vienna, to get accustomed to the process. Possible adverse weather conditions (rain, cold temperatures...) when monitoring or banding the birds were avoided or limited whenever possible. Hand sanitizer was used after handling of life birds to avoid cross contamination of nest sites with possible disease or parasites. Old nests, unhatched eggs and carcases were always discarded at a distance from the nest sites to avoid predation and scavenging. Bird banding was carried out only by trained experts (Co-supervisor Mag. Dr. Josef Hemetsberger, Tatjana Vogel, Veronika Weinhäupl, Andrew Katsis and Veera Jain) or under the guidance of said experts. The two-week resting phase after banding of the hatchlings was always respected to avoid premature fledging. Current Austrian laws for the handling of life animals were followed. Permission for the conduction of the study was granted by the Duke of Cumberland, landlord of the area, as well as the AOC and the Cumberland Wildpark direction. The data collection was conducted non-invasively following the "Guidelines for the use of animals in research" (Animal Behaviour, 1991).

3.8 Data analysis:

The data was analysed with the help of the statistics software R (version 4.0.2) and Microsoft Excel. The packages used in R where: tidyverse, stargazer, lubridate, car and psych.

3.8.1 The occupation rate:

The statistical model used to assess the occupation rate across the study areas was a generalized linear model (GLM) with a binomial distribution (0=unoccupied, 1=occupied). The predictors used were the tree-type (deciduous/coniferous), the position of the nest box on the tree (top/bottom) and human presence (low/high levels, depending on the location). The response variable was the occupation rate. Beforehand, the predictors were checked for collinearity using the variance inflation factor (VIF). No evidence for collinearity was found, with the VIF for all predictors being <1.45. Followingly, a full-null model comparison was exacted, wherein the full-model (predictors tree-type, position of the box on the tree and human presence) was compared to a null-model missing the predictor of interest (human presence).

3.8.2 The day of the first laid egg:

The statistical model used to assess the timing of egg laying was a generalized linear model (GLM) with a linear regression (LM). The predictors used were the human presence (low/high levels, depending on the location) and the position of the nest boxes on the tree (top/bottom). The response variable was the respective calendar week in which the first egg of a clutch was laid. Beforehand, the predictors were checked for normality using a Shapiro-Wilk test and for homogeneity with a qq-plot. The Shapiro-Wilk test showed that normality of the predictors was not given ($p=0,01$), which led to the usage of a bootstrap model. Additionally, the predictors were checked for collinearity using the variance inflation factor (VIF). No evidence for collinearity was found, with the VIF for all predictors being <1.02).

3.8.3 The clutch size:

The statistical model used to assess the clutch size was a generalized linear model (GLM) with a poisson distribution, using a dispersion parameter <1. The predictors used were the human presence (low/high levels, depending on the location) and the material of the nest box (wood/concrete). The response variable was the clutch size. Beforehand, the predictors were checked for collinearity using the variance inflation factor (VIF). No evidence for collinearity was found, with the VIF for all predictors being <1.015. Followingly, a full-null model comparison was exacted, wherein the full-model (predictors human presence and the material of the nest box) was compared to a null-model missing the predictors of interest (human presence, material of the nest box).

3.8.4 The reproductive success:

The statistical model used to assess the reproductive success was a Mann Whitney U-Test. The predictor used was human presence (low/high levels, depending on the location). The response variable was the reproductive success, calculated by dividing the number of fledgelings by the number of eggs (resulting in a value between 0-1). The level of significance was set at $p=\leq 0.05$. Since the number of breeding attempts in the study area Cumberland Wildpark is much larger (n=31) then in the other two study areas Oberganslbach (n=11) and the new woodland north of KLF (n=13), the latter two were combined into one group for this analysis, as both study areas are characterized by low human presence. This allowed for the investigation of possible differences in the reproductive success based on the distinctive trait of human presence (Cumberland Wildpark high levels of human presence/Oberganslbach + new woodland low levels of human presence).

3.8.5 Possible relationships among variables:

To determine possible relationships between the time of the first laid egg and the clutch size or between the time of the first laid egg and the reproductive success, Spearman correlations were used. The respective calendar week in which the first egg of a particular clutch was laid was hereby correlated with the clutch size as well as the reproductive success. The significance level was set at $p\leq 0.05$.

3.8.6 Possible interspecific diferences:

Possible interspecific differences in the occupation rate, the day of the first laid egg, the clutch size and the reproductive success were assessed with qualitative analysis using Microsoft Excel and R. The occupation rate was visualized through the number of occupied nest boxes by the number of occupied boxes per area, by the different study species and by the distribution of species within the respective study areas. Differences in the day of the first laid egg were assessed by comparing the dates of the first egg laying across the study locations. The differences in the duration of the breeding season across the study locations were assessed using the latest fledging times per location of the breeding season. Potential differences in the clutch size were assessed for the study species great tit *(Parus major)*, coal tit *(Periparus ater)* and marsh tit *(Poecile palustris)* across locations. This was done by calculating the standard deviation (SD) and the means. The same procedure (SD and means) was used to assess the reproductive success of the study species great tit *(Parus major)*, coal tit *(Periparus ater)* and marsh tit *(Poecile palustris)* across locations. Such calculations were not performed for the remaining study species blue tit *(Cyanistes ceruleus)*, nuthatches *(Sitta europaea)* and collared flycatchers *(Ficedula albicollis)*, as their respective breeding efforts resulted in only one occupied nest box each, therefore not providing the necessary data for means or standard deviation calculations.

Chapter 4

Results

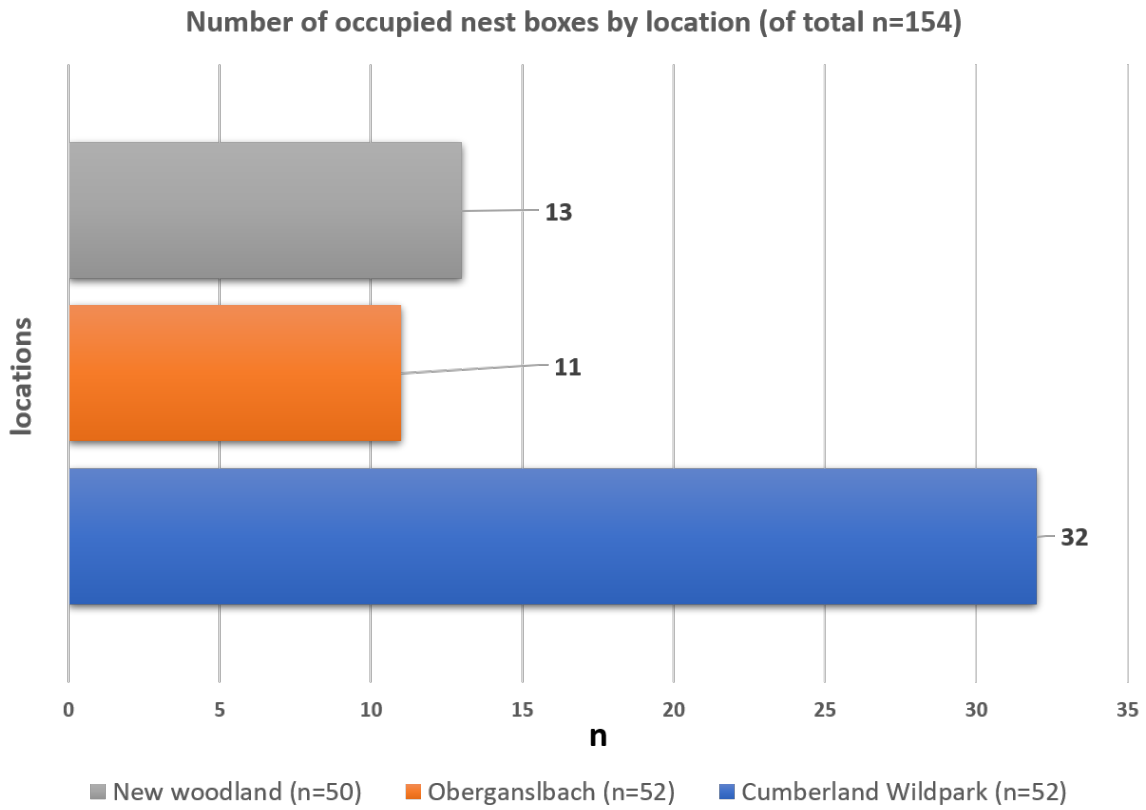
As seen in the overview (**Table 4.1**), a total of n=56 nest boxes were occupied by the different study species during the breeding season across the three study areas. This amounts to 36,4 percent of all available nest boxes. More specifically, of the n=52 nest boxes in the Cumberland Wildpark, n=32 were occupied, amounting to 61.5 percent of the available nesting sites in this study area. In Oberganslbach, n=11 of the available n=52 nest boxes were occupied, equivalent to 21.2 percent of all nest boxes in this location. In the woodland north of the KLF, a total of n=13 of the available n=50 nest boxes were occupied, adding up to a total of 26 percent of nest boxes in the area. Sometimes the same nest box can be occupied multiple times across the breeding season, which was the case for n=4 nest boxes. All such instances were located in the Cumberland Wildpark.

Table 4.1: Overview of nest box occupation

Study location	Wooden nest boxes	Concrete nest boxes	Total (per location)	% (per location)
Wild Park (n=52)	15	17	32	61,5
Oberganslbach (n=52)	9	2	11	21.2
Woodland north of KLF (n=50)	5	8	13	26
Total (n=154)	**29**	**27**	**56**	**36,4**

The bar-graph in (**Figure 4.1**) depicts a visualization of the nest box occupation across all study areas by giving an overview of the general occupation in absolute numbers.

Figure 4.1: Nest box occupation in absolute numbers

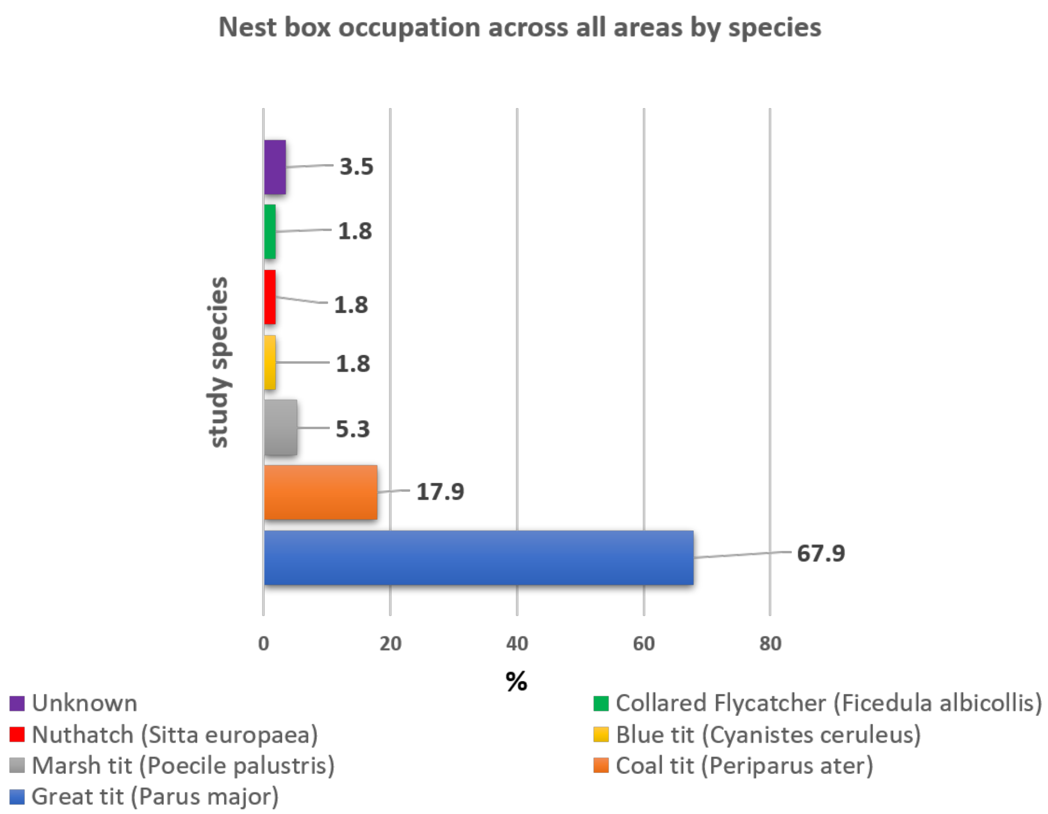


As seen in the overview of all occupied nest boxes (**Table 4.2**), n=38 were occupied by the great tit *(Parus major)*, adding up to 67,9 percent of all occupied nest boxes. The coal tit *(Periparus ater)* occupied a total of n=10 nest boxes, making up 17,9 percent of all occupied nest boxes. The marsh tit *(Poecile palustris)* used n=3 of the available nest boxes as their breeding grounds, amounting to 5,3 percent of all available nest boxes. The blue tit *(Cyanistes ceruleus)*, the nuthatch *(Sitta europea)* and the collared Flycatcher *(Ficedula albicollis)* each took up n=1 of the available nest boxes, amounting to 1,8 percent of all available nest boxes respectively. Additionally, n=2 nest boxes were occupied by nests of undetermined species. These breeding efforts failed or were abandoned before the appropriate species could be identified. These unknown breeding efforts amount to 3,5 percent of all available nest boxes. The pie chart in (**Figure 4.2**) depicts a visualization of the nest box occupation across areas in percentages.

Table 4.2: Overview of nest box occupation by species across areas

Great tit *(Parus major)*	Coal tit *(Periparus ater)*	Marsh tit *(Poecile palustris)*	Blue tit *(Cyanistes ceruleus)*	Nuthatch *(Sitta europea)*	Collared Flycatcher *(Ficedula albicollis)*	Unknown
38	**10**	**3**	**1**	**1**	**1**	**2**
67,9%	**17,9%**	**5,3%**	**1,8%**	**1,8%**	**1,8%**	**3,5%**

Figure 4.2: Overview of nest box occupation by species across areas in percentages

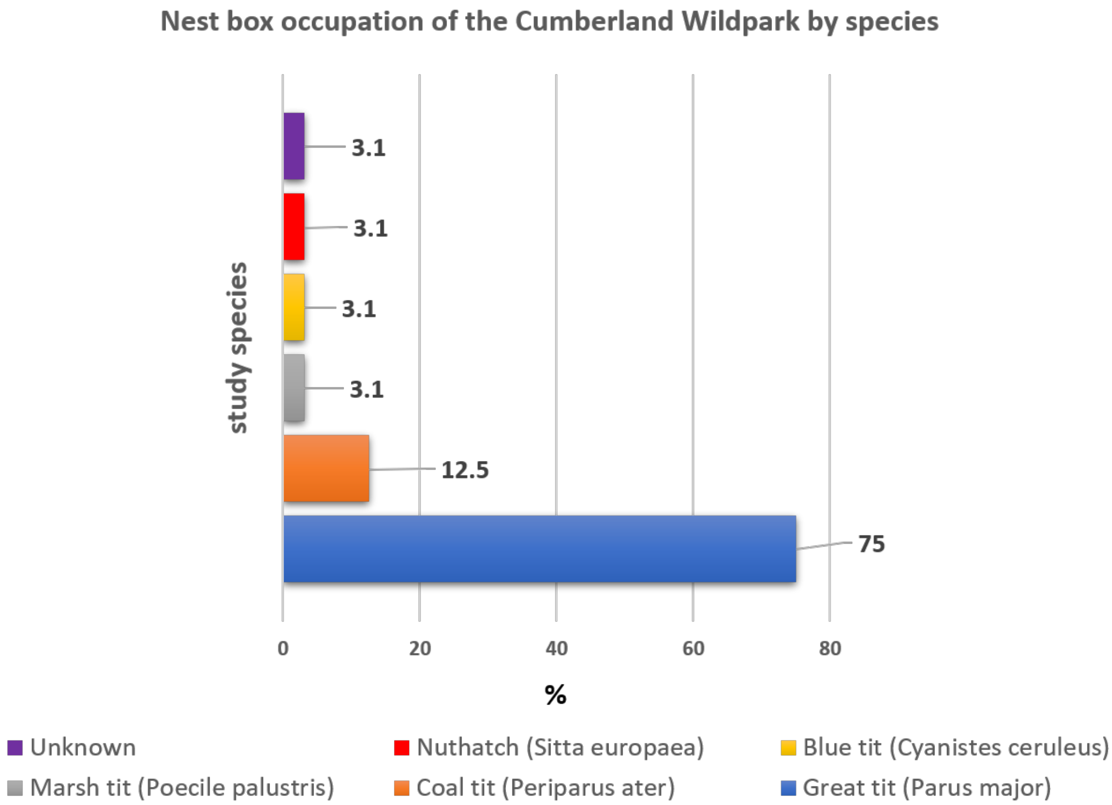


When looking at the three different study areas independently , the great tit *(Parus major)* occupied n=24 of the n= 32 occupied nest boxes in the Cumberland Wildpark (**Table 4.3**), amounting to 75 percent of all occupied nest boxes in the area. The coal tit *(Periparus ater)* occupied n=4 of the n=32 occupied nest boxes in the Cumberland Wildpark, making up 12,5 percent of the occupied nest boxes in the Cumberland Wildpark. The marsh tit *(Poecile palustris)*, the blue tit *(Cyanistes ceruleus)* and the nuthatch *(Sitta europaea)* used n=1 of the n=32 occupied nest boxes in this location respectively, adding up to 3,1 percent each for the occupied nest boxes of the Cumberland Wildpark. A single nest box was occupied by an unknown species, also making up 3,1 percent of the occupied nest boxes. The pie chart in (**Figure 4.3**) depicts a visualization of the nest box occupation in the Cumberland Wildpark in percentages.

Table 4.3: Nest box occupation of the Cumberland Wildpark

Great tit (*Parus major*)	Coal tit (*Periparus ater*)	Marsh tit (*Poecile palustris*)	Blue tit (*Cyanistes ceruleus*)	Nuthatch (*Sitta europea*)	Collared Flycatcher (*Ficedula albicollis*)	Unknown
24	**4**	**1**	**1**	**1**	**0**	**1**
75%	**12,5%**	**3,1%**	**3,1%**	**3,1%**	**0**	**3,1%**

Figure 4.3: Nest box occupation of the Cumberland Wildpark in percentages

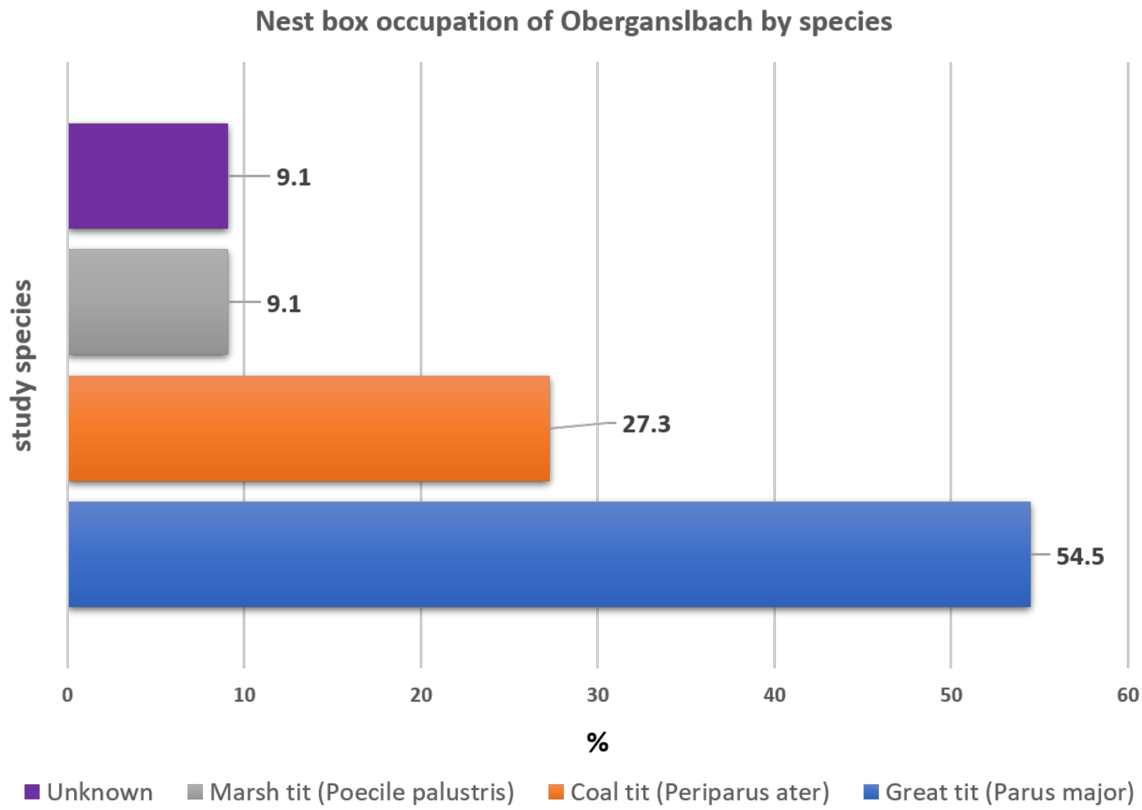


When looking at the three study areas independently , the great tit *(Parus major)* occupied n=6 of the n= 11 occupied nest boxes in Oberganslbach (**Table 4.4**), amounting to 54,5 percent of all occupied nest boxes in that area. The coal tit *(Periparus ater)* occupied n=3 of the n=11 occupied nest boxes in Oberganslbach, making up 27,3 percent of the occupied nest boxes in this location. The marsh tit *(Poecile palustris)*, occupied n=1 of the n=11 occupied nest boxes in Oberganslbach, amounting to 9,1 percent of the occupied nest boxes. A single nest box was occupied by an unknown species, also making up 9,1 percent of the occupied nest boxes. The pie chart in (**Figure 4.4**) depicts a visualization of the nest box occupation in Oberganslbach in percentages.

Table 4.4: Nest box occupation of Oberganslbach

Great tit (Parus major)	Coal tit (Periparus ater)	Marsh tit (Poecile palustris)	Blue tit (Cyanistes ceruleus)	Nuthatch (Sitta europea)	Collared Flycatcher (Ficedula albicollis)	Unknown
6	3	1	0	0	0	1
54,5%	27,3%	9,1%	0%	0%	0%	9,1%

Figure 4.4: Nest box occupation of Oberganslbach in percentages

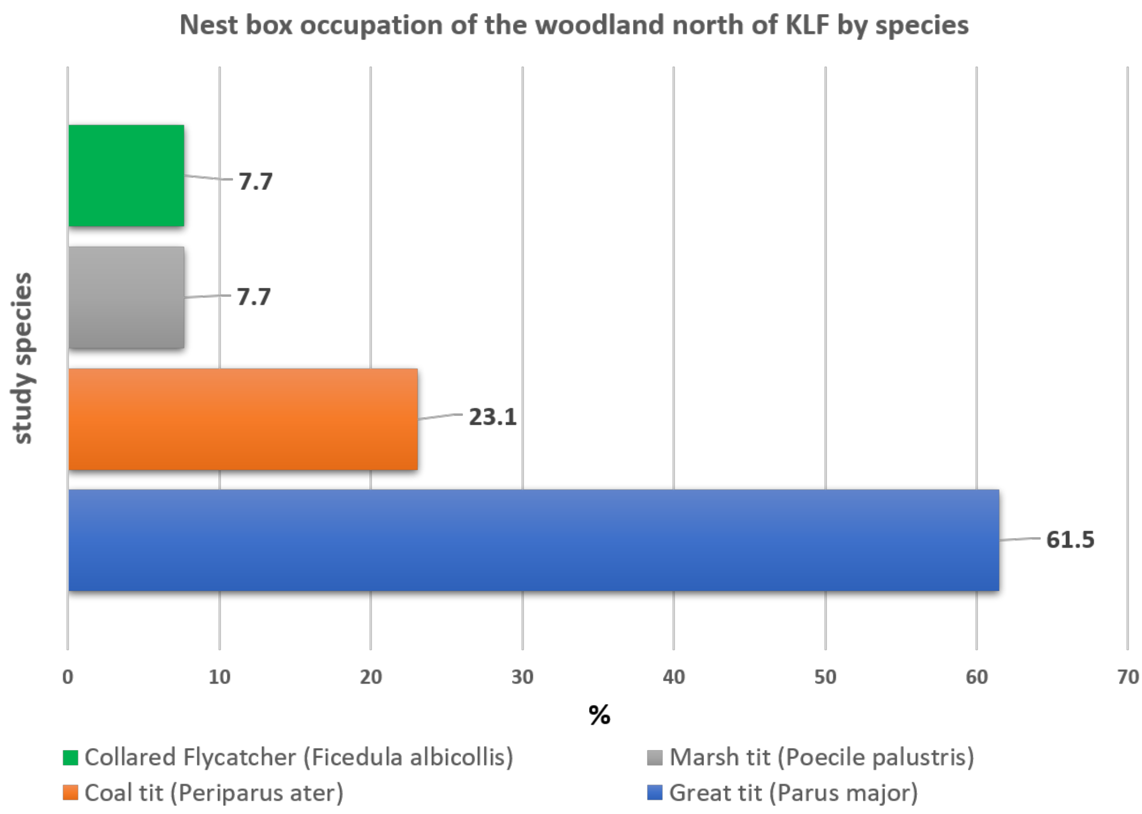


When looking at the three study areas independently , the great tit *(Parus major)* occupied n=8 of the n= 13 occupied nest boxes in the woodland north of the KLF (**Table 4.5**), amounting to 61,5 percent of all occupied nest boxes in this location. The coal tit *(Periparus ater)* occupied n=3 of the n=13 occupied nest boxes in the woodland north of the KLF, making up 23,1 percent of the occupied nest boxes in the area. The marsh tit *(Poecile palustris)*, occupied n=1 of the n=13 occupied nest boxes in the woodland north of KLF, amounting to 7,7 percent of the occupied nest boxes. The collared flycatcher *(Ficedula albicollis)* also occupied n=1 of the n=13 occupied nest boxes in the area, making up 7,7 percent of the occupied nest boxes. The pie chart in (**Figure 4.5**) depicts a visualization of the nest box occupation in the woodland north of KLF in percentages.

Table 4.5: Nest box occupation of the woodland north of KLF

Great tit (Parus major)	Coal tit (Periparus ater)	Marsh tit (Poecile palustris)	Blue tit (Cyanistes ceruleus)	Nuthatch (Sitta europea)	Collared Flycatcher (Ficedula albicollis)	Unknown
8	**3**	**1**	**0**	**0**	**1**	**0**
61,5%	**23,1%**	**7,7%**	**0%**	**0%**	**7,7%**	**0%**

Figure 4.5: Nest box occupation of the woodland north of KLF in percentages



4.1 The occupation rate:

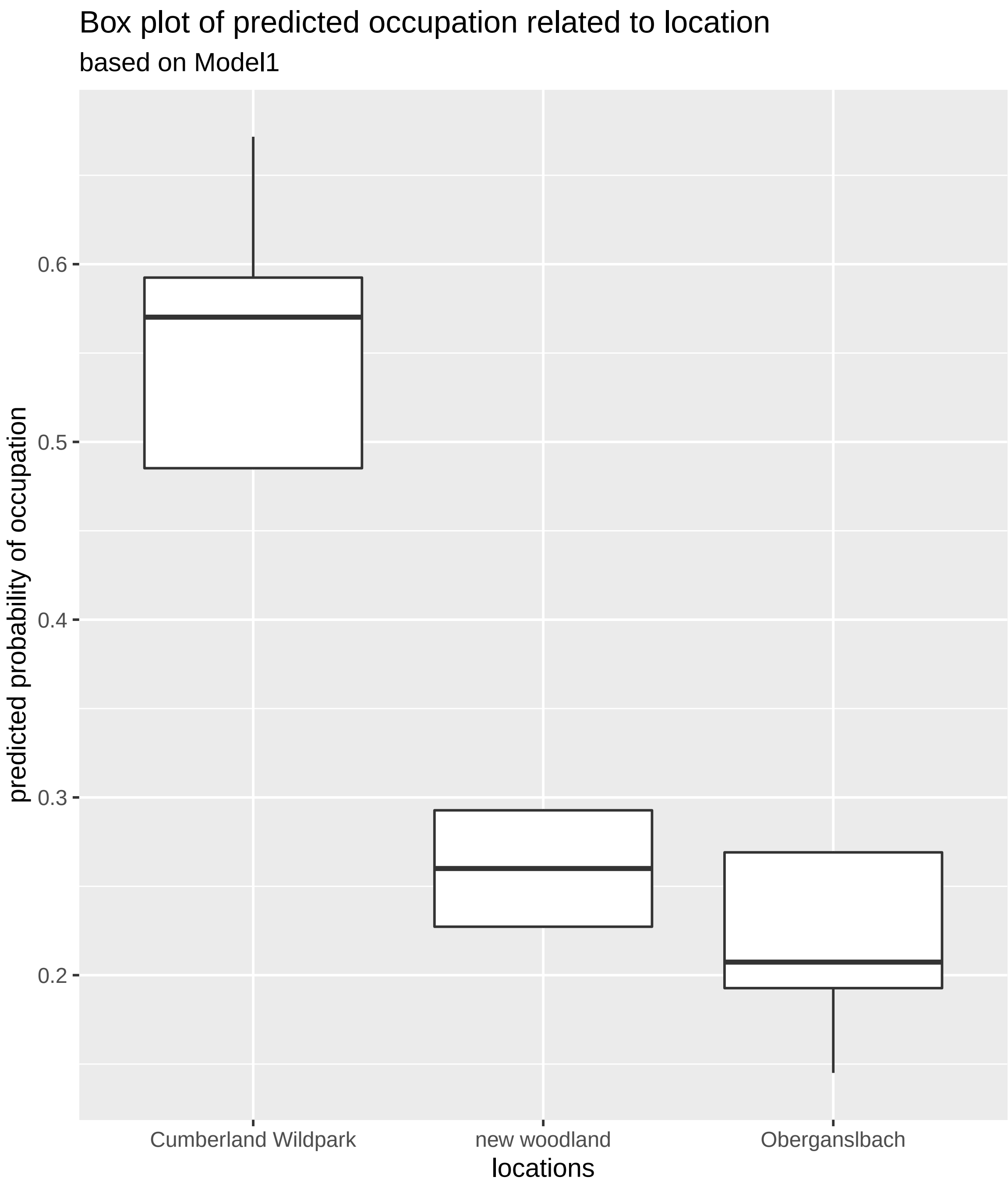
The occupation rate (**Table 4.6**) for the nest boxes in the Cumberland Wildpark was significantly elevated compared to the nest boxes of the other two study areas.

Table 4.6: The occupation rate

	Dependent variable:		
	occupation		
	(1)	(2)	(3)
	Model0	Model1	Model2
Constant	-0.914^{***}	-1.224^{***}	-1.318^{***}
	(0.278)	(0.376)	(0.421)
forest_type Oberganslbach		-0.117	-0.115
		(0.493)	(0.494)
forest_type Cumberland Wildpark		1.598^{***}	1.608^{***}
		(0.529)	(0.530)
Tree-type	0.376	-0.433	-0.442
	(0.342)	(0.457)	(0.458)
On_top	0.312	0.342	0.346
	(0.335)	(0.355)	(0.355)
Material			0.179
			(0.355)
Observations	159	159	159
Log Likelihood	-102.116	-93.645	-93.517
Akaike Inf. Crit.	210.232	197.291	199.035
Note:			*p<0.1; **p<0.05; ***p<0.01

Human presence has a significant influence ($p<0.01$) on the occupation rate.
In the study area with high levels of human presence, the Cumberland Wildpark, the occupation of a nest box was more likely. The inclusion of the variable material lowers the accuracy of the model, without providing further information (AICmodel1=197.291<AICmodel2=199.035, with lower values being better).

Figure 4.6: The predicted likelihood of occupation



Based on the results of model1 (**Table 4.6**), a prediction of the likelihood of occupation was conducted, and the distribution based on human presence was plotted with the help of a box-plot (**Figure 4.6**). The box-plot shows that the predicted probability of occupation in the Cumberland Wildpark, the area with high levels of human presence, was significantly higher compared to the other two study areas Oberganslbach and the woodland north of KLF with low levels of human presence.

4.2 The timing of egg laying:

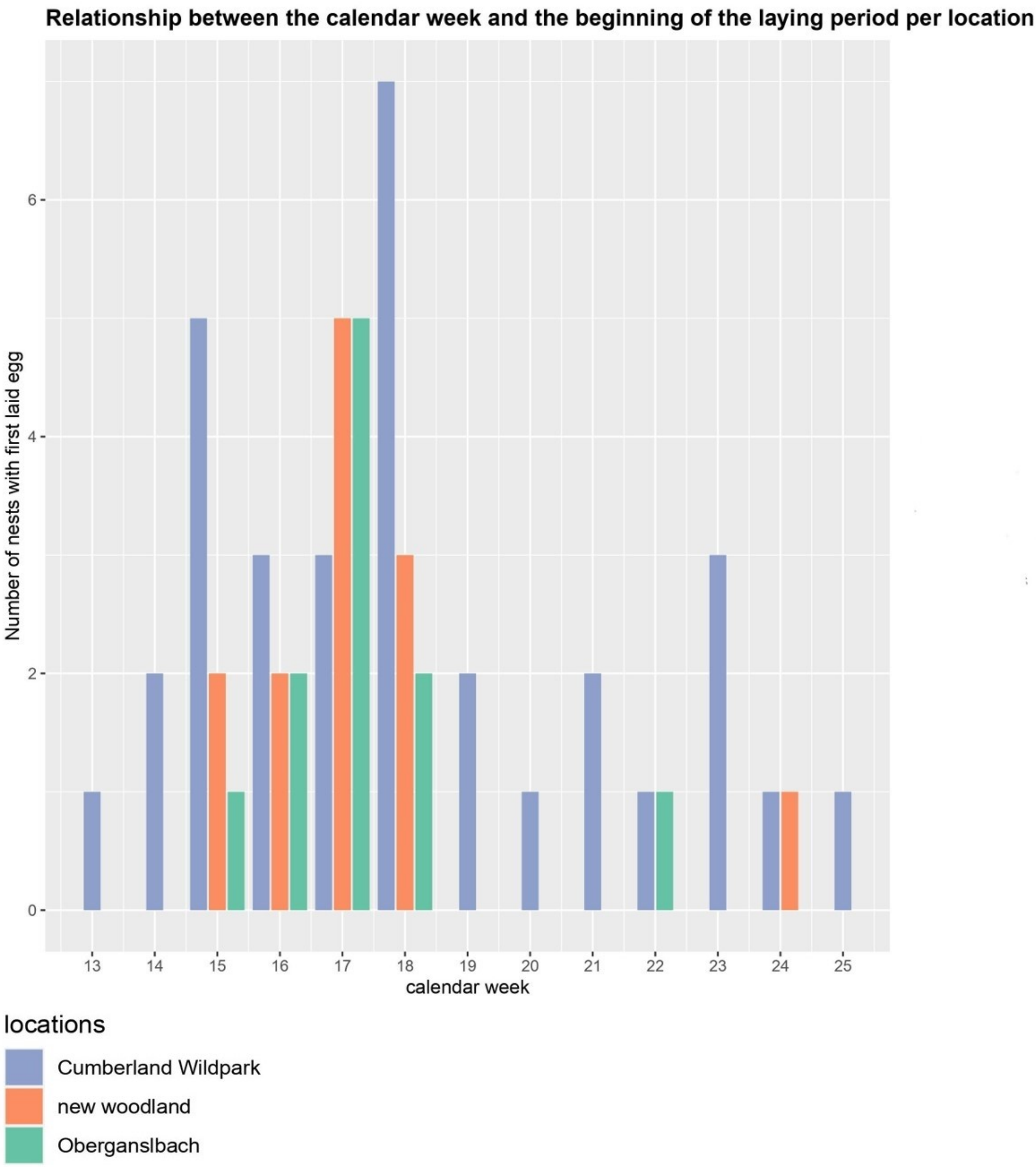
The date of the first laid egg was significantly earlier in the Cumberland Wildpark. The first egg in general was laid by the breeding pair of nuthatches *(Sitta europaea)* on the 31st of March, in the Cumberland Wildpark. The first egg in Oberganslbach was laid by a breeding pair of marsh tits *(Poecile palustris)* on the 13th of April. The first egg in the woodland north of KLF was laid by a breeding pair of coal tits *(Periparus ater)*, also on the 13th of April.

The last egg in general was laid by a breeding pair of great tits *(Parus major)* on the 25th of June, in the Cumberland Wildpark. The last egg in Oberganslbach was laid on the 31th of May, by a breeding pair of great tits *(Parus major)*. The last egg in the woodland north of KLF was laid on the 11th of June by the breeding pair of collared flycatchers *(Ficedula albicollis)*.

The last chicks in general fledged in the first week of August, in the Cumberland Wildpark. The last chicks in Oberganslbach fledged between the second and third week of July. The last chicks in the woodland north of KLF also fledged between the second and third week of July. The last chicks to fledge in all study areas were great tits *(Parus major)*.

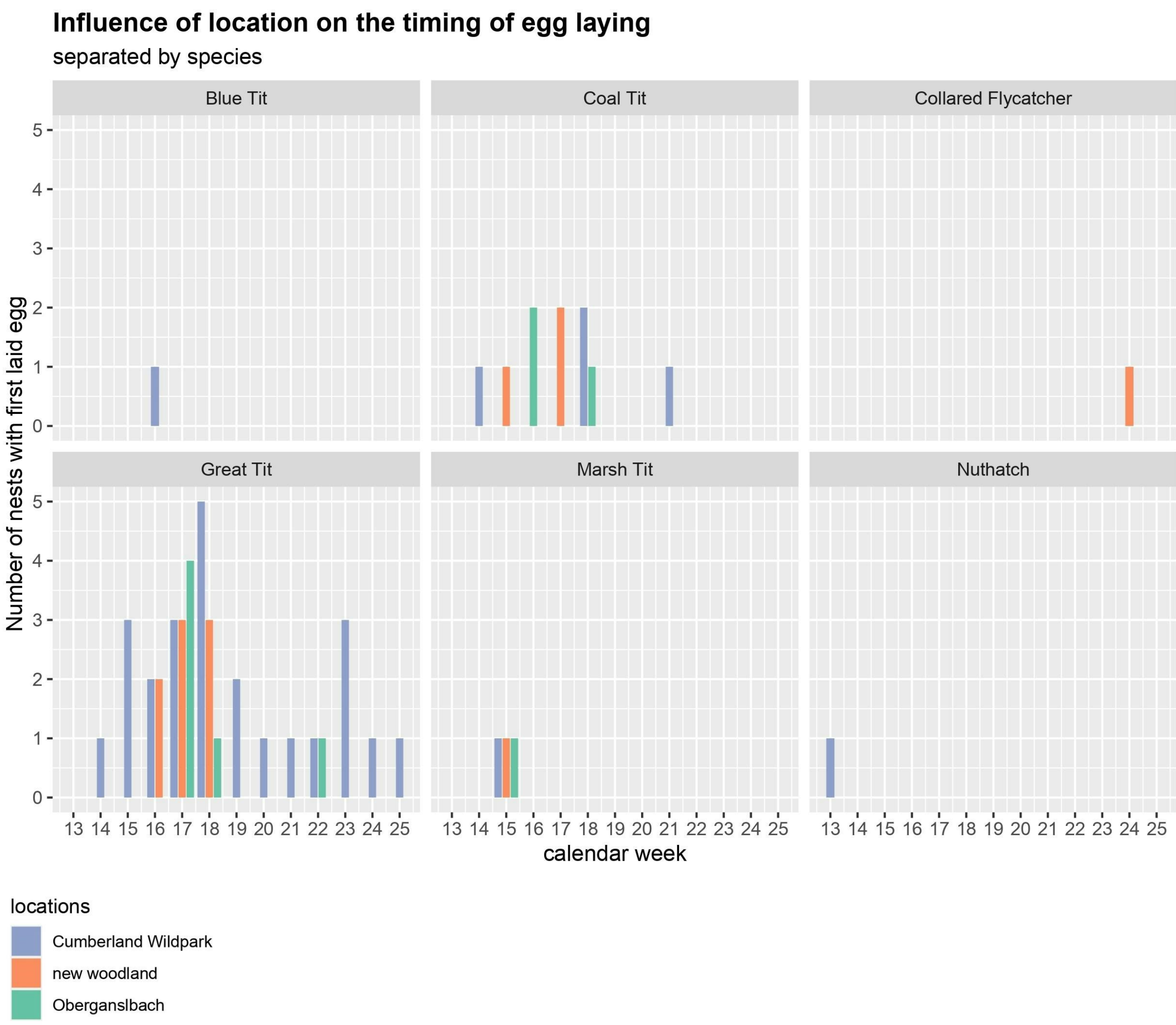
The breeding season therefore lasted longer in the Cumberland Wildpark compared to Oberganslbach and the woodland north of KLF, with a difference of close to a month between the last eggs laid in Oberganslbach, the woodland north of KLF and the Cumberland Wildpark. Additionally, there was a difference of about two weeks between the last chick fledging in Oberganslbach, the woodland north of KLF and the last chick fledging in the Cumberland Wildpark.

Figure 4.7: The laying period per location



The diagram (**Figure 4.7**) shows the egg laying in the Cumberland Wildpark to be more consistent over time, starting earlier and going on for longer than in the other two study areas Oberganslbach and the new woodland north of KLF. Egg laying peaks from calendar week 15 to approximately calendar week 19, across all locations. Followingly it falls off in the areas Oberganslbach and the new woodland north of KLF, with a minor uptake in the rate of egg laying occurring approximately in the 21 calendar week up to the 23/24 calendar week across all locations. This is most likely due to the occurrence of replacement/secondary clutches. In the Cumberland Wildpark, there is no pause in egg laying. However, the rate falls off after calendar week 19. A minor uptake in the rate of egg laying is noticeable at around calendar week 23 also in this study location, again most likely due to the occurrence of replacement/secondary clutches.

Figure 4.8: The timing of egg laying by species

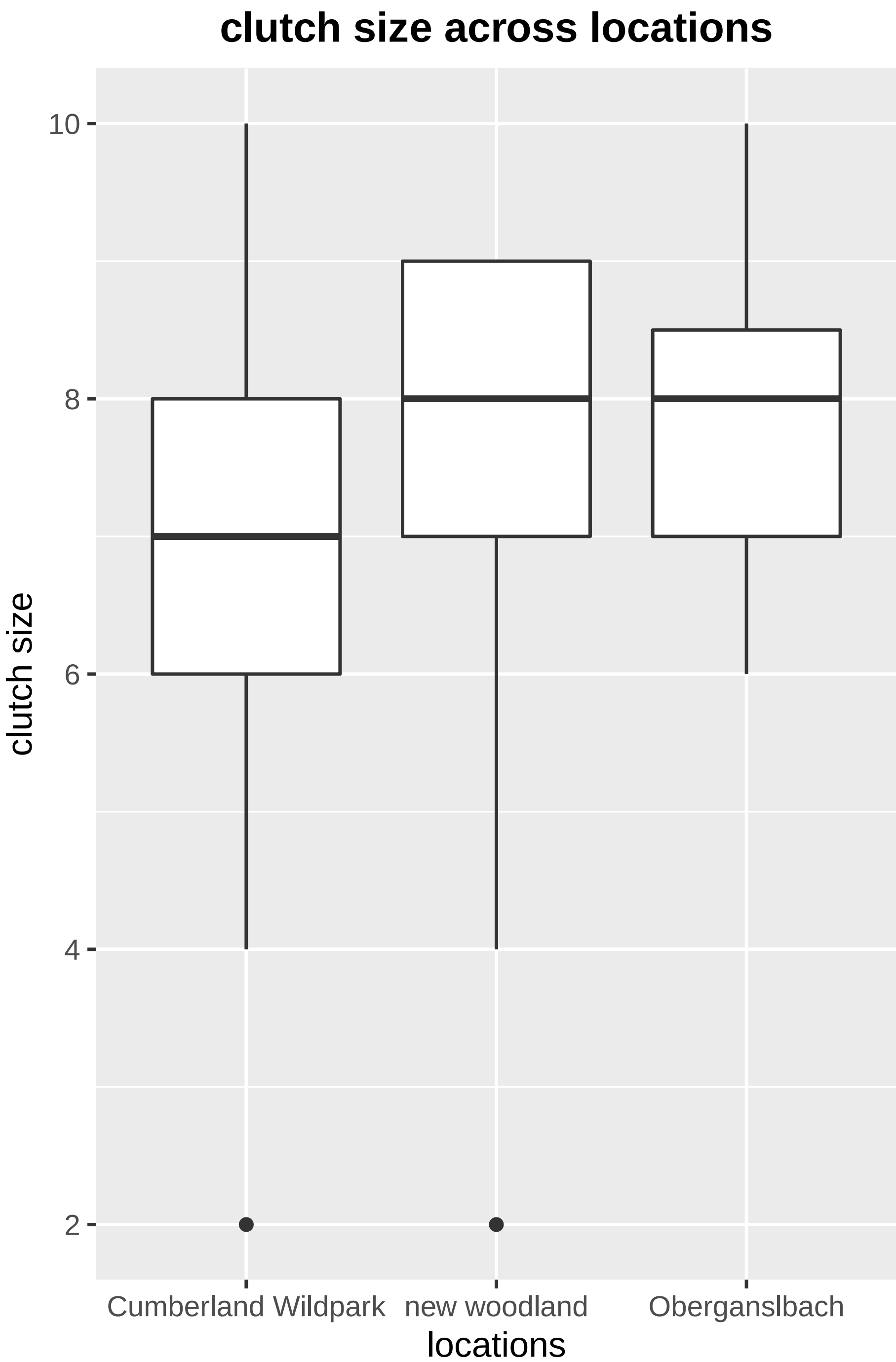


The diagram (**Figure 4.8**) shows that generally, egg laying seems to be most prevalent near the beginning and middle of the breeding season. This appears visible across all study species, except for the collared flycatcher *(Ficedula albicollis)*. It is most pronounced in the study species nuthatch *(Sitta europaea)*, which was the first to lay eggs (calendar week 12). It appears also visible in the blue tit *(Cyanistes ceruleus)* and the marsh tit *(Poecile palustris)*. However, these specie's breeding efforts amounted to only one occupied nest box for the blue tit *(Cyanistes ceruleus)* and nuthatches *(Sitta europaea)* respectively, and only three occupied nest boxes for the marsh tit *(Poecile palustris)* and are therefore not statistically significant. The great tit *(Parus major)* seems to lay its eggs throughout the whole breeding season, with a peak at calendar week 18 and a second, smaller spike at around calendar week 22. The second spike most likely represents secondary or replacement clutches. The egg laying also continues for longer in the Cumberland Wildpark for this species compared to the other study locations. The coal tit *(Periparus ater)* also seems to lay most of its eggs near the beginning of the breeding season, from approximately calendar week 13 to 19 but continuing for a bit longer compared to the other less prevalent study species (not including the great tit *(Parus major)*). A second spike is also visible in the breeding of the coal tit *(Periparus ater)* at around calendar week 21, most likely representing secondary or replacement clutches as well. The only species to solely lay their eggs close to the end of the breeding season was the collared flycatcher *(Ficedula albicollis)*, at around calendar week 23. Once again, only one nest box was occupied by this species, most likely representing a replacement/secondary clutch.

4.3 The clutch size:

No significant differences in the clutch size were found across the three study locations.

Figure 4.9: Box plot of the clutch size



The box-plot (**Figure 4.9**) suggests that the clutch size in the Cumberland Wildpark, with higher levels of human presence, might be slightly smaller compared to the other two study areas with lower levels of human presence.

Table 4.7: The clutch size model

	Dependent variable:	
	clutch size	
	(1)	(2)
	Clutch Model	null
Constant	1.945***	1.959***
	(0.112)	(0.050)
Material	0.083	
	(0.106)	
forest_type Oberganslbach	0.054	
	(0.155)	
forest_type Cumberland Wildpark	−0.076	
	(0.124)	
Observations	56	56
Log Likelihood	-118.827	-119.921
Akaike Inf. Crit.	245.654	241.842
Note:	*p<0.1; **p<0.05; ***p<0.01	

However, the linear model (**Table 4.7**) shows that neither the material of the nest box, nor the location (i.e. different levels of human presence) seems to have a significant influence on the clutch size of the study species.

4.4 The reproductive success:

The reproductive success (**Figure 4.10**) was found to be significantly (p=0.02804) lower in the Cumberland Wildpark compared to the other two study areas of Oberganslbach and the woodland north of KLF, based on the differing means.

Figure 4.10: The reproductive success

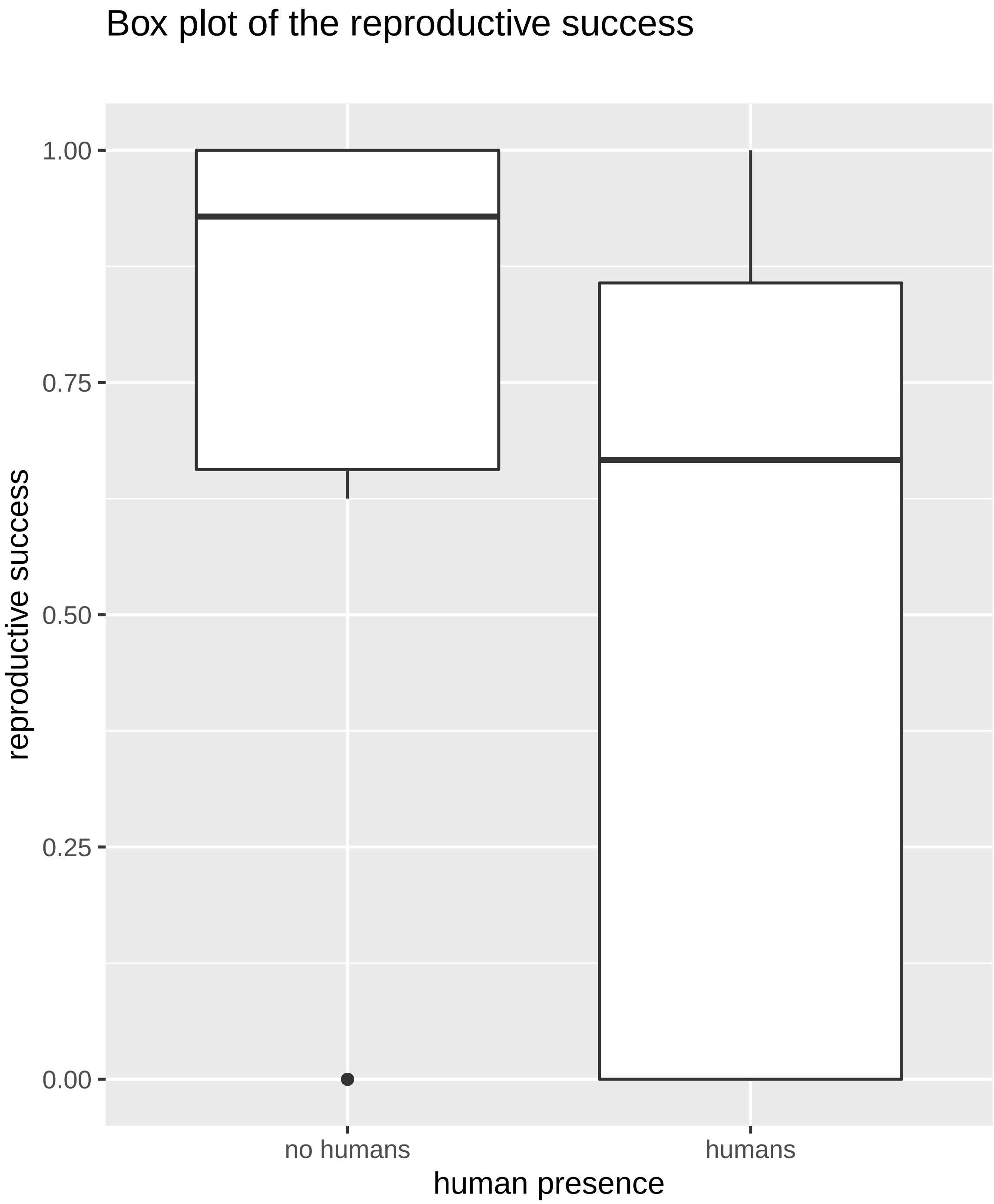
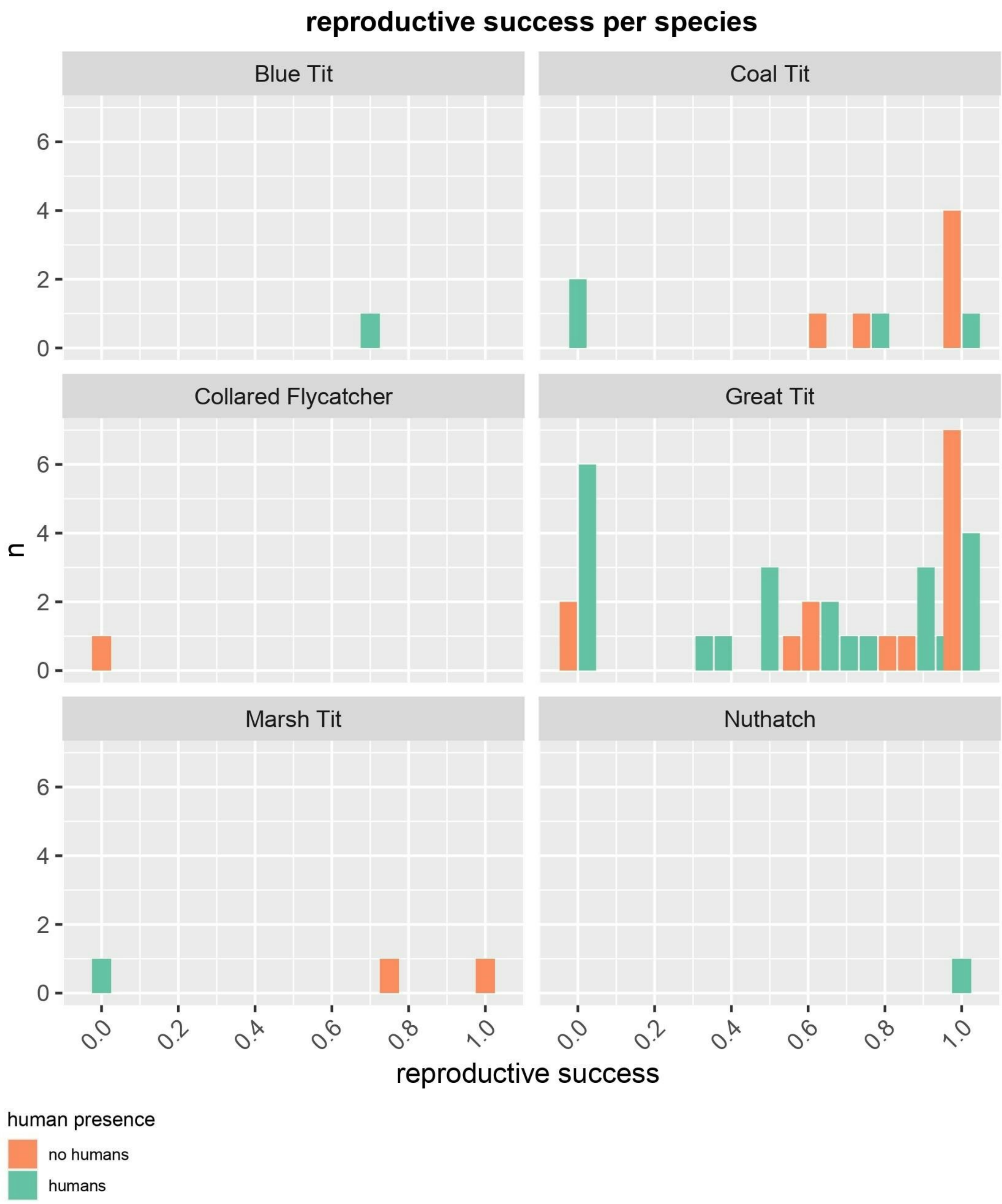


Figure 4.11: The reproductive success across species

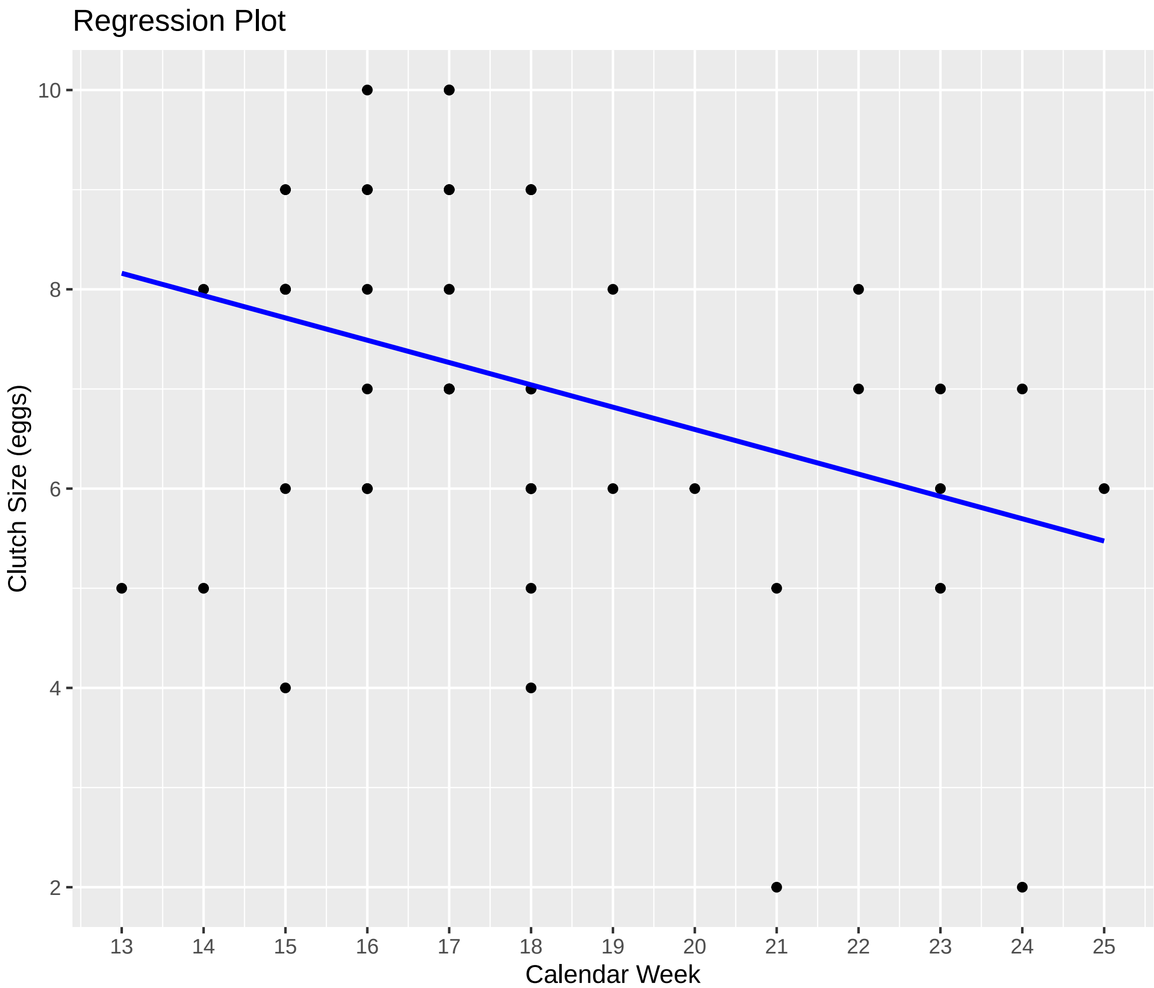


A high level of variance in the reproductive success appears visible across the species (**Figure 4.11**). This holds especially true for the more frequent species, such as the great tit *(Parus major)* and the coal tit *(Periparus ater)*. The effect of human presence seems most significant for the species great tit *(Parus major)*. This species, as well as to a lesser extend the species coal tit *(Periparus ater)*, have a higher level of variance in the reproductive success in the Cumberland Wildpark, the area with high levels of human presence.

4.5 Relationships among variables:

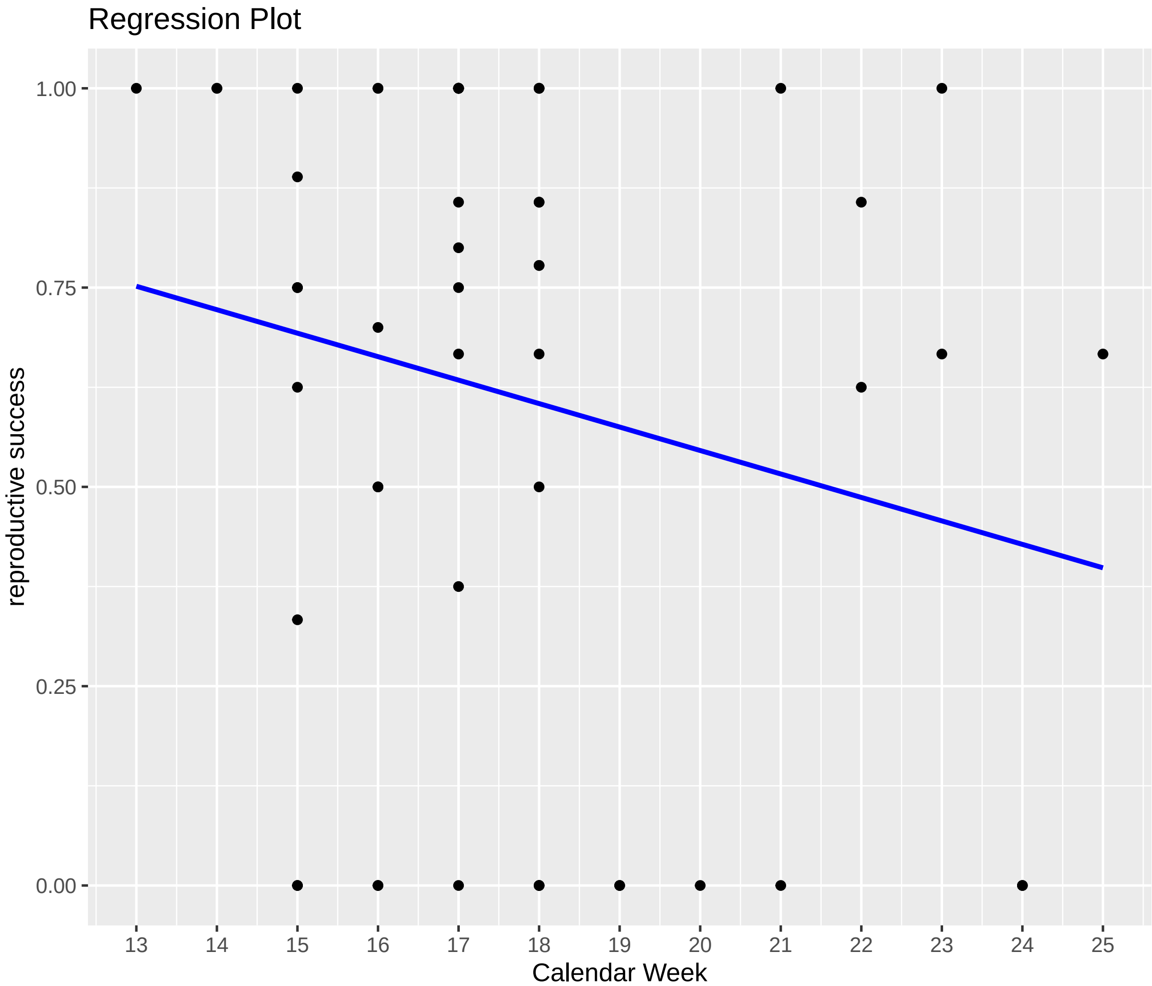
A significant, (p=0.0287, rho=-0.292) moderately negative relation between the clutch size and the calendar week was found using Spearmans rank correlation coefficient (**Figure 4.12**). This implies that the general clutch size, regardless of species, diminishes with the progression of the season. Therefore, the later in the season a breeding attempt occurs, the fewer eggs are likely to be in that particular clutch.

Figure 4.12: The relationship between the clutch size and the respective calendar week in which the first egg was laid



Using Spearmans rank correlation coefficient model (**Figure 4.13**), no significant relation between the reproductive success and the calendar week was found (p=0,139)

Figure 4.13: The (lack of) relationship between the reproductive success and the respective calendar week in which the first egg was laid



4.6 Interspecific differences:

Possible interspecific differences across the more prevalent study species were investigated through qualitative analysis. Herefore, means (**Table 4.8** and **Table 4.10**) and standard deviations (SD) (**Table 4.9** and **Table 4.11**) were calculated. These calculations were exacted for the study species great tit *(Parus major)*, coal tit *(Periparus ater)* and marsh tit *(Poecile palustris)*. The other study species were not assessed, as their respective breeding efforts amounted to only one occupied nest box respectively. This does not allow for calculation of the means or standard deviations, as the given data for the concerned species is equal to the means and the standard deviations of each respective species. Following this logic, the standard deviation could not be calculated for the marsh tit *(Poecile palustris)* across the study locations, as this species occupied one nest box per study area (n=3 nest boxes in total), with the data therefore lacking the basis for standard deviation calculations.

Table 4.8: The mean clutch size across species

mean clutch size	great tit (*Parus major*)	coal tit (*Periparus ater*)	marsh tit (*Poecile palustris*)
wild park	**6.92**	**5.25**	**8**
Oberganslbach	**7.83**	**7.66**	**8**
new woodland	**8.13**	**7.33**	**4**

Table 4.9: The standard deviation of the clutch size across species

clutch size SD	great tit (*Parus major*)	coal tit (*Periparus ater*)
wild park	**1.38**	**2.87**
Oberganslbach	**1.47**	**0.58**
new woodland	**1.25**	**0.58**

Table 4.8 and **Table 4.9** depict the means and standard deviations of the clutch size across study -species and -locations. The clutch size of the great tit *(Parus major)* across locations was at its lowest in the Cumberland Wildpark, where it had a range of (6.9 +- 1.38) eggs. It was followed by Oberganslbach, where it ranged from (7.83 +- 1.47). This specie's clutch size was highest in the new woodland, where it ranged from (8.13 +- 1.25). The clutch size of the coal tit *(Periparus ater)* across locations was at its lowest in the Cumberland Wildpark, where it had a range of (5.25 +- 2.87) eggs. It was followed by the new woodland, where it ranged from (7.33 +- 0.58). This species clutch size was highest in Oberganslbach, where it ranged from (7.66 +- 05.8). The clutch size of the marsh tit *(Poecile palustris)* ranged from 4 eggs in the new woodland to 8 eggs in the Cumberland Wildpark and Oberganslbach. The blue tit *(Cyanistes ceruleus)* had a single clutch of 10 eggs, which were laid in the wild park. The nuthatches *(Sitta europaea)* had a single clutch of 5 eggs, which were laid in the Cumberland Wildpark. The collared flycatcher *(*Ficedula albicollis) had a single clutch of 2 eggs, which were laid in the new woodland. This specie's clutch seems to have been abandoned prematurely.

Table 4.10: The mean reproductive success across species

mean breeding success	great tit (*Parus major*)	coal tit (*Periparus ater*)	marsh tit (*Poecile palustris*)
wild park	**0.54**	**0.44**	**0**
Oberganslbach	**0.85**	**1**	**1**
new woodland	**0.69**	**0.79**	**0.75**

Table 4.11: The standard deviation of the reproductive success across species

breeding success SD	great tit (*Parus major*)	coal tit (*Periparus ater*)
wild park	**0.38**	**0.52**
Oberganslbach	**0.17**	**0**
new woodland	**0.44**	**0.19**

Table 4.10 and **Table 4.11** depict the means and standard deviations of the reproductive success across study -species and -locations.The reproductive success of the great tit *(Parus major)* across locations was at its lowest in the Cumberland Wildpark, where it had a range of (0.54 +- 0.38). It was followed by the new woodland, where it ranged from (0.69 +- 0.44). This specie's reproductive success was highest in Oberganslbach, where it ranged from (0.85 +- 0.17) The reproductive success of the coal tit *(Periparus ater)* across locations was at its lowest in the Cumberland Wildpark, where it had a range of (0.44 +- 0.52). It was followed by the new woodland, where it ranged from (0.79 +- 0.19). This specie's reproductive success was highest in Oberganslbach, where it reached its maximum with a value of 1 (no mortality of chicks or loss of eggs). The reproductive success of the marsh tit *(Poecile palustris)* was at its lowest in the Cumberland Wildpark, with a value of 0 (all eggs/ chicks lost). It was followed by the new woodland, with a value of 0.75. This specie's reproductive success was highest in Oberganslbach, where it reached its maximum with a value of 1 (no mortality of chicks or loss of eggs). The blue tit *(Cyanistes ceruleus)* had a reproductive success of 0.7. The nuthatches *(Sitta europaea)* had a reproductive success of 1. The collared flycatcher *(Ficedula albicolis)* had a reproductive success of 0.

Chapter 5

Discussion

Annual environmental fluctuations such as in climate, population density, the sex ratio, nesting space density, food source availability as well as the respective life history-traits are thought to be the main drivers of differences in the breeding ecology of the study species (Stevenson and Bryant, 2000; Farina, 1983). The more generalist great tit *(Parus major)* and blue tit *(Cyanistes ceruleus)* are known to inhabit various different forest types as well as urban areas such as cityscapes and parks. The coal tit *(Periparus ater)* mostly inhabits coniferous forests (BirdLife International, 2023). The marsh tit *(Poecile palustris)*, the nuthatches *(Sitta europea)* and the collared flycatcher *(Ficedula albicollis)* prefer mixed or deciduous forest habitats, as do many other species of secondary hole nesting birds (BirdLife International, 2023). This preference among some secondary hole nesting birds for deciduous or broad-leaved forests might partly derive from the fact that tree cavities are naturally more abundant in such woodlands, as deciduous wood is often softer than conifer wood. The more abundant resin exudation of conifers might also seal or block potential cavities more frequently (Peace *et al.*, 1962). Primary hole nesting birds such as woodpeckers *(Picidae)* seem to prefer excavating their nesting cavities in deciduous forests for the same reasons, which may later become available for secondary hole nesting birds as additional nesting sites (Newton, 1998; Peace *et al.*, 1962). Resident bird species seem to be less negatively affected by human presence compared to migratory species, as they may get accustomed to reoccurring human presence and come to learn it to be non-threatening (Baudains and Lloyd, 2007; Klein *et al.*, 1995). This might explain the relative in-sensitiveness of the study species toward human presence/disturbances as all of the study species, except for the collared flycatchers *(Ficedula albicollis)*, are resident species.

Regarding species dominance, the great tit *(Parus major)* clearly stands out.
The species was most abundant across all three study areas. It was followed by the coal tit *(Periparus ater)* as the second most common species across all study locations. Next number-wise was the marsh tit *(Poecile palustris)*, across all three areas. Finally, there was one breeding pair of blue tits *(Cyanistes ceruleus)* and nuthatches *(Sitta europea)* respectively, both breeding in nest boxes of the Cumberland Wildpark. A single nest box in the woodland north of the KLF was occupied by collared flycatchers *(Ficedula albicolis)*. However, their particular breeding efforts did not produce offspring as the nest was abandoned with two eggs laid. The cause might be disturbance due to logging directly adjacent to the particular nest box, as noise is a known stressor for birds (Isaksson, 2018; Forman *et al.*, 2002; Reijnen *et al.*, 1995). Generally, the diversity of bird species tends to decline in proximity to humans and their settlements (Clergeau *et al.*, 2006; McKinney, 2002; Van der Zande *et al.*, 1984; Cooke, 1980). However, a number of studies point out that some avian species might be more tolerant toward humans and urbanisation then others (Remacha and Delgado, 2009; Clergeau *et al.*, 2006; Cooke, 1980). An important factor for a taxa's tolerance toward humans could be the ecological niche of a particular species, with generalist taxa that have a wider ecological niche being better suited for life near humans than specialist species with a more narrow ecological niche. This would explain the dominance of the great tit *(Parus major)* in the area, as it is a larger, more generalist species compared to the other, smaller and more specialist study species (Farina, 1983). A study by Van der Zande *et al.* (1984) supports this notion, as it identified a population density increase of great tits *(Parus major)* in correlation to the density of recreational (greenspace) areas in cityscapes. A local exception is the blue tit *(Cyanistes ceruleus)*. It is, like the great tit *(Parus major)*, a more generalist species (BirdLife International, 2023). Nevertheless, it is found breeding significantly less often in the provided nest boxes then the great tit *(Parus major)*, the coal tit *(Periparus ater)* and the marsh tit *(Poecile palustris)*. Dhondt (1977) found considerable interspecific competition between the great tit *(Parus major)* and blue tit *(Cyanistes ceruleus)* in his study, with the blue tit *(Cyanistes ceruleus)* having the edge when competition for food is concerned, due to it having a wider range of different food items. However, with the great tit *(Parus major)* having a larger body mass, the blue tit *(Cyanistes ceruleus)* is often outcompeted for suitable nesting sites by the former (Minot and Perrins, 1986; Minot, 1981; Dhondt, 1977). Additionally, it has been shown by Jabłoński and Lee (1999) and Hogstad (1978) that social dominance is related to body size and mass in tits *(Paridae spp.)*. Therefore, blue tits *(Cyanistes ceruleus)* as well as other smaller species often prefer nesting sites with smaller entry hole diameters inaccessible to the great tit *(Parus major)* and other larger cavity nesters (Lambrechts *et al.*, 2010; Sorace and Carere, 1996). All nest boxes used in this study have the same entry diameter of 32mm, thus favouring the great tit *(Parus major)*. Therefore, interspecific competition for suitable nesting sites between the smaller secondary hole nesting birds of the area -i.e., the blue tit *(Cyanistes ceruleus)*, marsh tit *(Poecile palustris)*, coal tit *(Periparus ater)* and nuthatches *(Sitta europaea)* - might be aggravated. Competition for

suitable nesting sites from the larger, more dominant great tit *(Parus major)* might affect other study species -not only the blue tit *(Cyanistes ceruleus)*- as well, potentially increasing the competitive pressure further. To limit competition, marsh tits *(Poecile palustris)* may practice niche separation. The species seems to favour the shrub layer, which is lower in the tree line and therefore less attractive to other *Paridae* such as the blue tit *(Cyanistes ceruleus)* or great tit *(Parus major)* (Perrins, 2003). These findings could be addressed in future studies by the means of nest boxes with differently sized entry hole diameters. These factors might in part explain the lower occupation rates of blue tits *(Cyanistes ceruleus)*, coal tits *(Periparus ater)*, marsh tits *(Poecile palustris)* and nuthatches *(Sitta europaea)* (**Figure 5.1 and 5.2**) compared to the great tit *(Parus major)* across the nest boxes of the Almtal area. When it comes to the degree of urbanisation, the Cumberland Wildpark is much more frequented by humans and obstructed by infrastructure such as roads, buildings and fences then the other two study areas. Nevertheless, it remains quite near natural and much less obstructed by buildings, roads and other human structures then cities or settlements. This implies that many of the necessary natural resources such as caterpillars and other arthropods or natural nesting sites such as tree hollows remain available. Likewise, artificial benefits such as the provided food sources and artificial nesting grounds might improve the general fitness of the birds in the area. Additionally, the level of human disturbance remains relatively low, as it is limited by the opening hours of the Cumberland Wildpark and never reaches the extent seen in cities or other urban environments. The same holds true for the level of pollution of the air, water, through noise, human garbage and soil- sealing or compaction (McKinney, 2002). Therefore, possible detrimental effects caused by human presence on the secondary hole nesting birds might be evened out by the higher abundance of food sources available year-round. However, overall Fitness cannot be reliably measured through changes in the abundance of birds and their distribution (Thompson and Schlacher, 2008; Yasué, 2005). A more fitting measure are foraging rates (Lyons *et al.*, 2008; Beale and Monaghan, 2004). Foraging behaviour in birds seems to be negatively affected by human presence, with the time spent foraging shorter in the presence of humans. For example, vigilance behaviour is prolonged for up to ten times in kentish plovers *(Charadrius alexandrinus)* when in close proximity to humans, reducing the individual fitness (Perez-Hurtado and Hortas, 1993). This could be examined in the future through observation of the study specie's foraging behaviour, using ethological observation methods such as scan sampling, continuous observation or time budget analysis.

5.1 The occupation rate:

The collected data revealed a significant preference for the deciduous Cumberland Wildpark as the study specie's favoured breeding site.

The Cumberland Wildpark is home to significantly higher occupation rates compared to the nest boxes of Oberganslbach and the woodland north of the KLF. Expressed in figures, n=32 nest boxes were occupied in the Cumberland Wildpark, while n=11 were occupied in Oberganslbach and n=13 in the woodland north of KLF. The preference among the study species for the Cumberland Wildpark as their chosen breeding grounds could partly derive from the availability of additional food sources (Branston *et al.*, 2021; Chamberlain *et al.*, 2009; Perrins and McCleery, 1989). Examples thereof are leftovers by visiting humans, as well as bird feeders present in the Cumberland Wildpark. Such bird feeders are well visited by many different bird species, including the study species (Marini *et al.*, 2017). The animals housed in the Cumberland Wildpark are also fed daily, which could represent another additional food source for the study species in the form of scavenging or stealing, especially in winter when food is more scarce. Such food sources might help in times of need and could increase the survivability of the study species. They cannot however, fully replace natural, more protein rich food sources such as arthropods like caterpillars and insects which are especially important for the development of healthy offspring (Vaugoyeau *et al.*, 2016; Van Balen, 1973). A second factor might be the abundance of deciduous trees across the Cumberland Wildpark. As described, they are often favoured by many secondary hole nesting bird species (Peace *et al.*, 1962). A third, perhaps more important factor influencing the nesting choice of the different study species is the familiarity with the possible nesting site. Avian taxa tend to prefer nesting sites that are familiar to them, for example nest sites that have been available in the same spot for many years and/or show signs of previous occupation (De León and Mínguez, 2003). This is the case for many of the nest boxes in the Cumberland Wildpark, as many of the nest boxes in this area have been hanging for up to 20 years. The nest boxes in the other two areas however might still be relatively novel to the secondary hole nesting birds of the area. The nest boxes in Oberganslbach have only been hung up in anticipation of last year's breeding season, and are therefore only in their second year of availability. The nest boxes in the woodland north of the KLF are completely new, as they have only been hung up in anticipation of this year's breeding season and are therefore in their first year of availability. This might make the nest boxes in these two areas less attractive a choice for the secondary hole nesting birds, as there are few traces of previous occupation such as leaf or nest remnants, and they lack familiarity (De León and Mínguez, 2003). These factors possibly explain the much lower occupation rates in the nest boxes not located in the Cumberland Wildpark. De León and Mínguez (2003) argue that this effect diminishes over time, as the birds get accustomed with the new nest boxes and their locations. The study reports a 29 percent increase in the occupation rate of the provided nest boxes within 5 years. This should be kept in mind and investigated in following studies and future monitoring.

5.2 The date of the first laid egg:

The timing of egg laying seems to be affected by human presence as well, with the breeding seasons starting earlier and going on for longer in the Cumberland Wildpark than in the other two study locations.
More specifically, this means that the date of the first laid egg was earlier in the season in the Cumberland Wildpark than in Oberganslbach or the woodland north of the KLF. This is in line with findings from a range of studies suggesting that eggs are often laid earlier in the season in more urban environments compared to more rural or natural regions (Branston *et al.*, 2021; Marini *et al.*, 2017; Chamberlain *et al.*, 2009). This might be explained by the more readily available food sources such as leftovers and bird feeders in more urban areas. These additional, easily accessible calories might provide the basis for earlier and longer egg laying (Marini *et al.*, 2017; Chamberlain *et al.*, 2009). Another influencing factor might be the ambient temperature, as the timing of egg laying is known to be affected it (Naef-Daenzer *et al.*, 2012; Visser *et al.*, 2009; Charmantier *et al.*, 2008). The generally higher temperatures in more urban environments, known as the heat island effect, might therefore allow for earlier egg laying than in the often colder rural, or more natural locations (Pachauri and Reisinger, 2008; Escourrou, 1990).

5.3 The clutch size:

The clutch size did not differ significantly across the three study areas.
Potential factors influencing the clutch size of breeding birds are the health conditions of the adult birds (Branston *et al.*, 2021; Chamberlain *et al.*, 2009; Solonen, 2001; Perrins and McCleery, 1989), as well as higher population densities that could lead to competition for food (Branston *et al.*, 2021; Solonen, 2001). Both are dependent and limited by the availability of food sources. Possible adverse effects on the clutch size caused by disturbances through human presence might therefore be negated by the provision of the additional food sources and nesting grounds in the Cumberland Wildpark, nullifying possible differences in the clutch size across the three study areas. Clutches from earlier in the season were found to generally be larger than clutches from later in the season, regardless of the breeding site. In other words, primary clutches generally consisted of more eggs than replacement/secondary broods. This is in agreement with findings by García-Navas *et al.* (2008), Perrins and McCleery (1989); Van Balen (1973) and Perrins (1965) stating that the number of eggs seems to be lower the later in the breeding season the eggs are laid. The explanation therefore seems to be the decreased availability of food sources with the progression of the seasons (Perrins and McCleery, 1989).

5.4 The reproductive success:

The reproductive success was found to be significantly lower in the Cumberland Wildpark compared to the other two study areas.

The probable cause therefore are the high predation rates in this study location, with all recorded predations having occurred in the Cumberland Wildpark. Nest predations seems to be the biggest driver of nestling mortality in the present study. In total, n= 7 nests have been preyed upon, all of which were located in the Cumberland Wildpark. This is in agreement with findings by Thorington and Bowman (2003) suggesting that predation rates of artificial nest boxes as well as predator densities are higher in vicinity to humans and their infrastructure. The Aesculapian snake *(Zamenis longissimus*, **Figure 5.1**) (Capizzi *et al.*, 2008) and the European edible dormouse *(Glis glis*, **Figure 5.2**) (Jurczyszyn, 2018) are thought to be the main nest predators. On more than one instance during the monitoring process an Aesculapian snake *(Zamenis longissimus)* was found inside one of the occupied nest boxes, presumably having prayed on the brood. The same holds true for the European edible dormouse *(Glis glis)*, however only in unoccupied nest boxes. Either the unoccupied nest box was used as temporary shelter or in n=3 cases as a den by the European edible dormouse *(Glis glis)*. All three of these dens were located in Oberganslbach. Generally, the height at which a nest boxes hangs seems to be important for the secondary hole nesting birds, as lower hanging nest boxes seem to be avoided (Menkhorst, 1984). The explanation therefore is assumed to be that the lower a box hangs, the likelier it is to be preyed upon by ground-dwelling predators (Serrano *et al.*, 2017; Wesołowski, 2002). Higher hanging boxes as well as nest boxes hanging in a more open area with fewer visual obstacles allow for a better overview of the adjacent area and facilitate the detection of possible threats (Kiss *et al.*, 2017; Lomas *et al.*, 2014; Bohus, 2002). However, no significant preference for higher or lower hanging nest boxes was found in the present study.

Figure 5.1: An Aesculapian snake *(Zamenis longissimus)* in a formerly occupied nest box of the Cumberland Wildpark

Figure 5.2: An European edible dormouse *(Glis glis)* in an empty nest box of Oberganslbach

Other sources of nestling mortality are illness and starvation due to abandonment by the parent birds. In total, n=6 nests were lost to abandonment or starvation. Two of said nests were located in the Cumberland Wildpark, one in Oberganslbach and three in the woodland north of the KLF. Sometimes clutches would be abandoned before hatching, other times during the nestling stage. The presumed causes are predation, illness or external stressors such as noise, light- or air pollution acting on one or both parent birds or the nestlings (Isaksson, 2018; Forman *et al.*, 2002; Reijnen *et al.*, 1995). A high number of failed breeding attempts, such as through predation or abandonment/illness as well as high levels of inter- or intraspecific competition can have a significant impact on the population of the study species. This appears most notable in already declining species such as the marsh tit *(Poecile palustris)* (Teufelbauer and Seaman, 2021; Eaton *et al.*, 2009). The decline in the populations of secondary hole nesting birds such as the marsh tits *(Poecile palustris)* might be slowed by changing forestry practices, such as not removing standing deadwood and cutting down trees only when they are older, therefore providing more mature trees with possible nesting cavities (Caine and Marion, 1991; Land *et al.*, 1989; Raphael and White, 1984; Davis, 1983). Another proposal is to change the logging time-period to increase heterogeneity in the forest structure by having more differently aged trees (Sandström, 1992). Breeding opportunities are generally limited by the number of natural tree cavities (Warakai *et al.*, 2013; Cockle *et al.*, 2010; Walankiewicz *et al.*, 2007). The number of breeding efforts in a given area increases significantly if adequate nest boxes are provided (Monti *et al.*, 2019; Gottschalk *et al.*, 2011; Berkunsky and Reboreda, 2009). Supplementation of breeding opportunities through artificial nest boxes therefore provides a way of increasing such breeding options if the preferences for the nesting sites of the particular species of secondary hole nesting birds are met (Robles *et al.*, 2011).

Chapter 6

Conclusion

The data presented in this master thesis appear mostly in line with last year's monitoring (Vogel, 2022). The occupation rate in the Cumberland Wildpark remained significantly elevated compared to the other study locations. The breeding season started earlier and went on for longer in the Cumberland Wildpark, with the date of the first laid egg being consistently earlier. The most prevalent and dominant species across study locations was the great tit *(Parus major)*. It was followed by significantly fewer numbers of coal tits *(Periparus ater)* and marsh tits *(Poecile palustris)*, and only single occurrences of the other study species. No significant differences in the clutch size were found across the study areas. However, differences did arise in the reproductive success, as it was significantly worse in the Cumberland Wildpark compared to the other study locations. This was not the case in last year's breeding season, where the reproductive success was not significantly different across locations (Vogel, 2022). The obtained data remains relevant as the second instance of the proposed continuous monitoring program of the cavity nesting birds of the area, as well as delivering the necessary data for the "Höhlenbrüter Monitoring" project of the Austrian ornithological centre (AOC). The collected information therefore adds to the databank on the populations of the secondary hole nesting birds of the Almtal area. With the continuation of the monitoring in the coming years, a larger and more detailed databank on the topic will emerge, allowing for better insight and elevated statistical relevance, possibly facilitating future scientific work. This might in turn allow for better knowledge on the breeding preferences of the study species, providing the scientific basis for the design of nest boxes specifically tailored to a particular specie's needs. It might therefore aid in the conservation and possible growth of bird populations, especially important for declining species such as the marsh tit *(Poecile palustris)*. Possible, yet unseen breeding preferences of the study species might only become visible once the secondary hole nesting birds of the area get accustomed and grow more familiar with the novel nesting grounds of the study locations Oberganslbach and the woodland north of the KLF. As the different species get accustomed with the nest boxes over time, possible effects on the occupation rate of said nest boxes might emerge. The annual continuation of the project therefore represents a topic of importance and scientific interest.

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