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„Occupancy preferences and breeding ecology of secondary hole-nesting birds depending on the material of the nest boxes and on human presence “

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Abstract:

There are different factors influencing the choice for a nest site and the breeding ecology from secondary hole-nesting birds like the degree of urbanization or the material of the nest boxes. The use of nest boxes allows to work in a standardized setting over time and is a common technique in the observation of secondary hole-nesting birds. This study examined the influence of the nest box material and the influence of human presence on the occupation preferences and the breeding ecology of secondary hole-nesting birds, measured by the occupation rate, time of the first laid egg, clutch size and breeding success. 104 nest boxes of two different materials (concrete/wood) were erected in two adjacent forests with different human presence (with/without human presence) and were controlled once per week during the whole breeding season 2022. Thirty-four nest boxes were occupied by five different bird species. The forest with human presence was occupied more. There was a trend towards concrete nest boxes. No obvious differences could be determined from the material of the nest boxes or human presence on time of the first laid egg, clutch size or breeding success, except a trend towards earlier laying dates and a longer breeding season in concrete nest boxes and in the forest with human presence. Interspecific differences could be shown. The knowledge about the nest boxes, the availability of food, potential competition and other thermal conditions inside the nest boxes are discussed as potential reasons for these results. Therefore, further investigations should be done.

1. Introduction:

The breeding ecology and the occupation preferences of secondary hole-nesting birds are investigated since many years. There are different parameters which affect the choice for a nest site and the breeding ecology like the degree of urbanisation (Remacha & Delgado, 2009; Clergeau et al., 2006; McKinney, 2002; van der Zande et al., 1984), the availability of food resources (Branston et al., 2021; Vaugoyeau et al., 2016; Chamberlain et al., 2009; Solonen, 2001; Perrins & McCleery, 1989) or for species using nest boxes (Lambrechts et al., 2010) the material of the nest boxes (Bueno-Enciso et al., 2016; Lambrechts et al., 2010; García-Navas et al., 2008; Browne, 2006) or the size of the nest boxes (Møller et al., 2014b; Sorace & Carere, 1996). Therefore, it is important for secondary hole-nesting birds to find a suitable nest site to be able to reproduce successfully.

The use of nest boxes is a common technique to investigate the occupation preferences and the breeding ecology of secondary hole-nesting birds and allows a standardized setting over time (Lambrechts et al. 2010). Studies using nest boxes over a long period of time can give an overview of different territory quality (Potti et al., 2018) or changes in the breeding behaviour because of climate changes (Samplonius & Both, 2019; Sanz, 2002). The use of nest boxes could also lead to better breeding success for endangered animals (European storm petrels, *Hydrobates pelagicus*, De León & Mínguez, 2003) and can help to increase the population of secondary hole-nesting birds (Lambrechts et al., 2010). Other goals of the use of nest boxes are, for example, investigations of preferences between the occupancy of nest boxes versus natural holes (crested flycatchers, *Myiarchus crinitus*, Miller, 2002; Marsh tits, *Poecile palustris*, and *Ficedula* flycatchers, Wesolowski & Stanska, 2001) or to examine which size or material of nest box would be preferred (different tit species; Bueno-Enciso et al., 2016; Møller et al., 2014; García-Navas et al., 2008; Summers & Taylor, 1996). All together nest boxes are an important scientific tool to get basic knowledge about the preferences and breeding ecology of the different species which could help to support conservation plans.

Some of the commonly observed parameters that can be affected by the material of the nest boxes are the occupancy rate, the time of the first laid egg, the clutch size and the breeding success. The material of the nest boxes seems to play an important role in affecting different parameters of the breeding ecology in different hole-nesting bird species (Bueno-Enciso et al., 2016; Møller et al., 2014a; Lambrechts et al., 2010; García-Navas et al., 2008). Evidence show preferences in the occupation for concrete nest boxes instead of wooden nest boxes in Great tits (*Parus major*) (Bueno-Enciso et al., 2016; Browne, 2006) and in Tree Sparrows (*Passer montanus)* (García-Navas et al., 2008). However, there might be interspecific differences, as in Blue tits (*Cyanistes caeruleus*) there are contrary results to that effect that Browne (2006) found also a preference for concrete nest boxes whereas Bueno-Enciso et al. (2016) could not find a clear preference for a material type of nest boxes in Blue tits. The preference might be related to thermal conditions inside the nest boxes, as the microclimate of concrete nest boxes seems to be warmer and more humid (García-Navas et al., 2008).

The material of the nest boxes and the various microclimate conditions inside are suggested to affect the time of the first laid egg too, as Bueno-Enciso et al. (2016) pointed out that Great tits and Blue tits laid their eggs significantly earlier in concrete nest boxes instead of wooden ones and García-Navas et al. (2008) showed also an earlier laying date in concrete nest boxes in Tree Sparrows.

But with regard to the clutch size, there are often no clear material-dependent differences in different hole-nesting species like in Great tits (Bueno-Enciso et al., 2016; Møller et al., 2014a; Browne, 2006), in Flycatchers (Møller et al., 2014a) and in Tree Sparrows (García-Navas et al., 2008). However, there seems to be interspecific differences as Møller et al. (2014a) found that Blue tits have significantly larger clutch sizes in wooden nest boxes than in concrete ones whereas other studies could not find material-dependent differences in the clutch size in Blue tits (Bueno-Enciso et al., 2016; Browne, 2006).

There are also contradictory results in the literature with regard to nest box material-dependent effects on breeding success. Bueno-Enciso et al. (2016) show a worse breeding success in concrete nest boxes than in wooden ones in Great tits and Blue tits, which could be attributed to the thermal conditions inside the nest boxes, but García-Navas et al. (2008) found a better breeding success in concrete nest boxes in Tree Sparrows in nearly the same study area (central Spain), but in other study years. So, there could be thermal reasons as well as interspecific differences. There are also findings that cannot show any differences in the breeding success depending on the nest box material in different tit species (*Parus spp.*) in the United Kingdom (Browne, 2006).

Another important factor affecting the breeding ecology and the occupation rate seems to be the degree of urbanization. Considering the occupation rate there are findings that proximity to some kind of infrastructure (like recreational infrastructure) or urbanization increases the occupation rate of nest boxes of some bird species like different Sparrows (Tree Sparrows, *Passer montanus*; House Sparrows, *Passer domesticus*), Great tits (Remacha & Delgado, 2009) or Bluebirds (Western Bluebird, *Sialia mexicana*; Mountain Bluebirds, *Sialia currucoides*; Dale et al., 2021). But there are also findings in a comparison between periurban, suburban and centre sectors, which show no constant pattern in the abundance of the different species like different Sparrows, Great tits and Blue tits across different study areas – sometimes some species preferred the centre sector and sometimes the periurban areas (Clergeau et al., 2006). Additionally, there are interspecific differences as it is shown that the number of Coal tits (*Parus ater*) and Marsh tits are decline in proximity to urban areas in a comparison between urban, suburban and rural habitats (Sidemo-Holm et al., 2022) and that the ecological niche of Marsh tits and Coal tits seems to be smaller to Great tits and Blue tits (Farina, 1983). Furthermore a decline of bird diversity with increasing proximity to urbanization is shown in different comparisons between different levels of human disturbances (Kang et al., 2015), or between urban, suburban and rural/periurban areas (Sidemo-Holm et al., 2022; Clergeau et al., 2006; McKinney, 2002, 2008).

The degree of urbanisation do not only influence the diversity of bird species, there is also evidence that many hole-nesting species are laying their eggs earlier in more urban environments than in rural ones like in Great tits (Branston et al., 2021; Chamberlain et al., 2009) and in Mountain chickadees (*Poecile gambeli)* (Marini et al., 2017). In Blue tits differently results are found, with a review showing earlier laying dates in urban to non-urban areas (Chamberlain et al., 2009) and a comparison between a native oak forest and a city centre park showing no differences in the time of the first laid egg (Branston et al., 2021). Therefore, interspecific differences could be possible.

Interspecific differences also seem to play a role with regard to the clutch size, since in Mountain chickadees no influence on clutch size could be determined depending on urban or rural study sites (Marini et al., 2017). But many other studies showing smaller clutch sizes in urban areas than in natural/rural areas for different bird species like for Great tits and Blue tits (Branston et al., 2021; Chamberlain et al., 2009; Solonen, 2001).

Most studies also point out a worse breeding success in urban areas in comparisons between different urban areas to different non-urban areas in Great tits (Chamberlain et al., 2009; Solonen, 2001; Hõrak, 1993) and Blue tits (Chamberlain et al., 2009; Solonen, 2001) as well as for other bird species (Wood thrush, *Hylocichla mustelina*; Common starling, *Sturnus vulgaris;* Eurasian magpie*, Pica;* Chamberlain et al., 2009). But in Mountain chickadees no differences could be found depending on the study sites (urban or rural) (Marini et al., 2017).

The breeding success seems also to be related to when the first egg of the respective clutch was laid, as Perrins (1965) showed that the weight of the young decreased the later in the breeding season they were born and that the mortality of the hatchlings increased the later the breeding season (worse breeding success). Another relationship is known between the time of the first laid egg and the clutch size (García-Navas et al., 2008; Perrins & McCleery, 1989; van Balen, 1973; Perrins, 1965) to the effect that later clutches consist of less eggs.

A project which is investigating the breeding ecology and the occupation rates of hole-nesting bird species is the secondary hole-nesting bird project from the Austrian Ornithological Centre (AOC). The project includes long-term monitoring using nest boxes to examine changes in the breeding success and brood phenology, the behavioural ecology, and the population biology as well as occupation preferences of the birds over a long period of time. The use of nest boxes allows to work in a standardized setting over time which is very important especially for long-term projects (AOC/Österreichische Vogelwarte, 2016b) and is a common technique in the observation of hole-nesting birds (Lambrechts et al. 2010).

Long-term monitoring is a common and important instrument in the scientific work to examine different trends in populations like increasing or decreasing from different populations as well as distributions or migrations. It can help to identify a possible risk status for the different species and thus help to formulate conservation plans (Gameiro et al., 2020; Nichols & Williams, 2006; Kéry & Schmid, 2004; Avilés & Parejo, 2004). Hence, long-term monitoring is also a tool to support the EU guidelines for the conservation of wild bird species which encourage the necessary science for the protection and regulation of wild bird species (Europäisches Parlament, 2010).

The region of Grünau im Almtal, Upper Austria, is a mostly natural area with a landscape consisting of limestone mountains (up to about 2500 m height), lakes, rivers and forests which offers habitat for many different species, including about 170 species of regularly breeding birds (Pühringer et al., 2020). A popular and well visited game park (the Cumberland Wildpark) is located in the region as well. Long-term monitoring of the different bird species has been a part of the study work from the Konrad Lorenz Research Centre for many years. Especially in collaboration with the Austrian Ornithological Centre (AOC) the Integrated Monitoring of Songbirds (IMS) is a long existing study program in the region (AOC/Österreichische Vogelwarte, 2016a). Additionally, many nest boxes have been hanging in the Cumberland Wildpark for more than twenty years. Thanks to this background, it was possible to start this project studying the breeding ecology of secondary hole-nesting bird species in order to gain insights into the occurrence and preferences of the different populations, which serve as the first exhaustive study in this area as a basis for further long-term monitoring.

The aim of this study is to investigate the effect of two parameters, namely (i) the material of the nest boxes (concrete or wood) and (ii) the human presence (a forest with human presence and a forest without human presence) on the occupation preferences and the breeding ecology of secondary hole-nesting birds as measured by the following variables: occupation rate (number of occupied nest boxes), the time of the first laid egg, the clutch sizes (number of eggs) and the breeding success (number of fledglings divided through the number of eggs). Therefore, nest boxes in two different materials were erected in two forests and being controlled once per week.

I predict that the material of the nest boxes will have an effect in that (i) the occupancy rate will be higher in the concrete nest boxes than in the wooden ones and that (ii) the time of the first laid egg will be earlier in the concrete nest boxes. Furthermore, I expect that (iii) the clutch sizes will not differ depending on the material and that (iv) there will be no clear difference in the breeding success depending on the material of the nest boxes.

The following predictions are made regarding the role of the of the human presence in the comparison between the forest without human presence (= rural forest) and the forest with human presence (=Wildpark): Firstly, that (i) the occupancy rate will be higher in the Wildpark and that (ii) the time of the first laid egg will be earlier in the Wildpark. Secondly, that (iii) the clutch sizes will be smaller in the Wildpark and that (iv) the breeding success will be lower in the Wildpark.

Furthermore, I predict that (i) the clutch size will be smaller the later the time of the first laid egg and that (ii) the breeding success will be lower the later the time of the first laid egg.

Lastly, I want to give an overview of the composition of the different species using the nest boxes in this first exhaustive study in this area considering the breeding ecology and the preferences depending on the material of the nest boxes and on human presence.

Regarding the common hole-nesting bird species in the area around the Cumberland Wildpark I assume to find Great tits, Blue tits, Coal tits, Marsh tits and Nuthatches (*Sitta europaea)*. Crested tits are living in the area as well, but as they seem to prefer nest boxes filled with sawdust (Summers & Taylor, 1996) because they seem to like to excavate their nesting sites (Perrins, 1979), I don’t assume to find Crested tits in the nest boxes of the present study.

2. Material and Methods:

First, I will give a brief overview of the study site and the breeding ecology of the study animals as well as their population trends to give a holistic impression about the species. Afterward I will give a detailed explanation about the dimensions, the location, the maintenance procedures and the inspection of the nest boxes (Lambrechts et al., 2010). Furthermore, I want to give an overview of the bird ringing process of the chicks during this study.

2.1 Study site

To find results depending on human presence and to avoid limitations through other geographical factors which could have an impact when doing the study in different locations (Bueno-Enciso et al., 2016; Lambrechts et al., 2010), the study area was chosen in two different forests which are adjacent to each other. First, (i) a forest with human presence (the Cumberland Wildpark = Wildpark) and second, (ii) a forest without human presence (= rural forest). Both forests are situated in Grünau im Almtal, Upper Austria (Figure 1). The forest with human presence was located in the Cumberland Wildpark (latitude 47.806859, longitude 13.950467). The Wildpark is a famous destination for tourists who want to see native wildlife and covers an area of 60 ha. The paths in the Wildpark are made of gravel. The position of the nest boxes was nearby the paths, sometimes visible for visitors and sometimes minimally hidden. The forest type without human presence was a rural forest (latitude 47.793763, longitude 13.950467) which was adjacent to the Wildpark. It is situated on a private hunting ground in a quiet area without paths. Both forest types were mixed deciduous and coniferous forests containing many old trees.

Figure 1: Map of Austria (google maps); the red star marks the location of the study site (Grünau im Almtal, Upper Austria)

2.2 Study animals

Secondary hole-nesting birds are using already existing cavities for their nests sites (Perrins, 1979). Therefore, they use nest sites which were made from primary hole-nesting birds (e.g. woodpeckers) or that arose naturally or they use artificial nest sites like nest boxes (Lambrechts et al., 2010; Perrins, 1979).

Regarding the common secondary hole-nesting bird species in the area around the Cumberland Wildpark I assume to find Great tits (*Parus major*), Coal tits (*Parus ater*), Marsh tits (*Poecile palustris*), Blue tits (*Cyanistes caeruleus*) and Nuthatches (*Sitta europaea*).

The basic structure of the nests of the different tit species consists of moss and a lining layer often made out of fur, wool, hair and some grass or leaves (Lambrechts et al., 2012; Alabrudzinska et al., 2003). Sometimes a layer of green plants used as a repellent to support the sanitary function is included (Alabrudzinska et al., 2003; Lambrechts & Dos Santos, 2000). Nuthatches build their nests without any structure out of loose bark flakes (Cantarero et al., 2014) and some protect their nests by reducing the entrance hole or closing other cracks with clay or mud (Löhrl, 1964).

The Great tit lives mostly in deciduous and mixed forests, but also in many other types of habitats like plantations and parks (BirdLife International, 2021b). The Blue tit can be found in broad-leave woodlands and also in gardens or parks or inner cities if there are suitable nest sites (BirdLife International, 2021a). Coal tits are living mostly in coniferous forests but can also be found in urban and suburban areas if they include at least some conifers (BirdLife International, 2021c). Marsh tits prefer mature deciduous woodlands with many rotting or dead trees, but can also be found in parks or gardens (BirdLife International, 2021d). The Nuthatches occupies deciduous and mixed forests with old trees, but can be also found in large gardens or cemeteries and parklands (BirdLife International, 2021e).

They usually start laying their eggs normally in April/May (Blondel, 1985) The clutch sizes differ from five to nine eggs in the nuthatches (BirdLife International, 2021e; or an average from six to seven in Cantarero et al., 2014) to nine to eleven eggs in the Great tits (Perrins, 1965; van Balen, 1973), to seven to thirteen in Blue tits (Perrins, 1979), an amount of five to ten eggs in Marsh tits (BirdLife International, 2021d) and an average around eight eggs in Coal tits (Blondel, 1985; five to thirteen in BirdLife International, 2021c). The females incubate the eggs alone and the males are feeding the females during the incubation period from about twelve to thirteen days (Perrins, 1979). The nestling period of the different tit species (*Parus spp.*) is about twenty days (Löhrl, 1964).

Regarding the population of the different species Teufelbauer et al. (2017) shows in the report about the population changes of common Austrian breeding birds (period 1998 – 2016) that the population of the Great tit, the Blue tit and the Marsh tit seems to be stable whereas the population of Coal tits and Nuthatches is moderate declining in Austria. Looking to the report from 2021 (Teufelbauer et al., 2022) the decline of the Coal tits is continuing, the decline of the Nuthatch seems to be stable, but there is a decrease in the population from the Marsh tits as well (the population of the Great tits and Blue tit is still stable). The British report of birds of conservation concern (Eaton et al., 2009) speaks about a long term decrease of the Marsh tit population of about -66%. Broughton et al. (2011) hypothesized that one problem could be breeding failure, considering usual reasons such as predation and the competition for nest locations with more dominant species like the Great tit or the Blue tit or the failure to reach the nesting stage. Teufelbauer et al. (2021) also shows in their report that in the “Woodland Bird Index” for the period from 1998 - 2012 (no current edition available) there was a decline of the Marsh tit population of up to -1,30% per year. And also the justification in the IUCN Red lists shows a decreasing from the Marsh tit population by -4% (EU28; BirdLife International, 2021d)

2.3 Maintenance procedures, dimensions and location of the nest boxes

Altogether 104 nest boxes were used for this study (52 wood, 52 concrete). First the already existing nest boxes from the Wildpark (27 concrete) and another forest (54 wood) were cleaned by hand (remove old nests and scratch out dirt with a spatula) - no chemicals were used for the cleaning process. New additional nest boxes were purchased. Two different types of material of the nest boxes were used – concrete and wood. To avoid possible limiting factors through different preferences for special tree types instead of the material of the nest boxes itself (Bueno-Enciso et al., 2016; Lambrechts et al., 2010) both nest box types (concrete and wood) were placed on top of each other (randomly switching which one is on top or bottom of each other) on the same tree (Tab.1, Figure 2). Therefore, in each forest type 26 trees were randomly chosen (Tab.1).

Tab. 1: Number of tree types on which the boxes were erected (left); Number of the nest boxes in the different material types in the respective position on the tree (bottom or top) (right).

Tree-Type	WP	F	Total
coniferous	16	32	48
deciduous	36	20	56
Total	**52**	**52**	**104**

Position	concrete	wood	Total
bottom	26	26	52
top	26	26	52
Total	**52**	**52**	**104**

Figure 2: Both nest box materials attached on top of each other

All nest boxes were tied on the trees with the same orientation for the entering hole (South) (Briggs & Mainwaring, 2021; Rendell & Raleigh, 1994) and in the same height between 2,5 – 3 meters to be able to reach them via a ladder, but high enough, as different secondary hole-nesting birds prefer higher nest boxes (Zhang et al., 2021). Some old nest boxes had already been nailed to the tree trunk. On every chosen tree were two nest boxes. The nest boxes were erected in a grid scheme in the two different forest types. GPS data was collected with a mobile GPS Handheld (Garmin GPSMAP 66ST). After that the GPS data was imported into QGIS (version 3.24.1) and was added as a layer to the base map (Figure 3). The base map in QGIS was from Google maps and was included in the XYZ tile.

Figure 3: Location of the trees on which the nest boxes were erected in the Wildpark (n = 26) and in the rural forest (n = 26).

The wooden nest boxes were built by a local carpenter and were quadrangular and made of spruce wood. To open it, the top of the box could be folded back. A hook with an eyelet was attached to the side to close it. The outside dimension was 25 x 12,5 x 16 cm (height/width/depth). The internal chamber was 23 x 8,8 x 12 cm. The height of the lower edge from the entrance hole to the base of the nest box from the outside was 16,4 cm. The concrete nest boxes were purchased from Schwegler Germany (model 1B) and were cylindrical and made out of a mixture of cement and other materials (Lambrechts et al., 2010) – in some studies called woodcrete, in the present study called concrete. To open it there was a removable frontal lid. To close it there was a metal lab on the bottom of the inside of the frontal lab. The outside dimensions were 26 x 17 x 18 cm. The internal chamber had a diameter of about 12 cm and a height of 17,5 cm. The height of the lower edge from the entrance hole to the base of the nest box from the outside was 13,5 cm. The entering hole of both nest box types had a diameter of 32 mm. (Figure 4)

Figure 4: Nest box made of concrete (left) and made of wood (right)

2.4 Data collection

2.4.1 Monitoring process:

The monitoring process started on the 26th of March 2022. Afterward the control of the nest boxes was done once per week. The observations were done by one person (the author) who was trained by the Austrian Ornithological Centre (AOC) beforehand. To do the observations I climbed up the trees using a ladder and opened the different nest boxes per hand. The nest box which was closed by their resident (e.g., a nuthatch) and the nest boxes which were not reachable (due to the growing vegetation or the height in combination with the condition of the soil) were controlled with an endoscope-camera (Depstech DS 450). If nesting material was inside, I looked for eggs – if the eggs were not visible, I pushed aside the nesting material from the top very carefully to see if there was a hidden clutch. After that I hid the eggs again with nesting material if they were covered before. If there were eggs inside, I counted them and felt the temperature of the eggs carefully with my dorsal finger sides to feel if they were warm (and the breeding process had already started). Hatched chicks were counted too – in the case that the mother was sitting on the chicks and did not fly away when I was opening the nest box, I pushed aside the adult very softly from the clutch to count the chicks and left them alone again as fast as I could. All the processes were done as quickly as possible to reduce the stress for the birds.

2.4.2 Collected variables:

The nest boxes were checked for occupation by birds and for their clutches. For each clutch I took data of the occupying species, day of the first laid egg, clutch size, breeding start, hatching day, number of hatchlings, number of fledglings and the breeding success.

Nest boxes were included in this study as *occupied* if at least one egg was laid inside the nest box (Zhang et al., 2021).

The *day of the first laid egg* was calculated by counting back as many days as how many eggs were inside the nest at the first observation of eggs (example: three eggs on a Friday – so the first egg was laid on Wednesday) under the assumption that the birds lay one egg per day (Perrins, 1979). For a better visualization and comparison all first eggs which were laid for one week (Monday to Sunday) were assigned to groups (*Calendar_week*) for the respective calendar week (cw) from the Julian calendar. Calendar week 1 (cw 1) in 2022 was from January 3rd to January 9th. The first egg in this study was laid on April 2nd. So, it was in calendar week 13 (cw 13) which was from February 28th to April 3rd (Tab. 2).

Tab. 2: Number of first laid eggs in the different calendar weeks (cw).

Calendar week (cw)	cw 13	cw 15	cw 16	cw 17	cw 18	cw 21	cw 22	cw 24	cw 25	cw 26	cw 27
Number of first laid eggs	1	5	9	4	6	2	1	3	1	1	1

The *clutch size* was defined by the number of eggs. The time of the possible *hatching day* of the chicks was calculated using a calculator function in Excel 365 (version 2207) adding 14 days to the day of the breeding start. The *breeding start* was defined as the day on which the last egg of the clutch was laid assuming that the birds were laying one egg per day. After hatching the *number of hatchlings* were counted and the age of the birds was controlled whether it matched with the calculated hatching day from the calculator by looking at the developmental status of the chicks. After the fledging of the chicks, I controlled whether all chicks had fledged. If the nest boxes were empty, I assumed that all hatchlings could fly out and noticed the *number of fledglings* as the number of hatchlings. If I found dead chicks inside the nest box, I subtracted the number of dead chicks from the number of hatchlings to get the number of fledglings. The *breeding success* was calculated by dividing the number of fledglings by the number of eggs (Zhang et al., 2021), yielding results between 0 and 1 (0 = all dead; 1 = all fledged).

$$\textit{Breeding success} = \frac{\textit{Number of fledglings}}{\textit{Number of eggs}}$$

2.5 Bird ringing

During the study period the chicks of the different hole-nesting birds were ringed when they had an age between 7 and 13 days (the day of the hatching was day 0). The location of the station with the bird ringing material was chosen so that it was close enough to the nest box to transport the young as quickly as possible, but far enough away not to interfere with the feeding process of the parents. To minimize stress, for the parents and to enable success for potential feeding attempts from the parents in the meantime only half of the young were removed from the nest at a time. The chicks were carefully removed from the nest by hand and placed in a cloth bag for the transfer to the bird ringing station. Then they got ringed, weighed and measured (tarsus length). The time of this process was kept as short as possible and was done by two persons (Author and Co-Supervisor, both trained in bird ringing). After the ringing, the respective nest box was not controlled for about two weeks to reduce stress and prevent premature fledging of the chicks. Then the nest box was checked to see whether all chicks had fledged.

2.5.1 Ethics

The Author was trained beforehand from the Austrian Ornithological Centre (AOC) to gain knowledge about the correct monitoring process and the handling of the eggs/nestlings as well as the correct bird ringing process. All bird ringing processes were observed by another person (mostly by the Co-Supervisor, who was an experienced bird ringer: Mag. Dr. Josef Hemetsberger; license: BHGMN-2015-287501/16-BUT, exceptional permit according to §29 Oö NSSchG 2001 for scientific purposes for catching and ringing songbirds in the Almtal area). This study was carried out taking into account all current Austrian laws and regulations on working with wild animals. The Duke of Cumberland, the owner of the land, granted permission to carry out the study on this site. All data were collected non-invasively and all included persons followed the „Guidelines for the use of animals in research" (Animal Behaviour, 1991).

2.6 Data analysis

The data analysis was done with the statistics program R (R version 4.0.3 (2020-10-10); Platform: i386-w64-mingw32/i386 (32-bit); Running under: Windows 10 x64 (build 22000)). The visualization of the results was done with R and with Excel 365 (version 2207).

2.6.1 Occupation rate

To find out whether there were differences in the occupation rate depending on the material of the nest boxes (wood or concrete) or depending on human presence (forest with human presence (Wildpark) or forest without human presence (rural forest) a Generalized Linear model (GLM) with a binomial distribution (occupied = 1; non-occupied = 0) was used. As response the occupation rate (binomial) was taken, the predictors consisting of the material of the nest boxes (wood/concrete), the human presence (Wildpark/rural forest), the position of the nest boxes on the trees (bottom/top) and the different tree types (deciduous/coniferous). The position on the tree and the different tree types were included too to find out if there are unintentional effects of the occupation rate from these factors too. The predictors were checked for distribution. The collinearity of the predictors were checked via the variance inflation factor (VIF) and could be excluded (VIF for all predictors was < 1.110). A full-null model comparison was performed by comparing the full model to a null model that lacked all predictors of interest (material of the nest boxes and human presence) and included only the position on the tree and the different tree types as predictors. The analysis and the graphs were done in R using the packages “lme4” (Bates et al., 2015), “car” (Fox & Weisberg, 2019), “ggplot2” (Wickham, 2016), “ggthemes” (Arnold, 2021), “plyr” (Wickham, 2011), “extrafont” (Chang, 2022), “ggsignif" (Ahlmann-Eltze & Patil, 2021) and "gridExtra" (Baptiste, 2017).

2.6.2 Day of the first laid egg

To find out whether the time of the first laid eggs was dependent on the material of the nest boxes (wood/concrete) or on human presence (Wildpark/rural forest) a General Linear Model (LM; Linear Regression) was used. For the response variable the Calendar_week group was taken (group of first laid eggs during the respective calendar weeks). The residuals (material of the nest boxes (wood/concrete) and human presence (Wildpark/rural forest)) were checked for normality (using a qq-plot) and homogeneity (checking the plotted residuals against the fitted values). The predictors were checked for collinearity via the variance inflation factor (VIF) and collinearity could be excluded (VIF of the predictors was 1.138). A full-null model comparison was included in the model. The analysis was done in R using the packages “lme4” (Bates et al., 2015), “car” (Fox & Weisberg, 2019), “ggplot2” (Wickham, 2016), “ggthemes” (Arnold, 2021), “plyr” (Wickham, 2011), “extrafont” (Chang, 2022) and the graphs were done with Excel 365 (version 2207).

2.6.3 Clutch size

To analyse whether clutch size was dependent on the material of the nest boxes (wood/concrete) or on human presence (Wildpark/rural forest) a Generalized Linear model (GLM) with a poisson distribution was used (dispersion parameter < 1; overdispersion was excluded). Response variable was the clutch size, the predictors consisted of the material of the nest boxes (wood/concrete) and human presence (Wildpark/rural forest). The predictors were checked for distribution. The collinearity of the predictors were checked via the variance inflation factor (VIF) and could be excluded (VIF of the predictors was 1.138). A full-null model comparison was performed by comparing the full model to a null model that lacked all predictors of interest (material of the nest boxes and human presence). The analysis and the graphs were done in R using the packages “lme4” (Bates et al., 2015), “car” (Fox & Weisberg, 2019), “ggplot2” (Wickham, 2016), “ggthemes” (Arnold, 2021), “plyr” (Wickham, 2011), “extrafont” (Chang, 2022).

2.6.4 Breeding success

To find results for the breeding success depending on the material of the nest boxes (wood/concrete) or on human presence (Wildpark/rural forest) Mann Whitney U-Tests were used. The response variable was the breeding success (breeding success = number fledglings/number of eggs), the predictors were the material of the nest boxes (wood/concrete) and the human presence (Wildpark/rural forest). The significance level was set at $p \leq 0.05$.

2.6.5 Relationship between the time of the first laid egg and the clutch size or the breeding success

A potential relationship between the time of the first laid egg and the clutch size or the breeding success was determined by Spearman correlations. For that the Calendar_week-Group (group of first laid eggs during the respective calendar weeks) was correlated with the clutch size as well as with the breeding success. The significance level was set at $p \leq 0.05$.

2.6.6 Interspecific differences

Due to the small sample size the interspecific differences were determined using qualitative analysis. Therefore, the occupation rate, day of the first laid egg, clutch size and breeding success for the five different bird species were illustrated with graphs using Excel 365 (version 2207). An overview of the number of the individuals of the respective species was given using the total number of birds per species. For all variables firstly an overview of the interspecific differences of all bird species were given. Secondly for all variables the differences between the most common bird species (Great tit, Coal tit, Marsh tit) were pointed out.

The *occupation rate* depending on the material of the nest boxes or on human presence was analysed in a comparison between all bird species regarding the number of the respective occupying birds per material of the nest boxes (concrete/wood) and per human presence (Wildpark/rural forest).

The *day of the first laid egg* was illustrated using the number of first laid eggs which were laid from the different individuals in the different calendar weeks. After that, a comparison between the most common species of the study (Great tit, Coal tit, Marsh tit) was done regarding the number of first laid eggs per species depending on the material of the nest boxes and on human presence.

The *clutch sizes* consist of the number of eggs in the respective clutches. To consider potential interspecific differences in the clutch sizes the number of the respective clutch sizes for the different species were illustrated as well as their means and standard deviations (mean ± SD) in total. Additionally mean ± SD for the clutch sizes from the most common bird species depending on the material of the nest boxes and on human presence were calculated.

The *breeding success* was calculated by dividing the number of fledglings by the number of eggs (Zhang et al., 2021). For a better visualization of the results regarding the comparison of the different breeding successes for all bird species together a “breeding success code” was created. For that every single breeding success was multiplied with 100 to get the percent of the breeding success. Afterward the results were grouped in increments of 20 percent. Additionally, the mean ± SD for every species in total was calculated. To show potential differences in the breeding success for the most common bird species the respective mean ± SD depending on the material of the nest boxes and on human presence were pointed out.

3. Results

All together 34 nest boxes (= 32 %) of the 104 nest boxes were occupied by birds (one nest box was occupied twice) (Tab. 3).

Tab. 3: Number of occupied nest boxes in the different materials and forests

	concrete	wood	Total
rural forest	2	5	7
Wildpark	19	8	27
Total	21	13	**34**

Five different species of birds were occupying the nest boxes. Most of the nest boxes were occupied by Great tits followed by Coal tits and Marsh tits. Only one breeding pair was found for the Blue tits and Nuthatches (Tab.4, Figure 5).

Tab. 4: Number of occupying birds from the different species (n = 34)

Great tit	Coal tit	Marsh tit	Blue tit	Nuthatch
19	8	5	1	1

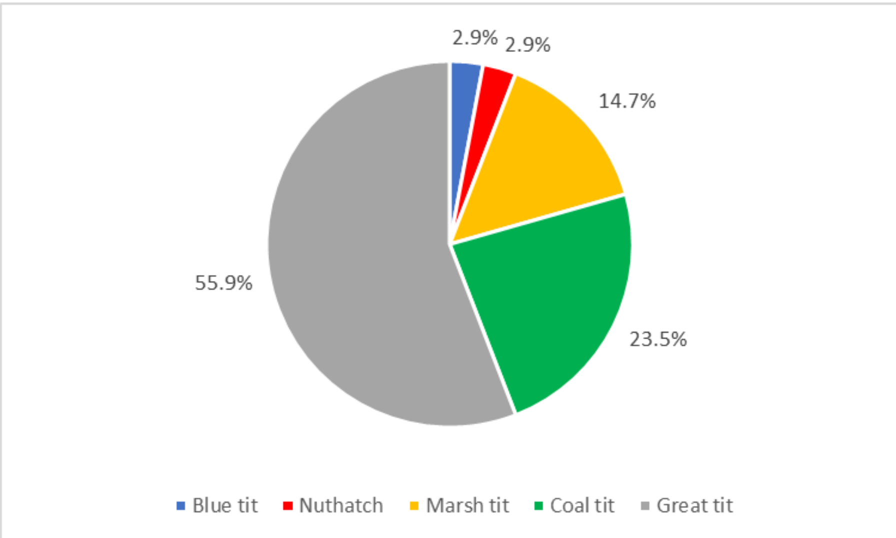


Figure 5: Percentage of each species.

The first egg was laid on April 2nd, the last egg was laid on July 10th. The last chick fledged on August 11th.

3.1 Nest box material

3.1.1 Occupation rate

The material of the nest box did not have a real effect of the occupancy rate, but there was a trend that the concrete nest boxes were occupied more than the wooden nest boxes (wood: Est = -0.79, SE = 0.47, p = 0.091) (Figure 6).

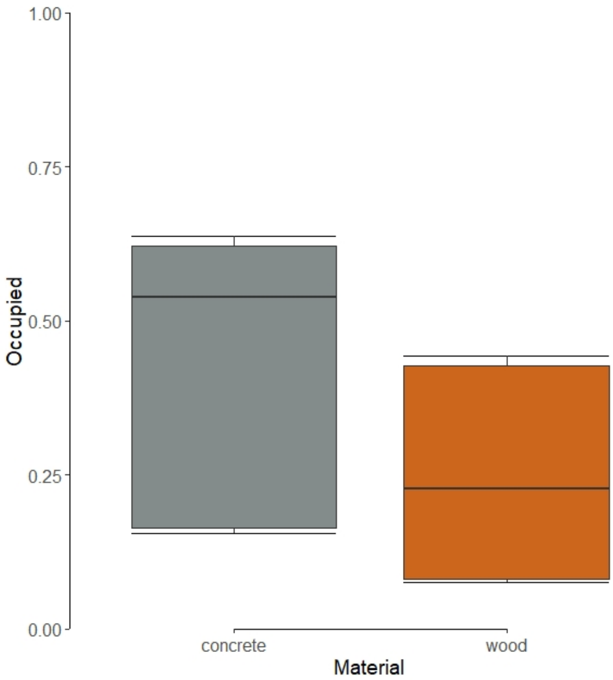


Figure 6: Occupation rate (n=34) depending on the material of the nest boxes (concrete = 21; wood = 13). Median + quartiles

There was no effect on the occupation rate whether the nest box was at the top or bottom position of the tree. Similarly, there was no difference in the occupation rate depending on the tree type to which the nest box was attached (deciduous or coniferous).

3.1.2 Day of the first laid egg

The descriptive statistics shows that in the concrete nest boxes the day of the first laid eggs was earlier to the wooden nest boxes and the birds laid their eggs for a longer time period in the concrete nest boxes, but the full-null model comparison of the General Linear model shows no influence (p = 0.857) of the material of the nest boxes on the time of the first laid eggs (wood: Est = 0.02, SE = 1.42, p = 0.99) (Figure 7).

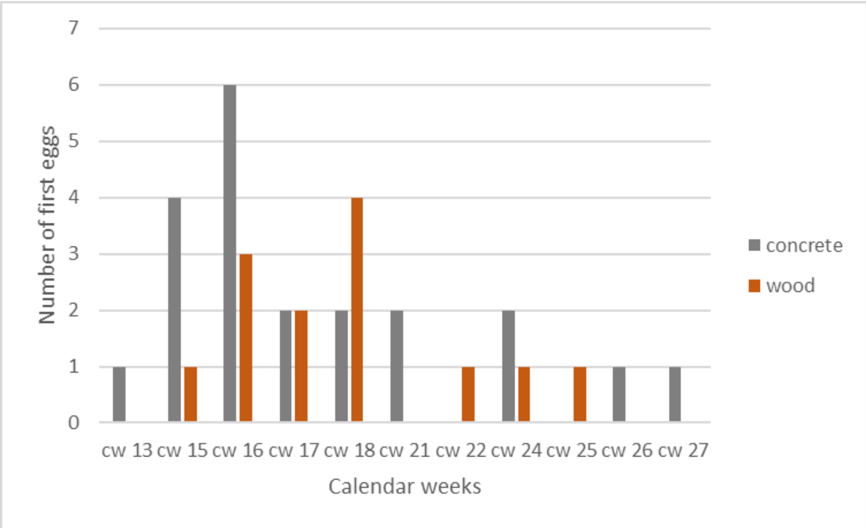


Figure 7: Number of first laid eggs (n = 34) during the different calendar weeks (cw) depending on the material of the nest boxes (concrete = 21; wood = 13).

3.1.3 Clutch size

There were no differences (p = 0.977) in the clutch size depending on the material of the nest boxes (wood = Est: 0.014, SE = 0.134, p = 0.917) (Figure 8).

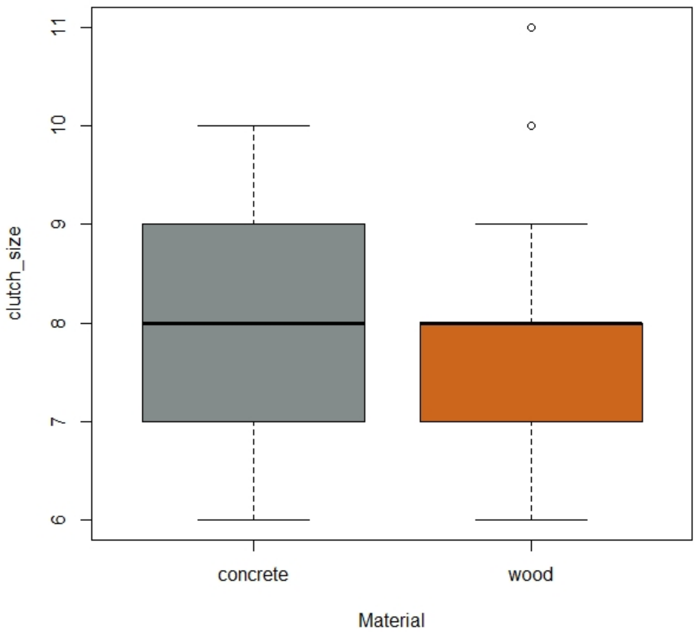


Figure 8: Clutch size (n = 34) depending on the material of the nest box (concrete = 21; wood = 13). Median + quartiles.

3.1.4 Breeding success

The breeding success did not differ between the different materials of the nest boxes (W = 161, p = 0.386) (Figure 9).

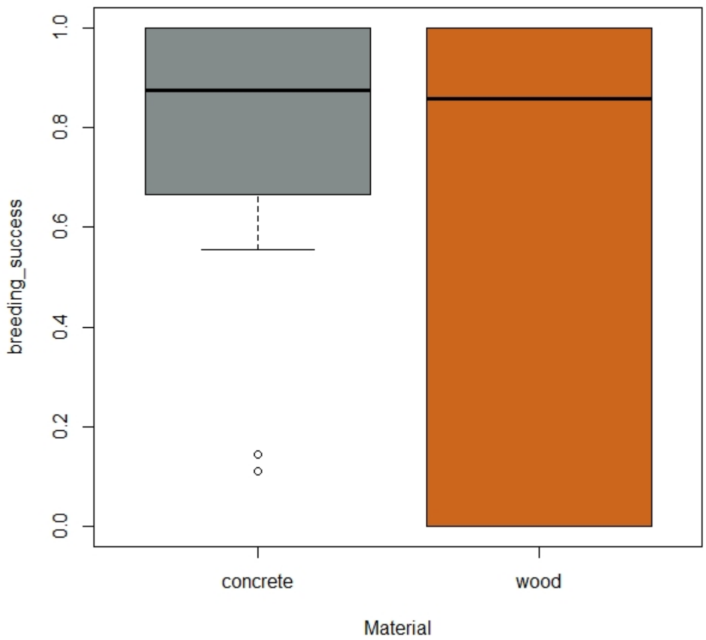


Figure 9: Breeding success (n = 34) depending on the material of the nest boxes (concrete = 21; wood = 13). Median + quartiles

3.2 Human Presence

3.2.1 Occupation rate

The occupation rate was much higher in the Wildpark (WP) than in the rural forest (WP: Est = 1.85, SE = 0.52, p < 0.001) (Figure 10).

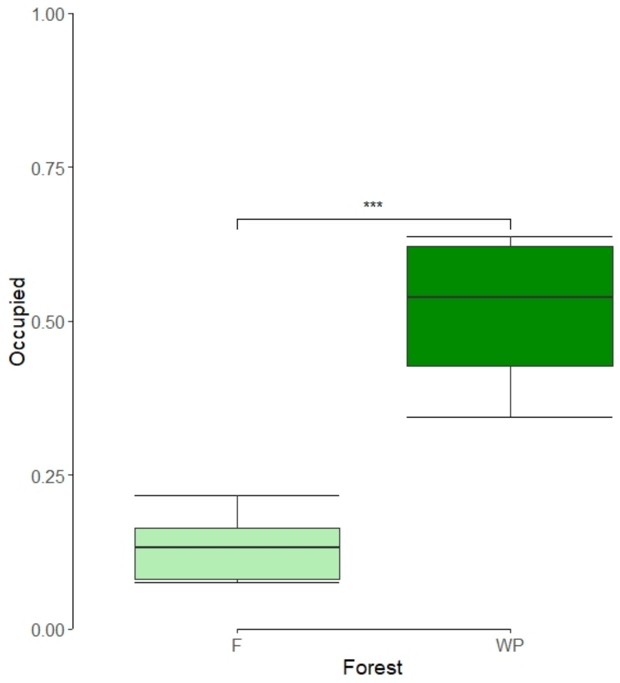


Figure 10: Occupation rate (n=34) depending on human presence (F = rural forest, WP = Wildpark; F = 7; WP = 27). Median + quartiles

There was no effect on the occupancy whether the nest box was at the top or bottom position of the tree. Similarly, there was no difference in the occupation rate depending on the tree type to which the nest box was attached (deciduous or coniferous).

3.2.2 Day of the first laid egg

In the descriptive statistics it seems that the time of the first laid eggs was earlier and longer in the Wildpark (WP), but the full-null model comparison of the General Linear model shows no influence (p = 0.857) of human presence on the time of the first laid eggs (WP: Est = -0.88, SE = 1.70, p = 0.608) (Figure 11).

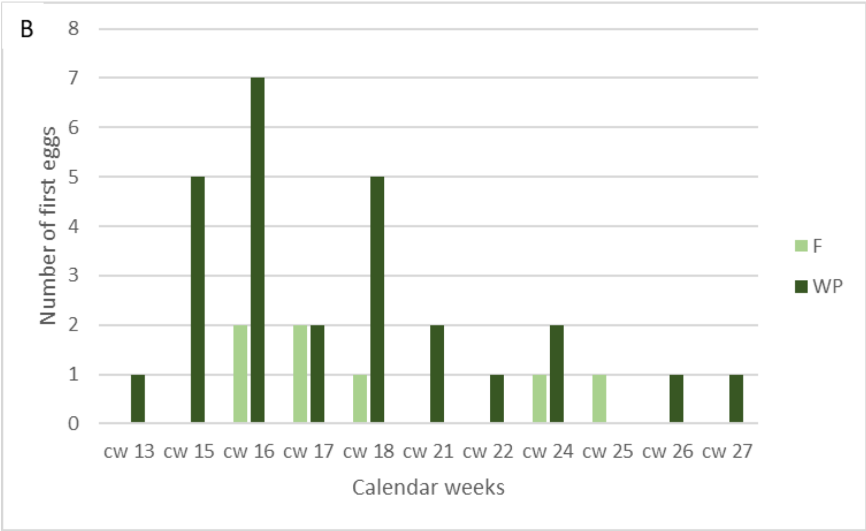


Figure 11: Number of first laid eggs (n = 34) during the different calendar weeks (cw) depending on human presence (F = rural forest, WP = Wildpark; F = 7; WP = 27).

3.2.3 Clutch size

There were no differences (p = 0.977) in the clutch size depending on human presence (WP: Est: -0.02, SE = 0.16, p = 0.890) (Figure 12).

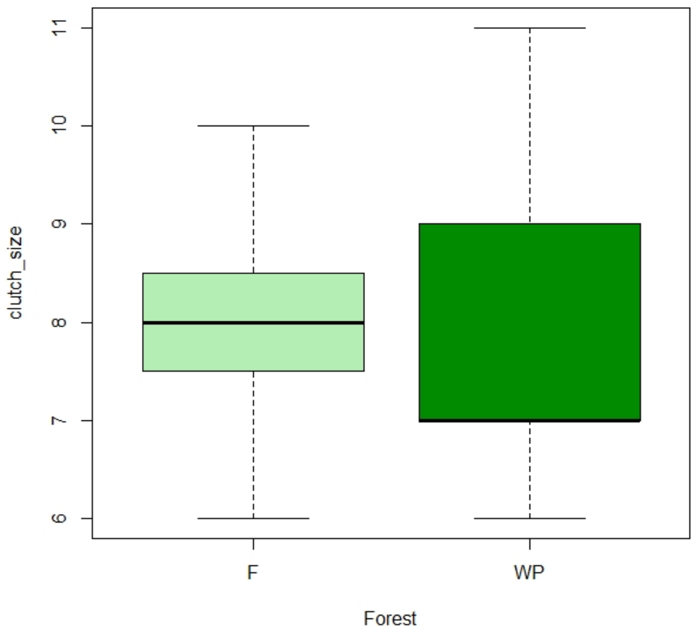


Figure 12: Clutch size (n = 34) depending on human presence (F = rural forest, WP = Wildpark; F = 7; WP = 27). Median + quartiles

3.2.4 Breeding success

The breeding success did not differ depending on human presence (W = 90, p = 0.862) (Figure 13).

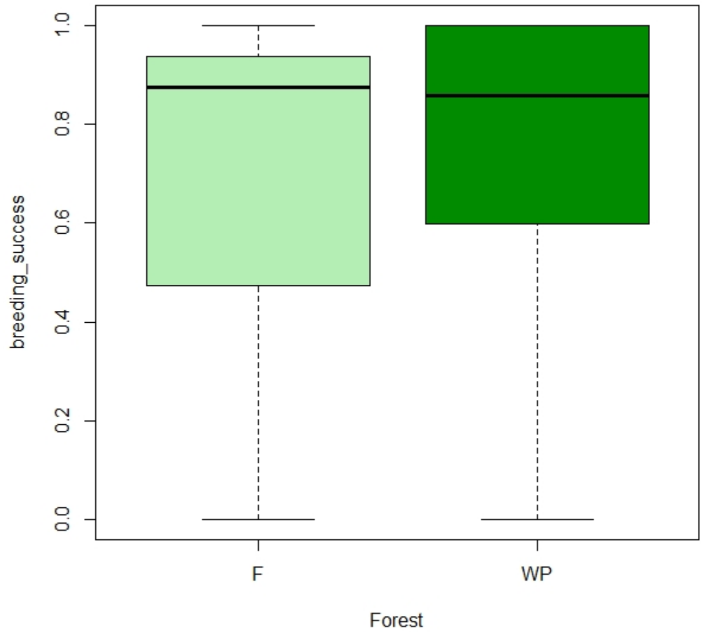
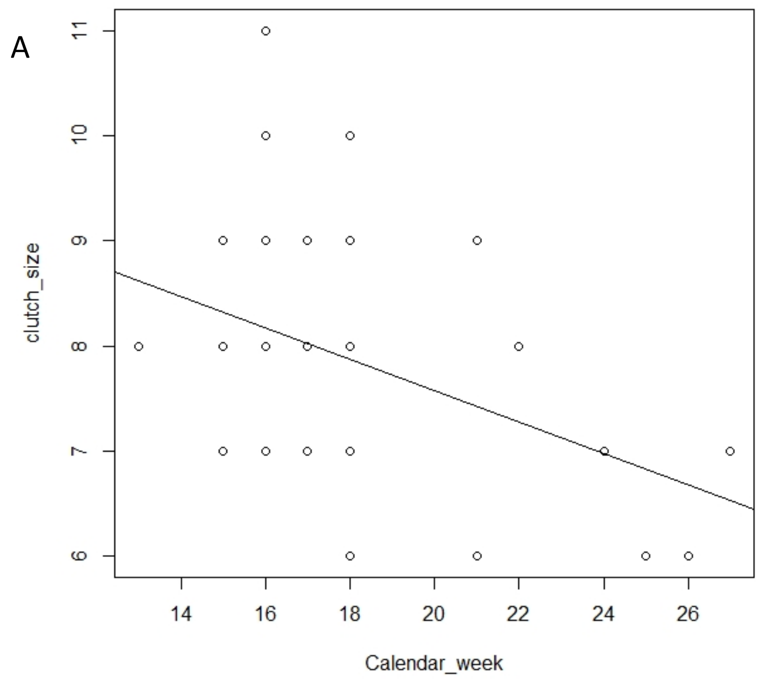


Figure 13: Breeding success (n = 34) depending on human presence (F = rural forest, WP = Wildpark; F = 7; WP = 27). Median + quartiles

3.3 Relationship between the time of the first laid egg and the clutch size or the breeding success

There was a significant negative correlation between the day of the first laid egg and the clutch size (rS = - 0.41, p = 0.016). The later the birds lay, the smaller the clutches (Figure 14A). However, there was no relationship between the day of the first laid egg and the breeding success (rS = 0.03, p = 0.860; Figure 14B).



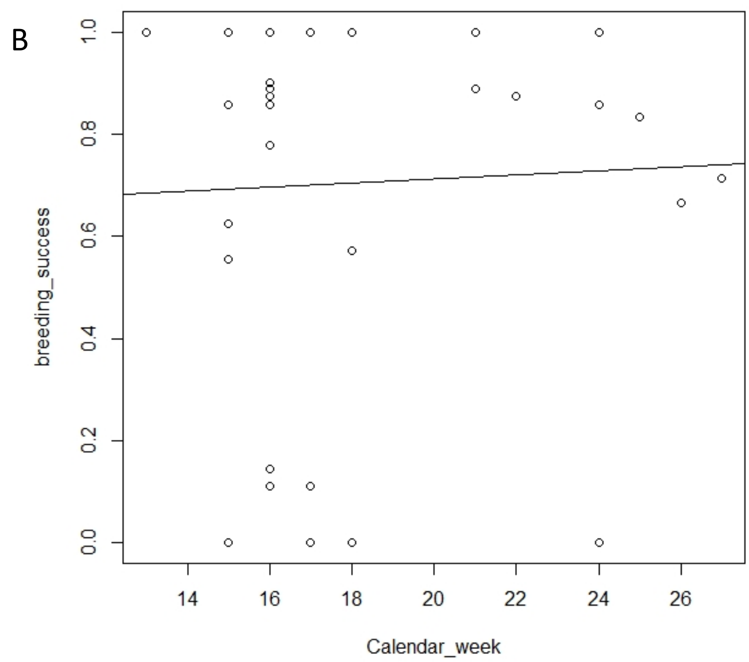


Figure 14: Relationship between the time of the first laid egg (Calendar_week) and (A) the clutch size (n = 34, p = 0.016) and (B) between the time of the first laid egg and the breeding success (n = 34, p = 0.86).

3.4 Interspecific differences

3.4.1 Occupation rate:

Great tits, Coal tits and Marsh tits occupied both nest box materials. The Coal tit was found more in the concrete nest boxes compared to wooden ones. Great tits and Marsh tits were found nearly the same in both materials. The breeding pair of the Blue tits occupied a wooden nest box. The breeding pair of the Nuthatches occupied a concrete one (Figure 15A).

Great tits, Coal tits and Marsh tits were found in the Wildpark and in the rural forest but much more in the Wildpark. The breeding pairs of the Blue tits and the Nuthatches were found in the Wildpark (Figure 15B).

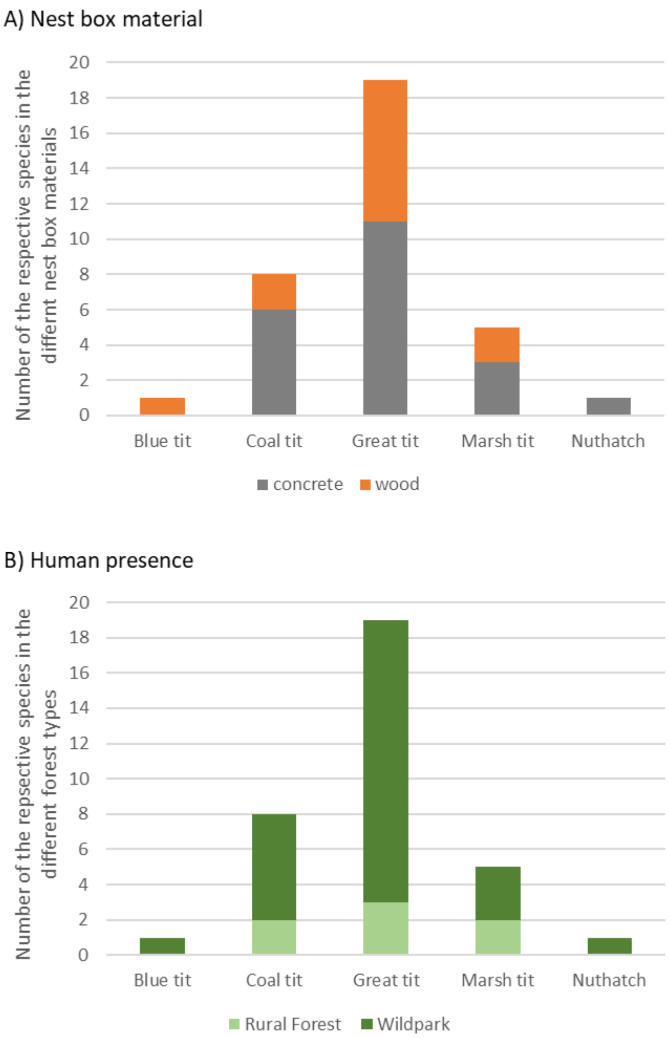


Figure 15: Occupation rate (n=34) depending on (A) the nest box material and depending on (B) human presence.

3.4.2 Day of the first laid egg:

The breeding pair of the Nuthatches was the first to lay eggs (first laid egg: April 2nd). The Great tits were laying their eggs nearly through the entire breeding season with a peak in the beginning (from April 23rd to May 14th). The Coal tits laid their first eggs also mostly through the entire breeding season but much less than the Great tits. The Marsh tits laid their first eggs only in the beginning of the breeding season and the only breeding pair of the Blue tits also laid their first egg rather at the beginning (Figure 16).

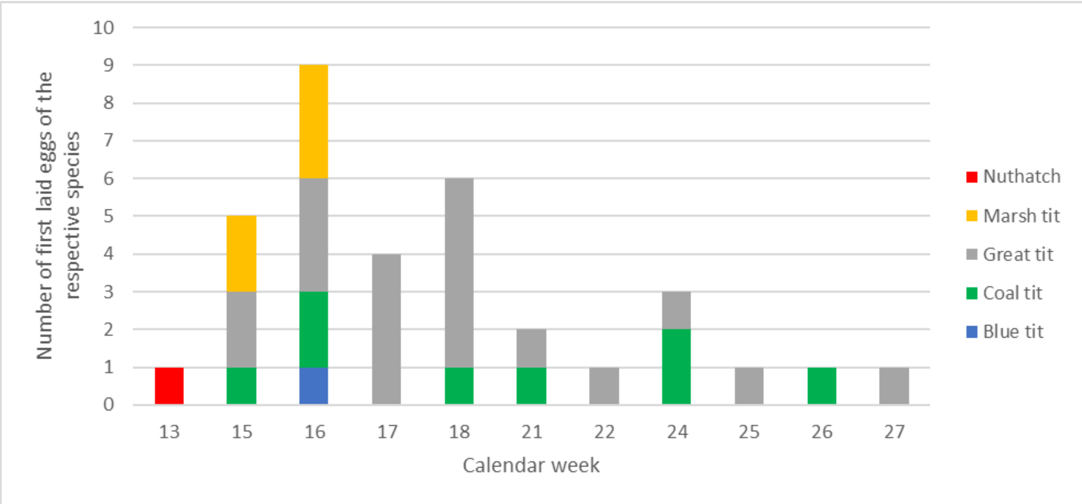


Figure 16: Number of first laid eggs (n = 34) of the respective species during the different calendar weeks.

The Great tits were laying their eggs nearly in both nest box materials through the breeding season. The Coal tits were laying their eggs in the wooden nest boxes only in the middle of the breeding season and laid their eggs earlier in the concrete nest boxes. The Marsh tits started laying their eggs in both nest box materials in the beginning of the breeding season (Figure 17A). The Coal tits and the Great tits were laying their eggs in the Wildpark nearly through the whole breeding season and they laid their eggs earlier in the Wildpark than in the rural forest. In the rural forest they were laying their eggs in a shorter time period in the middle of the breeding season. The Marsh tits laid their eggs in both forest types only in the beginning of the breeding season (Figure 17B).

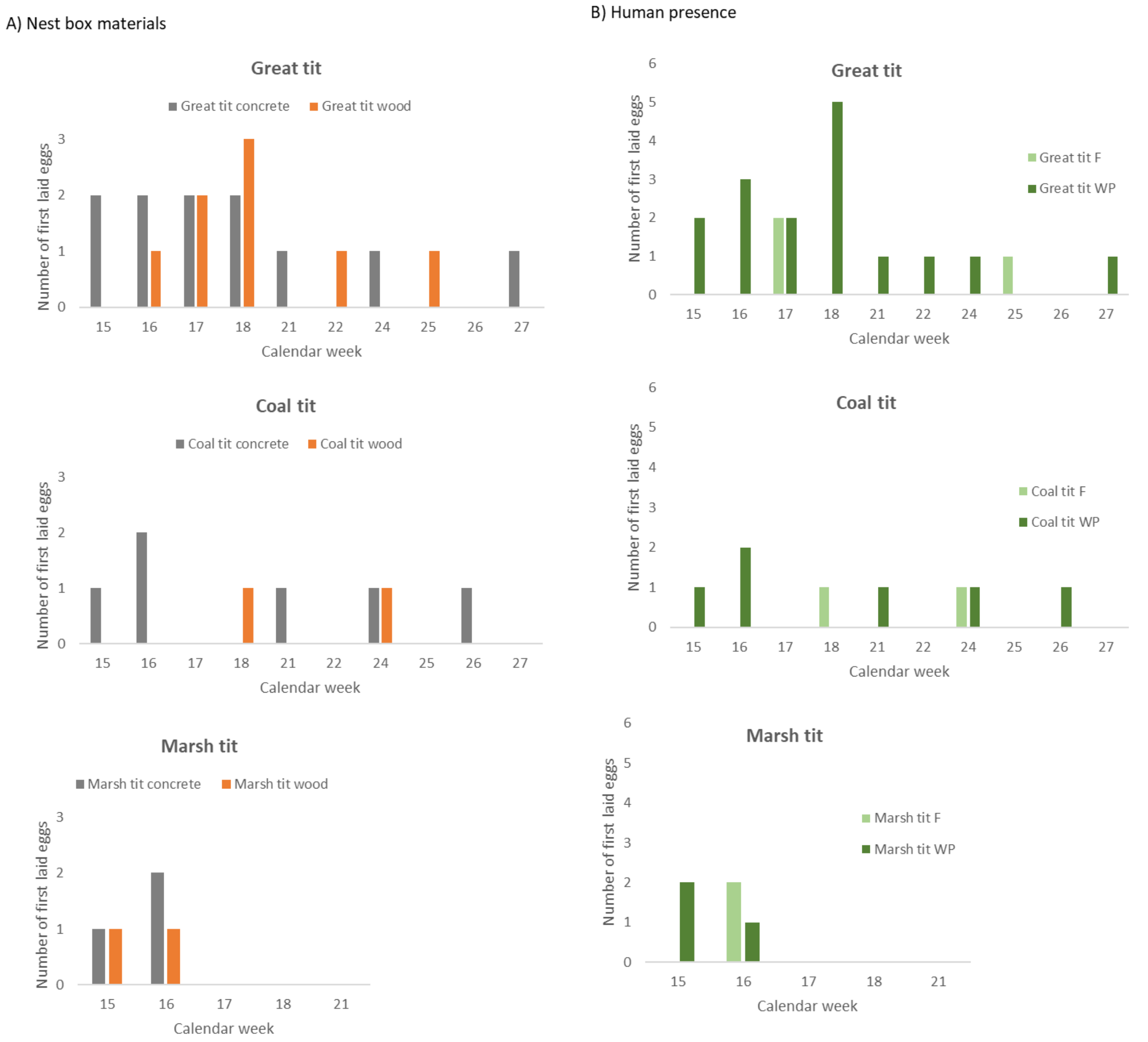


Figure 17: Comparison between the number of first laid eggs (n = 32) from the respective species during the different calendar weeks depending on (A) the material of the nest boxes (concrete/wood) or depending (B) on human presence (F = rural Forest; WP = Wildpark) for the most common bird species Great tits (n=19), Coal tits (n=8) and Marsh tits (n=5).

3.4.3 Clutch size:

The clutches from the Great tits and the Coal tits consisted of six to ten eggs (Great tits: *MW = 7.58, SD = 1.17*; Coal tits: *MW = 8.13, SD = 1.36*). The clutch size of the Marsh tits was between seven and eight eggs (*MW = 7.60, SD = 0.55*). The female of the Nuthatches laid eight eggs. The Blue tit breeding pair had a clutch with eleven eggs which was the largest clutch of all (Figure 18).

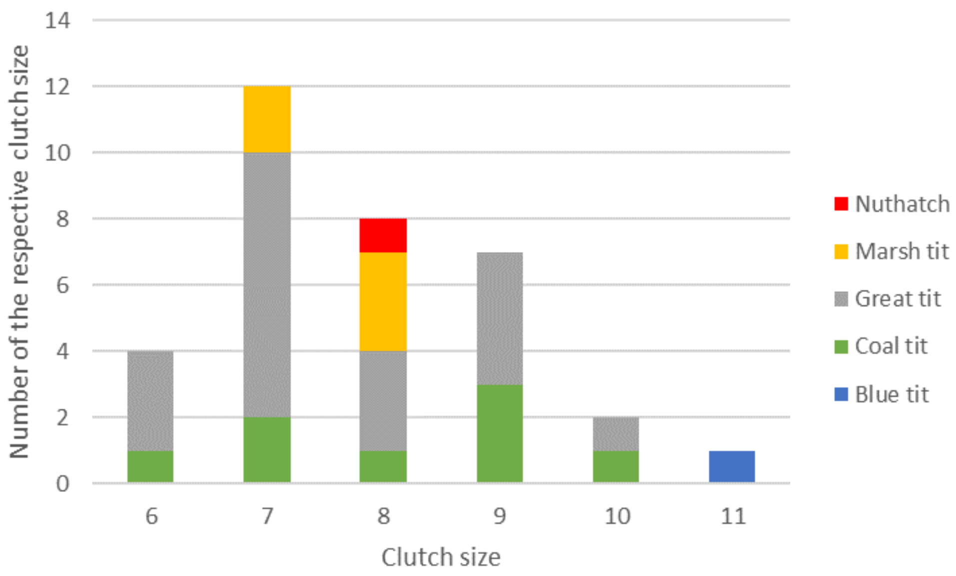


Figure 18: Number of the respective clutch sizes (n = 34) for the different bird species

There are no obvious interspecific differences in the clutch size depending on the material of the nest boxes (concrete/wood) (Figure 19, Tab. 5).

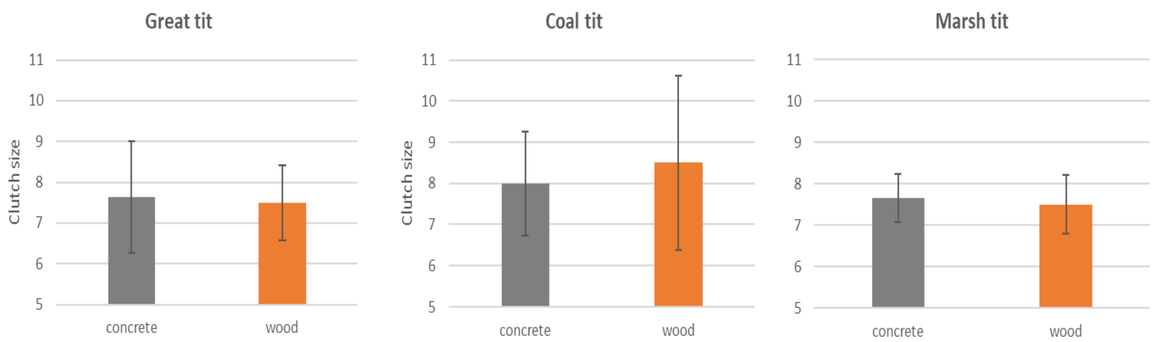


Figure 19: Mean clutch size and standard deviation of the Great tit (n = 19; concrete = 11, wood = 8), Coal tit (n = 8; concrete = 6, wood = 2) and Marsh tit (n = 5; concrete = 3, wood = 2)

Tab. 5: Mean clutch size and standard deviation (mean ± SD) for the Great tit, Coal tit and Marsh tit in the different materials of the nest boxes (concrete/wood).

Clutch size	Great tit	Coal tit	Marsh tit
concrete	*7.64 ± 1.36*	*8.00 ± 1.26*	*7.67 ± 0.58*
wood	*7.50 ± 0.93*	*8.50 ± 2.12*	*7.50 ± 0.71*

There are no obvious interspecific differences in the clutch size depending on human presence in the comparison between the forest without human presence (rural forest = F) and the forest with human presence (Wildpark = WP) (Figure 20; Tab. 6).

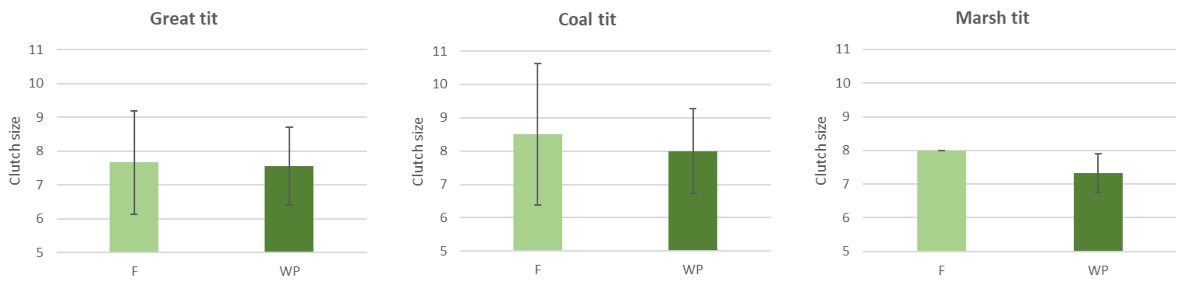


Figure 20: Mean clutch size and standard deviation of the most common bird species. Great tit (n = 19; F = 3, WP = 16), Coal tit (n = 8; F = 2, WP = 6) and Marsh tit (n = 5; F = 2, WP = 3).

Tab. 6: Mean clutch size and standard deviation (mean ± SD) for the Great tit, Coal tit and Marsh tit in the forest without human presence (rural forest) and the forest with human presence (Wildpark).

Clutch size	Great tit	Coal tit	Marsh tit
rural forest	*7.67 ± 1.52*	*8.50 ± 2.12*	*8.00 ± 0*
Wildpark	*7.56 ± 1.15*	*8.00 ± 1.26*	*7.33 ± 0.58*

3.4.4 Breeding success:

Great tits had breeding success in all categories, mostly between 81 – 100% (*MW* = *0.73, SD* = *0.34*). Coal tits showed breeding success in nearly all categories (*MW* = *0.69, SD* = *0.41*). The Marsh tits had the worst breeding success (*MW* = *0.50, SD* = *0.41*). For the only breeding pairs of the Blue tits and the Nuthatches all eggs resulted in fledglings (Figure 21).

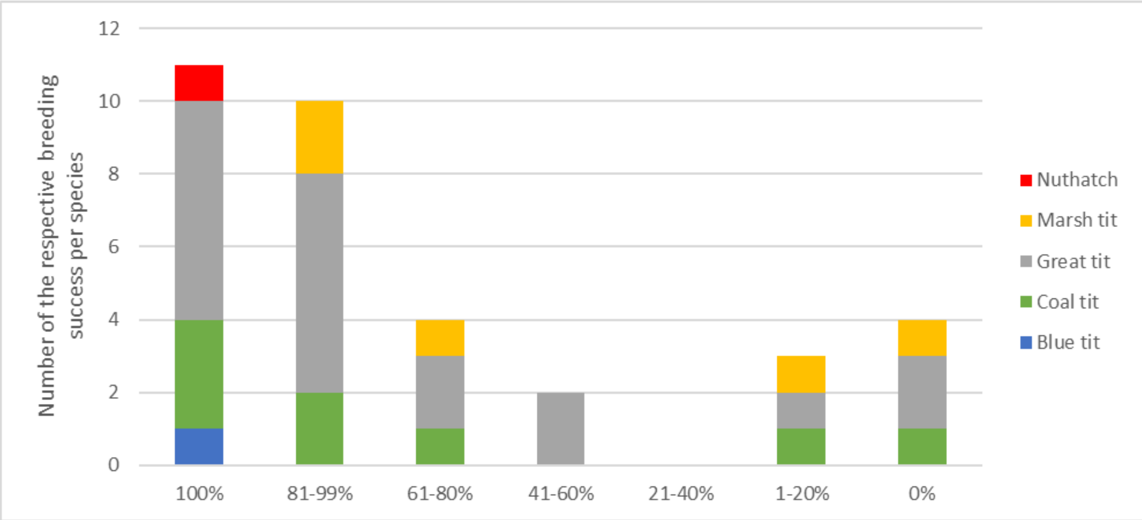


Figure 21: Number of the respective breeding success (n = 34) for the different bird species

There are no obvious interspecific differences in the breeding success depending on the material of the nest boxes, but the mean breeding success was slightly higher in the concrete nest boxes than in the wooden nest boxes for all most common bird species. This slight difference was greatest in the Coal tit (Figure 22 , Tab. 7).

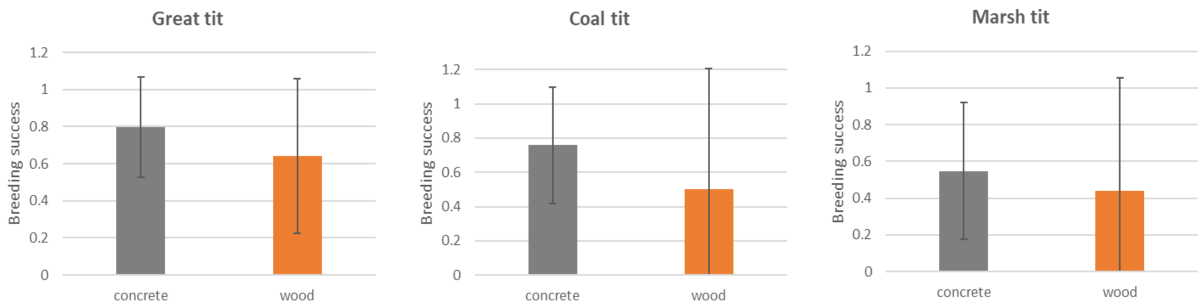


Figure 22: Mean breeding success and standard deviation of Great tit (n = 19; concrete = 11, wood = 8), Coal tit (n = 8; concrete = 6, wood = 2) and Marsh tit (n = 5; concrete = 3, wood = 2)

Tab. 7: Mean breeding success and standard deviation (mean ± SD) for the Great tit, Coal tit and Marsh tit in the different materials of the nest boxes (concrete/wood).

Breeding success	Great tit	Coal tit	Marsh tit
concrete	*0.79 ± 0.27*	*0.76 ± 0.34*	0.55 ± *0.37*
wood	*0.64 ± 0.42*	*0.50 ± 0.71*	0.44 ± *0.62*

The Great tit had nearly the same breeding success in the forest without human presence (F) and the forest with human presence (Wildpark = WP). For Coal tits the breeding success was slightly higher in the Wildpark. The Marsh tit had a lower breeding success in the Wildpark (Figure 23, Tab. 8).

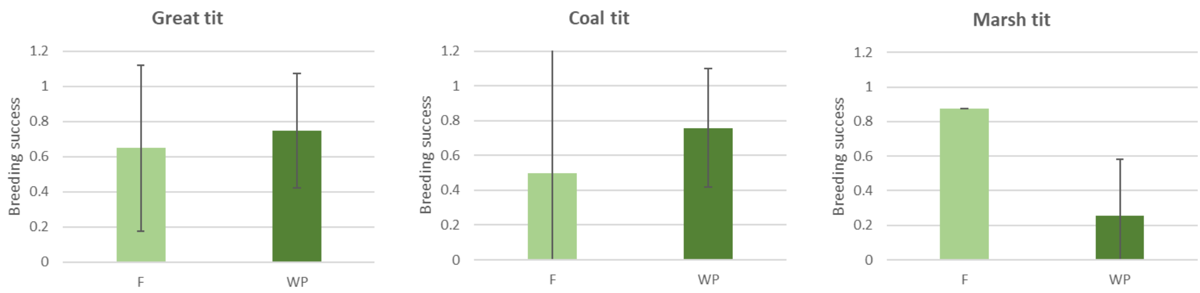


Figure 23: Mean breeding success and standard deviation of the most common bird species. Great tit (n = 19; F = 3, WP = 16), Coal tit (n = 8; F = 2, WP = 6) and Marsh tit (n = 5; F = 2, WP = 3).

Tab. 8: Mean breeding success and standard deviation (mean ± SD) for the Great tit, Coal tit and Marsh tit in the forest without human presence (rural forest) and the forest with human presence (Wildpark).

Breeding success	Great tit	Coal tit	Marsh tit
rural forest	*0.65 ± 0.47*	*0.5 ± 0.70*	*0.88 ± 0*
Wildpark	*0.75 ± 0.32*	*0.76 ± 0.34*	*0.26 ± 0.33*

4. Discussion

A clear difference in the occupation rate depending on human presence to a preference for the forest with human presence over the forest without human presence could be shown. There was no obvious influence of the material of the nest boxes on the occupation rate, but there seems to be a trend to a preference for concrete nest boxes to wooden ones. Furthermore, no obvious differences could be determined regarding the influence of the material of the nest boxes or the influence of human presence on the time of the first laid egg, the clutch size or the breeding success. However, there seems to be trends for earlier laying dates and a longer breeding season in concrete nest boxes and in the forest with human presence. There was a clear relationship between laying date and the clutch size, as later clutches consisted of less eggs. No relationship between the time of the first laid egg and the breeding success could be found. The most common species were the Great tit, the Coal tit and the Marsh tit. All the most common species were found more frequently in the forest with human presence. Slight interspecific differences could be found regarding the effect of the nest box material on the occupation rate and on the breeding success as well as the effects of human presence on the breeding success. No obvious interspecific differences could be found in the clutch size depending on the material of the nest boxes or depending on human presence.

A possible reason for the higher occupation rate in the forest with human presence (Wildpark) could be the additional food resources (Branston et al., 2021; Chamberlain et al., 2009; Solonen, 2001; Perrins & McCleery, 1989). In the Wildpark, some bird feeders were erected, which are well visited by the different bird species (Marini et al., 2017) and there is also potential food from the visitors and the other animals in the Wildpark, which get fed as well. Nevertheless, food from the bird feeders or other sources cannot substitute the availability of natural food resources especially like proteins from caterpillars which are important for the survival of the nestlings (Vaugoyeau et al., 2016; van Balen, 1973). But since the Wildpark is still an area which is mostly natural it could be that there are enough natural food resources like caterpillars (which should get investigated in further studies) and that the bird feeders are just an additional food resource which could maybe attract some bird species. Therefore, it is interesting to look which species are most present. The most common bird species in the present study was the Great tit. Other studies pointed out that some bird species like the Great tits are more tolerant to humans and could be often seen in urban areas (Remacha & Delgado, 2009; Clergeau et al., 2006; Cooke, 1980). Van der Zande et al. (1984) could even show an increase in the population of Great tits correlated to urban recreation density. However, the diversity of bird species seems to decline with the proximity to urban areas (Clergeau et al., 2006; McKinney, 2002; van der Zande et al., 1984; Cooke, 1980). There are also findings which show a competition between different bird species or rather a preference from smaller species for nest boxes with smaller entrance holes, which larger species could not use (Lambrechts et al., 2010; Sorace & Carere, 1996). Hence, different diameters of the entrance holes from the nest boxes could lead to different occupying species (Lambrechts et al., 2010). However, in the study from Browne (2006) both, the bigger Great tits and the smaller Blue tits, were occupying the nest boxes although the entrance holes of the nest boxes had the same diameters (Blue tits occupied them even more often). Dhondt (1977) showed that the competition consists of an interplay between density and food, in which the Blue tit has more influence over the Great tit than vice versa. Furthermore, some studies pointed out, that Great tits have an advantage where nesting space is limited, while Blue tits have an advantage in areas with many nesting opportunities which seems to be due to Blue tits having a wider food range than Great tits during the breeding season (Minot & Perrins, 1986; Minot, 1981; Dhondt, 1977). In the present study just one pair of Blue tits were integrated. The second most common bird species after the Great tit was the Coal tit – also a species which is smaller than the Great tit and which could also use nest boxes with smaller entrance holes like the Blue tits. Therefore, potential competition cannot be ruled out. However, in the present study all different bird species occupied the nest boxes in the Wildpark more to the forest without human presence. Therefore, another reason for the preference for the Wildpark beside the additional food resources or potential competition could be that the nest boxes in the Wildpark are “known” to the birds as they have been hanging there for several years, whereas those in the forest without human presence were newly hung. De León & Mínguez (2003) showed in their study about European storm-petrels that the occupation rate may be related to the fact that the birds already know the position of the nest boxes. In their study the birds occupied nest boxes which were built on old nesting places more to nest boxes which were built in new places in the first year of the study (De León & Mínguez, 2003). However, this effect diminished over the years of study (De León & Mínguez, 2003). These results could also be an explanation for the preference for the Wildpark but is not so easily transferable to the trend towards the concrete nest boxes to wooden ones since both types of material that were hung up in the Wildpark had already been in use for at least one breeding season. However, the concrete nest boxes had been hanging in the Wildpark itself for a long time, while the wooden nest boxes were in another forest before. Thus, any trends in the preferences could be related both to the already known location and to the already known material at that very location. Because, interestingly, in the forest without human presence the wooden nest boxes were preferred more and they were hung in another forest before whereas the concrete nest boxes in the forest without human presence had been bought new. This would support the suggestion that any knowledge of the nest boxes or signs of previous occupation could influence the occupation rate. However, due to the very small sample size especially in the forest without human presence (only seven nest boxes were occupied) no clear statements can be made. It is known that occupation rates in the first year of a study could be very low and increases during the following years (Remacha & Delgado, 2009; García-Navas et al., 2008). Hence, further investigations should be done in the following years. Another possibility for the trend towards the concrete nest boxes can be due to different thermal conditions inside the nest boxes which could have an impact of the reproductive performance (as concrete nest boxes seems to be warmer and show a higher thermal conductivity, which could help the females to get ready for the breeding earlier; see explanation below) (García-Navas et al., 2008; Browne, 2006) and what could be the reason to choose this nest boxes in foresight. Especially the Coal tit seems to prefer concrete nest boxes to wooden ones. Another finding from previous studies that suggested birds prefer larger or deeper nest boxes (Browne, 2006; Summers & Taylor, 1996) could not be confirmed with the results so far, as the wooden nest boxes were the larger and deeper ones, but the concrete nest boxes were preferred a bit more. That points towards the thermal conditions inside the nest boxes or the knowledge about the nest boxes being more important than the size of the boxes.

However, different thermal conditions inside the nest boxes could be a reason for the trend for earlier laying dates in the concrete nest boxes to wooden ones (Bueno-Enciso et al., 2016; García-Navas et al., 2008) especially for Great tits and Coal tits. They were also laying their eggs nearly through the entire breeding season in concrete nest boxes whereas wooden nest boxes were used more in the middle of the breeding season. This trend supports the outcomes from the studies from García-Navas et al. (2008) considering Tree Sparrows and Bueno-Enciso et al. (2016) investigating Great tits and Blue tits, who showed earlier eggs in concrete nest boxes. They suggested the thermal conditions inside the concrete nest boxes as a possible reason for the earlier laying start, as the warmer conditions inside could help the females to get ready for the breeding faster (Bueno-Enciso et al., 2016; García-Navas et al., 2008). A trend for an earlier laying start has also been found in the forest with human presence to the forest without human presence. Great tits and Coal tits were laying earlier in the Wildpark, and the breeding season was longer in the Wildpark to the forest without human presence. The Marsh tit were laying in both nest box materials and both forests nearly the same and only in the beginning of the breeding season. The pair of Nuthatches and the pair of Blue tits were laying their eggs in the beginning of the breeding season in the Wildpark. These results are in agreement with the findings from other studies in which the time of the first laid eggs was earlier in urban areas (Branston et al., 2021; Marini et al., 2017; Chamberlain et al., 2009). Chamberlain et al. (2009) and Marini et al. (2017) suggested that the availability of food in urban habitats may improve the condition of the adult birds which could lead to earlier laying dates. This could be a reason for the earlier laying starts in the Wildpark in which on one hand bird feeders are set up and on the other hand many other animals are fed in winter from which the birds could also steal food.

Additional food resources could also explain that in the present study no differences in the clutch size depending on human presence have been found. Since the availability of food seem to affect the condition of the birds and thus the clutch size (Branston et al., 2021; Chamberlain et al., 2009; Solonen, 2001; Perrins & McCleery, 1989) and due to the fact that the Wildpark is still a mostly natural area it could be that there are enough natural food resources like caterpillars which are important especially for the nestlings (Vaugoyeau et al., 2016; van Balen, 1973) as well as the birds could benefit from the additional food resources from the bird feeders (Marini et al., 2017) and the food from the other animals in the Wildpark as already discussed. Furthermore, the human presence in the Wildpark is limited through opening hours and the area is still very natural, so human disturbance as from pollution (air and soil) or floor sealing cannot be compared to that found in cities (McKinney, 2002). All these considerations could also be reasons why there were no material-dependent differences in clutch size, which supports the initial prediction. These results agree with the results of other studies, which also could not find any differences in the clutch size depending on the nest box material (Bueno-Enciso et al., 2016; Møller et al., 2014a; García-Navas et al., 2008; Browne, 2006). Additionally to the effect of the condition from the birds to the clutch size like discussed before (Branston et al., 2021; Chamberlain et al., 2009; Solonen, 2001; Perrins & McCleery, 1989) in some studies the clutch size is related to the nest floor area of the nest boxes (Møller et al., 2014b; Sorace & Carere, 1996) which would be consistent with the present results as the two nest boxes had approximately the same nest floor area. Another factor that can affect clutch size are higher population densities, which could lead to potential competition for food (Branston et al., 2021; Solonen, 2001). Therefore, food availability and the potential competition for food from higher bird densities and nest box floor area could affect clutch size more than the material or the thermal conditions of the nest boxes or the human presence in the present study site.

There were also no clear differences in the breeding success depending on the material of the nest boxes. These results support the initial prediction and are in agreement with the results from Browne (2006), but there was a small trend that the breeding success was slightly higher in the concrete nest boxes. However, there are many studies with different results regarding the breeding success depending on the nest box material (Bueno-Enciso et al., 2016; García-Navas et al., 2008; Browne, 2006). Bueno-Enciso et al. (2016) showed more pronounced temperature fluctuations, higher and lower maximum temperatures and higher humidity in concrete nest boxes to wooden ones in a study in central Spain, which are suggested to lead to a worse breeding success as the higher temperatures could lead to nestling death from hyperthermia. Due to the milder weather conditions in the present study, the thermal conditions of the nest boxes are maybe not as high as in central Spain, showing no obvious impact on breeding success. In another study in central Spain García-Navas et al. (2008) made the same suggestion, that the temperatures inside the concrete nest boxes are maybe not high enough to generate hyperthermia in nestlings as they found a better breeding success in concrete nest boxes to wooden ones in Tree Sparrows. But the temperature inside the nest boxes was not investigated in the present study. Furthermore, there are also findings that could not show any differences in the breeding success depending on the nest box material in different tit species (Parus spp.) in the UK (Browne, 2006). Hence, thermal conditions and interspecific differences depending on the material of the nest boxes could influence the breeding success and should be further investigated. However, there were slight interspecific differences in the breeding success depending on human presence, as the Great tit showed nearly the same in both forests, the Coal tit showed a slightly higher breeding success in the Wildpark, and the Marsh tit showed a worse breeding success in the Wildpark. So, the initial prediction to a lower breeding success in the forest with human presence could only be supported from the results for the Marsh tit. Regarding the breeding success of the other species it could be that, like discussed before, any possible negative influence from the human presence in the Wildpark (McKinney, 2002) will be balanced by the rich offer of old trees and maybe enough food resources like natural food resources like caterpillars (Branston et al., 2021; Vaugoyeau et al., 2016; Chamberlain et al., 2009; Solonen, 2001; Perrins & McCleery, 1989; van Balen, 1973) and the additional food offer from the bird feeders (Marini et al., 2017). Regarding the worse breeding success of the Marsh tits Wesolowski (2002) figured out in a study with natural holes that predation was the biggest reason for nest losses. But compared to the breeding success of the other bird species that bred under the same conditions and whose breeding success was not as bad as that of the Marsh tit, predation cannot really explain the worse breeding success of the Marsh tit. There are also findings for a smaller ecological niche of Marsh tits to Great tits (Farina, 1983). Therefore, further investigation should be done keeping an eye of the population density and potential losers in a potential competition especially in view of the declining population trend of the Marsh tit (Teufelbauer et al., 2022; Eaton et al., 2009).

Interestingly, the time of the first laid egg had no influence of the breeding success of the respective clutches in the present study. This fact could be interesting for further studies, because in many studies later clutches are not involved in the sample size (Bueno-Enciso et al., 2016; Møller et al., 2014a ; García-Navas et al., 2008) due to smaller clutch sizes (Møller et al., 2014a) as well as there seems to be a poorer breeding success (as the number of fledglings) in later clutches (Lambrechts et al., 2008; Perrins, 1965). The present study could not support these results because the breeding success (as the result from the number of fledglings which result from the eggs laid) did not decline with increasing breeding season. Therefore, it would be worthwhile to investigate the influence of the time of the first laid egg on the breeding success (as the number of fledglings which result from the eggs laid (Zhang et al., 2021)). However, regarding the influence of the time of the first laid egg on the clutch size, the present results are in agreement with further studies (García-Navas et al., 2008; Lambrechts et al., 2008; Perrins & McCleery, 1989; van Balen, 1973; Perrins, 1965), as later clutches consist of less eggs. The reason for this seems to be, again, the food availability, as there is often a lower food availability in the later breeding season (Perrins & McCleery, 1989).

5. Conclusion

The preference for the forest with human presence instead to the forest without human presence was the clearest result of the present study. This could be for a number of reasons, the most likely being the additional supply of food and knowledge of the nest boxes in the area. Therefore, further studies should be done. Firstly, long-term monitoring should be carried out to get an overview of potential changes, regarding the fact that nest box occupancy is lowest in the first year of the study, but this effect diminishes over time. Further studies are recommended to investigate the natural food resources and the development of the population densities over the years. Especially considering the number of Great tits in comparison to the other bird species to figure out potential losers in a potential competition for breeding sites and food resources. Therefore, the population of the Marsh tit should be observed in particular, as their population status is declining, and the present study showed a worse breeding success of the Marsh tits. But due to the very small sample size further investigations are recommended. Additional boxes with a smaller entrance hole in the same areas and in the same kind of arrangement could give answers to potential interspecific competitions. Furthermore, an observation of the thermal conditions in the nest boxes and the climatic conditions of the region would be interesting to be able to investigate whether the trend towards concrete nest boxes could be related to other thermal conditions and whether there are interspecific differences.

This study was the first exhaustive study investigating the breeding ecology and occupation preference of secondary hole-nesting birds in the Cumberland Wildpark and the forest adjacent to the Wildpark, in Grünau im Almtal, Upper Austria. It shows the present circumstances regarding the preferences and differences of the different bird species depending on different nest box materials and depending on different human presence. Hence, this study helps to gain important insights into the prevailing conditions in the study area. The results of this study can be used as a basis for further studies. They thus make it possible to examine and show any potential changes and special conditions of the region.

6. References

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7. Appendix

7.1 R Codes

R Codes and results

Occupation rate

Generalized Linear Model – binomial distribution

full=glm(Occupied~On_top+Tree.type+Material+Forest, family=binomial, data=Complete)

null=glm(Occupied ~ On_top+Tree.type, family=binomial, data=Complete)

Table 1: Results of the Generalized Linear Model (binomial distribution) with Occupied as the response variable and the position (On_top: top/bottom), the tree type (deciduous/coniferous), the nest box material (concrete/wood) and the forest type (Wildpark/rural Forest) as explanatory variables for all different occupying bird species (n = 34)

Term	Estimate	SE	z-value	p-value
Intercept	-1.699	0.547	-3.106	0.002
On_top	0.068	0.464	0.146	0.884
Tree.typedeciduous	0.347	0.492	0.706	0.480
Materialwood	-0.794	0.470	-1.689	0.091
ForestWP	1.852	0.517	3.582	< 0.001

Day of the first laid egg

General Linear Model

CW_MF=lm(Calendar_week~Material+Forest, data=Complete)

Table 2: Results of the General Linear Model with the code for the calendar_week as the response variable and the nest box material (concrete/wood) and the forest type (Wildpark/rural Forest) as explanatory variables for all different occupying bird species (n = 34)

Term	Estimate	SE	t-value	p-value
Intercept	18.989	1.745	10.883	< 0.001
Materialwood	0.016	1.416	0.011	0.991
ForestWP	-0.882	1.702	-0.518	0.608

Clutch Size

Generalized Linear Model – binomial distribution

full=glm(clutch_size~Material+Forest, family=poisson, data=Complete)

null=glm(clutch_size ~ 1, family=poisson, data=Complete)

Table 3: Results of the Generalized Linear Model (poisson distribution) with clutch size as the response variable and the nest box material (concrete/wood) and the forest type (Wildpark/rural Forest) as explanatory variables for all different occupying bird species (n = 34)

Term	Estimate	SE	z-value	p-value
Intercept	2.069	0.165	12.561	< 0.001
Materialwood	0.014	0.134	0.105	0.917
ForestWP	-0.022	0.161	-0.139	0.890

Breeding success

wilcox.test(breeding_success~Material)

Wilcoxon rank sum test with continuity correction

data: breeding_success by Material

W = 161, p-value = 0.3862

wilcox.test(breeding_success~Forest)

Wilcoxon rank sum test with continuity correction

data: breeding_success by Forest

W = 90, p-value = 0.8622

Relationship between the time of the first laid egg and the clutch size or the breeding success

cor.test(Calendar_week, clutch_size,method="spearman")

Spearman's rank correlation rho

data: FED_weekcode and clutch_size
S = 9234.8, p-value = 0.01576
alternative hypothesis: true rho is not equal to 0
sample estimates:
rho
-0.410977

cor.test(FED_weekcode, breeding_success,method="spearman")
Spearman's rank correlation rho

data: FED_weekcode and breeding_success
S = 6339.2, p-value = 0.8599
alternative hypothesis: true rho is not equal to 0
sample estimates:
rho
0.03143784

7.2 Zusammenfassung

Es gibt verschiedene Faktoren, welche die Wahl eines Brutplatzes und die Brutökologie von sekundären Höhlenbrütern beeinflussen, wie der Grad der Urbanisierung oder das Material der Nistkästen. Die Verwendung von Nistkästen erlaubt ein standardisiertes Arbeiten über einen langen Zeitraum und ist eine gängige Technik in der Beobachtung von sekundären Höhlenbrütern. Diese Studie untersucht den Einfluss des Nistkastenmaterials und den Einfluss von menschlicher Präsenz auf die Belegungspräferenzen und die Brutökologie von sekundären Höhlenbrütern, gemessen an der Belegungsrate, dem Zeitpunkt der ersten Eiablage, der Gelegegröße und dem Bruterfolg. 104 Nistkästen aus zwei verschiedenen Materialien (Beton/Holz) wurden an zwei angrenzenden Wäldern mit unterschiedlicher menschlicher Präsenz (mit/ohne menschlicher Präsenz) errichtet und einmal pro Woche während der gesamten Brutsaison 2022 kontrolliert. 34 Nistkästen wurden von fünf verschiedenen Vogelarten belegt. Der Wald mit menschlicher Präsenz wurde mehr belegt. Es gab einen Trend für Nistkästen aus Beton. Es konnten keine offensichtlichen Unterschiede hinsichtlich eines Einflusses des Nistkastenmaterials oder der menschlichen Präsenz auf den Zeitpunkt der ersten Eiablage, der Gelegegröße oder dem Bruterfolg gefunden werden, außer einem Trend für eine frühere Eiablage und einer längeren Brutsaison in Nistkästen aus Beton und im Wald mit menschlicher Präsenz. Interspezifische Unterschiede konnten gezeigt werden. Das Wissen über die Nistkästen, die Futterverfügbarkeit, etwaige Konkurrenz sowie unterschiedliche thermische Bedingungen innerhalb der Nistkästen werden als mögliche Gründe für die Ergebnisse diskutiert. Weiterführende Studien sollten daher durchgeführt werden.