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Ecosystem analysis

Breeding tree selection of the rook: spatial distribution in the Vorder- and Südpfalz and influence of temperature, artificial light and noise in urban areas

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Prof Dr. Martin Entling and Dr. Verena Rösch

Declaration of Authorship

Hereby, I declare that I have composed the presented paper independently on my own and without any other resources than the ones indicated. All thoughts taken directly or indirectly from external sources are properly denoted as such.

Landau, 28.03.2021 **(Place, Date)** [redacted] **_ (Signature)**

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Abstract

The growing numbers of breeding rooks (*Corvus frugilegus*) in the city of Landau (Rhineland-Palatinate, Germany) increase the potential for conflict between rooks and humans, which is mainly associated with noise and faeces. Therefore, the aim of this work is a better understanding of the breeding tree selection of the rook in order to develop options for action and management in the future.

Part I of this thesis provides general background information on the rook and includes mapping of the rookeries in the Anterior Palatinate and South Palatinate including Landau in the year 2020. That mapping revealed that the number of rural colonies has decreased, while the number of urban colonies has increased in the study area in the last few years. In line with current literature, tree species and tree size were important criteria for breeding tree selection. However, the mapping showed that additional factors must be important as well.

Therefore, as rooks seem to often breed along traffic axes, Part II of this thesis examines how temperature, artificial light and noise, which are all linked to traffic axes, affect the breeding tree selection of the rook in the city of Landau. The following three hypotheses are developed: (1) manually selected breeding trees (Bm) have a warmer microclimate than manually selected non-breeding trees (Nm) or randomly selected non-breeding trees (Nr), (2) Bm are exposed to a higher light level than Nm or Nr and (3) Bm are exposed to a higher noise level than Nm or Nr. To test these hypotheses, 15 Bm, 13 Nm and 16 Nr are investigated.

The results show that Bm were exposed to more noise than both types of non-breeding trees ($\mu_{Bm,\ noise}$ = 36.52481 dB, $\mu_{Nm,\ noise}$ = 31.27229 dB, $\mu_{Nr,\ noise}$ = 29.17417 dB) where the difference between Bm and Nr was significant. In addition, there was a tendency for Bm to be exposed to less light ($\mu_{Bm,\ light}$ = 0.356 lx) than Nm ($\mu_{Nm,\ light}$ = 0.4107692 lx) and significantly less light than Nr ($\mu_{Nr,\ light}$ = 1.995 lx), while temperature did not differ between the groups ($\mu_{Bm,\ temp}$ = 16.90549 °C, $\mu_{Nm,\ temp}$ = 16.93118 °C, $\mu_{Nr,\ temp}$ = 17.28639 °C).

This study shows for the first time that rooks prefer trees which are exposed to low light levels and high noise levels, i.e. more intense traffic noise, for breeding. It can only be speculated that the cause of this is lower enemy pressure at such sites. The fact that temperature does not seem to have any influence on breeding tree selection may be due to only small temperature differences at nest height, which might be compensated by breeding behaviour. Consequently, in the long term one management approach could be to divert traffic from inner-city areas, especially schools and hospitals, to bypasses. If tree genera suitable for rooks, such as plane trees, are planted along the bypasses, those sites could provide suitable alternative habitats to inner-city breeding locations, which become less attractive for breeding due to noise reduction. In the short term in addition to locally implemented repellent measures the most effective approach is to strengthen rook acceptance among the population. However, further research is needed to verify the results of this thesis and to gain further insights into rook breeding site selection in order to develop effective management measures.

Aufgrund der ansteigenden Zahl von Brutpaaren der Saatkrähe (*Corvus frugilegus*) in Landau (Rheinland-Pfalz, Deutschland) nimmt das Konfliktpotenzial, insbesondere aufgrund von Lärm und Verkotung, zwischen Saatkrähen und Menschen in der Stadt zu. Deshalb ist das Ziel dieser Arbeit die Brutbaumwahl der Saatkrähe besser zu verstehen, um basierend auf diesen Erkenntnissen Managementmaßnahmen abzuleiten.

Part I dieser Arbeit gibt einen allgemeinen Überblick über die Ökologie der Saatkrähe und beschreibt die Ergebnisse der Kartierung der Brutkolonien in der Vorder- und Südpfalz inklusive Landau im Jahr 2020. Diese Kartierung zeigt, dass die Anzahl an Nestern im ländlichen Raum in den letzten Jahren zurückgegangen ist, während die Anzahl an Brutpaaren in urbanen Gebieten zugenommen hat. In Übereinstimmung mit existierender Literatur waren Baumart und Baumgröße wichtige Kriterien für die Brutbaumwahl. Darüber hinaus zeigt die Kartierung, dass andere Faktoren entscheidend sein müssen.

Da Saatkrähen insbesondere entlang von Verkehrsachsen gebrütet haben wird in Part II dieser Arbeit untersucht, inwiefern Temperatur, künstliches Licht und Lärm, die allesamt in Zusammenhang mit Verkehrsachsen stehen, Einfluss auf die Brutbaumwahl der Saatkrähe in Landau haben. Dafür wurden die nachfolgenden drei Hypothesen geprüft: (1) Manuell ausgewählte Brutbäume (Bm) befinden sich in einem wärmeren Mikroklima als manuell ausgewählte Nicht-Brutbäume (Nm) oder zufällig ausgewählte Nicht-Brutbäume (Nr), (2) Bm sind einer höheren Beleuchtungsstärke ausgesetzt als Nm oder Nr und (3) Bm sind mehr Lärm ausgesetzt als Nm oder Nr. Um diese Hypothesen zu testen wurden 15 Bm, 13 Nm und 16 Nr untersucht.

Die Ergebnisse zeigen, dass Bm mehr Lärm ausgesetzt waren als die beiden Gruppen der Nicht-Brutbäume ($\mu_{Bm,\ noise} = 36.52481$ dB, $\mu_{Nm,\ noise} = 31.27229$ dB, $\mu_{Nr,\ noise} = 29.17417$ dB), wobei der Unterschied zwischen Bm und Nr signifikant ist. Bm ($\mu_{Bm,\ light} = 0.356$ lx) waren außerdem tendenziell weniger Licht ausgesetzt als Nm ($\mu_{Nm,\ light} = 0.4107692$ lx) und signifikant weniger Licht als Nr ($\mu_{Nr,\ light} = 1.995$ lx). Die Temperatur hingegen war bei allen drei Gruppen ähnlich ($\mu_{Bm,\ temp} = 16.90549$ °C, $\mu_{Nm,\ temp} = 16.93118$ °C, $\mu_{Nr,\ temp} = 17.28639$ °C).

Dies ist die erste Studie, die zeigt, dass Saatkrähen Bäume zur Brut bevorzugen, die weniger Licht und mehr Lärm, insbesondere Verkehrslärm, ausgesetzt sind. Es kann nur vermutet werden, dass dies mit geringerem Feinddruck an diesen Standorten zusammenhängt. Dass Temperatur keinen Einfluss gezeigt hat, könnte daran liegen, dass die Temperaturunterschiede so gering sind, dass sie durch das Brutverhalten ausgeglichen werden können. Somit könnte ein langfristiger Managementansatz sein den Verkehr von sensiblen innerstädtischen Bereichen, wie Schulen und Krankenhäusern, auf Umgehungsstraßen umzuleiten. Werden entlang dieser Umgehungsstraßen von den Saatkrähen als Brutbaum bevorzugte Baumarten, wie Platanen, gepflanzt, könnten diese als Alternativhabitat zu innerstädtischen Brutplätzen dienen, die aufgrund der Lärmreduktion für die Brut unattraktiv werden. Kurzfristig ist neben lokal begrenzten Vergrämungsmaßnahmen die Steigerung der Akzeptanz gegenüber der Saatkrähe innerhalb der Bevölkerung das einzige effektive Mittel. Weitere Studien sind notwendig, um die Ergebnisse dieser Thesis zu verifizieren, um die Brutbaumwahl der Saatkrähe noch besser zu verstehen und somit schlussendlich effektive Managementmaßnahmen entwickeln zu können.

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List of Abbreviations

ALAN	Artificial light at night
Bm	Manually selected breeding trees
DBH	Diameter at breast height
GNOR	Gesellschaft für Naturschutz und Ornithologie Rheinland-Pfalz e.V.
Nm	Manually selected non-breeding trees
Nr	Randomly selected non-breeding trees
UHI	Urban heat island

1 Problem description

In many cities in Germany, in Europe and throughout the species' range there is a great potential for conflict between humans and rooks (e.g. Bad Krotzingen Stadtverwaltung 2019; Bayerisches Landesamt für Umwelt 2011; Engelberth Hansen 2019; Fankhauser 2013; Gschweng 2016; Sepp and Dufner 2020; Stäbler 2019; Stabsstelle Umwelt Lahr 2010; Stadt Diepholz 2019; Stichmann 2016; Trondheim Kommune 2014; Waikato Regional Council n.d.). Noise from the rooks' calls (Bayerisches Landesamt für Umwelt 2011; Fankhauser 2013; Gschweng 2016; Stäbler 2019; Stabsstelle Umwelt Lahr 2010) and pollution from their faeces (Bayerisches Landesamt für Umwelt 2011; Gschweng 2016; Stäbler 2019; Stabsstelle Umwelt Lahr 2010) are perceived as problems by local residents especially in areas by public buildings and squares. Conflicts are common around hospitals (Bayerisches Landesamt für Umwelt 2011; Gschweng 2016; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Stadt Freiburg 2016; Stichmann 2016), schools (Bannas 2018; Bayerisches Landesamt für Umwelt 2011; Klöppel 2020; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015), playschools (Bayerisches Landesamt für Umwelt 2011; Klöppel 2020; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015) and restaurants (Schilling 2018), as well as in public parks, such as spa gardens (Bad Krotzingen Stadtverwaltung 2019) and cemeteries (Bayerisches Landesamt für Umwelt 2011; Bierl 2019; Sepp and Dufner 2020). Examples in Landau are the schoolyards of Otto-Hahn-Gymnasium (Bannas 2018; Klöppel 2020; Meyer 2018) and Pestalozzi-Schule (Bannas 2018; Klöppel 2020) as well as the outdoor area of the restaurant La Terrazza (Klöppel 2020; Schilling 2018). There is a growing consensus among the population that rooks in Landau should be driven away in many more places (Bannas 2018; Böckmann 2019; Meyer 2018; NABU n.d.).

However, until now no ideal solution for dealing with the conflict has been found, neither in cases described in the literature, nor in Landau itself. The rook is protected under the European Birds Directive (European Union 2009) and thus also under the Federal Nature Conservation Act (Deutscher Bundestag 2009). This means that hunting and disturbing and destroying the rook's breeding grounds are prohibited (Deutscher Bundestag 2009). Thus, repellent measures are not allowed. Nevertheless, due to the great potential for conflict between humans and rooks, it is possible to apply for a special permit for repellent measures (Deutscher Bundestag 2009). Such repellent measures include tree-cutting (Bayerisches Landesamt für Umwelt 2011; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Stäbler 2019), egg removal from nests (Sepp and Dufner 2020), nest splashing (Bayerisches Landesamt für

Umwelt 2011; Fünfstück and Rudolph 2011), nightly illumination (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015) and flights by a falconer's bird of prey as a warning, without really attacking the rooks (Bayerisches Landesamt für Umwelt 2011; Bierl 2019; Fünfstück and Rudolph 2011; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015).

Bannas (Bannas 2018) has developed a concept to deal with rooks in Landau. The concept includes recommendations for repellent measures, which were carried out at some places (Klöppel 2020). Nests were removed at playschools (Villa Mahla and Prot. Kindergarten Langstraße), trees were pruned at schools (Pestalozzischule, Otto-Hahn-Gymnasium), and both measures were carried out at the restaurant La Terrazza (Klöppel 2020).

However, existing repellent measures are rarely effective in the long term. In many cases, they even lead to splitting of colonies and colonisation of previously uninhabited parts of cities, which can increase the potential for conflict (e.g. Andris and Westermann 2011; Fünfstück and Rudolph 2011; Gschweng 2016; Sepp and Dufner 2020; Stabsstelle Umwelt Lahr 2010). With regard to Landau, most of the recommended measures proposed by Bannas (2018) were too expensive and were thus not implemented (Böckmann 2018; Böckmann 2019).

Nevertheless, due to the increasing numbers of rooks in cities (Andris and Westermann 2011; Bayerisches Landesamt für Umwelt 2011; Dietzen and Simon 2017; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015) the potential for conflict is growing. Therefore, there is an urgent need to develop feasible solutions for the conflict between humans and rooks.

The conflict is intensified by the fact that not only the absolute numbers of rooks are increasing, but the percentage of rooks in urban compared to rural areas is also growing (Andris and Westermann 2011; Bayerisches Landesamt für Umwelt 2011; Dietzen and Simon 2017; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015). Several factors can attract birds to cities: a better food supply (Allatson and Connor 2020; Ciach and Fröhlich 2017; Jadczyk and Drzeniecka-Osiadacz 2013; Rodewald and Shustack 2008; Tryjanowski et al. 2015), milder temperatures (Jadczyk and Drzeniecka-Osiadacz 2013; Partecke et al. 2004), the provision of suitable nesting habitats (Sacchi et al. 2002; Shaw et al. 2008), artificial light, which prolongs the period of activity by enabling nocturnal activity (Byrkjedal et al. 2012; Ciach and Fröhlich 2017; Dominoni et al. 2020), and reduced enemy pressure (Byrkjedal et al. 2012; Ciach and Fröhlich 2017; Dominoni et al. 2020; Gering and Blair 1999).

The warmer microclimate and lower enemy pressure (Dietzen and Simon 2017) as well as lower human hunting pressure on rooks in urban areas in comparison to rural areas (Gschweng 2016;

Stabsstelle Umwelt Lahr 2010) might be the reason for rooks to move to cities. However, up to now there are no scientific studies that have investigated those questions for the rook in particular.

All in all, the increasing number of breeding rooks in cities such as Landau entails a great potential for conflict, especially due to noise and faeces. Since there are no consistently promising countermeasures yet, there is an urgent need for action and research in this area. For that reason, the city council of Landau has launched a joint research project on the rook in Landau in cooperation with the University of Koblenz-Landau, which led to this thesis.

The aim of this thesis is to collect basic data by mapping the breeding situation of the rook in the Anterior and South Palatinate regions with a special focus on Landau as well as investigating the species' breeding tree selection. A better understanding of its breeding tree selection is a prerequisite for developing effective courses of action for possible control of breeding sites.

The thesis is divided into two parts. In Part I, based on mapping of rook nests in 2020, the distribution and development of breeding rooks in the Anterior and South Palatinate regions is presented and discussed. Furthermore, the results of this thesis are compared with existing literature, such as preferences of rooks for certain tree species as breeding trees or the increase in the number of urban nest sites. Part II is a detailed examination of the rook's breeding tree selection within the city of Landau in particular. As Part I demonstrates that many breeding trees in Landau are located along traffic routes and since temperature, artificial light and noise are associated with traffic routes their influence on the rook's breeding tree selection within Landau is investigated in Part II.

Part I – Rookery mapping

In Part I of this thesis first some background information on the rook in general is provided. Afterwards the mapping of the rookeries in the Anterior and South Palatinate and its results are presented and discussed.

2 Theoretical background regarding the rook and the conflict between humans and rooks

In order to better understand the breeding behaviour and the conflict between humans and rooks, this chapter provides some basic information about the ecology of the rook and the causes and consequences of the conflict between humans and rooks.

2.1 Ecology of the rook

Rooks belong to the family of corvids (*Corvidae*; Svensson 2017). Compared with the carrion crow, which is also completely black, adult rooks can be recognised by their grey beaks (Bitz 1990; Rörig 1900; Svensson 2017; Wolsbeck 1989; Figure 1). The most important difference is that rooks like to stay in larger groups, also in community with other species like starling or jackdaw (Bitz 1990; Rörig 1900) and breed in colonies (Bitz 1990; Svensson 2017; Wolsbeck 1989).
Rooks occur from Western Europe to East Asia and from Central Europe to South Scandinavia and are very common in Eastern Europe (Svensson 2017; Wolsbeck 1989). However, rooks are partly migratory birds, but partly also resident birds, whereas the rooks breeding in Germany are mainly resident birds (Bitz 1990; Dietzen and Simon 2017).

Figure 1: Rook (Corvus frugilegus)

A basic prerequisite for the establishment of a breeding colony is sufficient and accessible feeding habitat within the movement radius around the breeding trees (Bitz 1990; Czarnecka and Kitowski 2013). The movement radius cited in literature varies from 0.3 km (Czarnecka and Kitowski 2013) to 3 km (Griffin and Thomas 2000). For most of the year, rooks mainly feed on plant material, e.g. nuts, seeds, potato and sugar beet residues, fruits and berries (Dietzen and Simon 2017; Rörig 1900). During the breeding season they also consume slugs, earthworms or arthropods (Dietzen and Simon 2017; Rörig 1900) and occasionally they also feed on household waste (Târnoveanu 2012).

In addition to sufficient food availability (Czarnecka and Kitowski 2013), breeding tree selection depends on enemy pressure (Dietzen and Simon 2017) as well as on the availability of trees that are suitable as breeding trees. Rooks prefer tree genera with appropriate ramifications (Bayerisches Landesamt für Umwelt 2011) and genera that sprout late, thus enabling better identification of enemies (Dietzen and Simon 2017; Eislöffel 1995). Therefore, plane trees and poplars are often used as breeding trees (Andris 1996; Dietzen and Simon 2017; Eislöffel 1995; Olea 2009). There is also a theory that rooks choose the tree species for breeding on which they hatched (Weiper 2013). However, no scientific literature could be found to confirm this.

The nests are usually located in the upper third of the trees and thus often more than 5 m above the ground, in poplars often more than 15 m high (Dietzen and Simon 2017).

The time when the rooks start nest building and breeding depends on the weather (Dietzen and Simon 2017). In Rhineland-Palatinate they sometimes start nest building as early as January or February. Breeding usually starts at the beginning of March (Dietzen and Simon 2017). After the breeding season, which ends around June, the colonies split up (Dietzen and Simon 2017).

During the breeding season communication between the rooks is most intense, as they fight for nest sites and nesting material or chicks call for food later in the season (Fankhauser 1995). However, studies in Bern have shown that traffic noise (car: 69.3 dBA, lorry: 73.7 dBA) is louder than the calls of a breeding rookery (64.1 dBA). The fact that rooks are nevertheless perceived as more disturbing than traffic noise could be due to the high frequency of rook calls of 1.3 to 2.5 Hz as well as their impulsive nature. In addition, rooks also call at times when there is less traffic, such as early in the morning from 5:20 am (Fankhauser 1995).

Naturally, rooks prefer open landscapes. In Rhineland-Palatinate they often use arable land and vineyards (Andris and Westermann 2011; Bayerisches Landesamt für Umwelt 2011; Dietzen and Simon 2017; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015).

2.2 Conflict between humans and rooks

2.2.1 Increasing rook populations in urban areas

Whereas up to the second half of the 20th century rooks were mostly only observed as winter guests in Rhineland-Palatinate (Dietzen and Simon 2017), the number of breeding rooks in Rhineland-Palatinate has increased over the last few years (Bannas 2018; Dietzen and Simon 2017). However, a systematic survey of the rook population in Rhineland-Palatinate is not being performed (Bannas 2018; Dietzen and Simon 2017).

Nevertheless, Dietzen and Simon (2017) have published data showing that the number of breeding pairs has steadily increased from 3,000 breeding pairs in 2008 to 5,500 in 2012, but with a slight decline to 4,800 in 2014 (Figure 2).

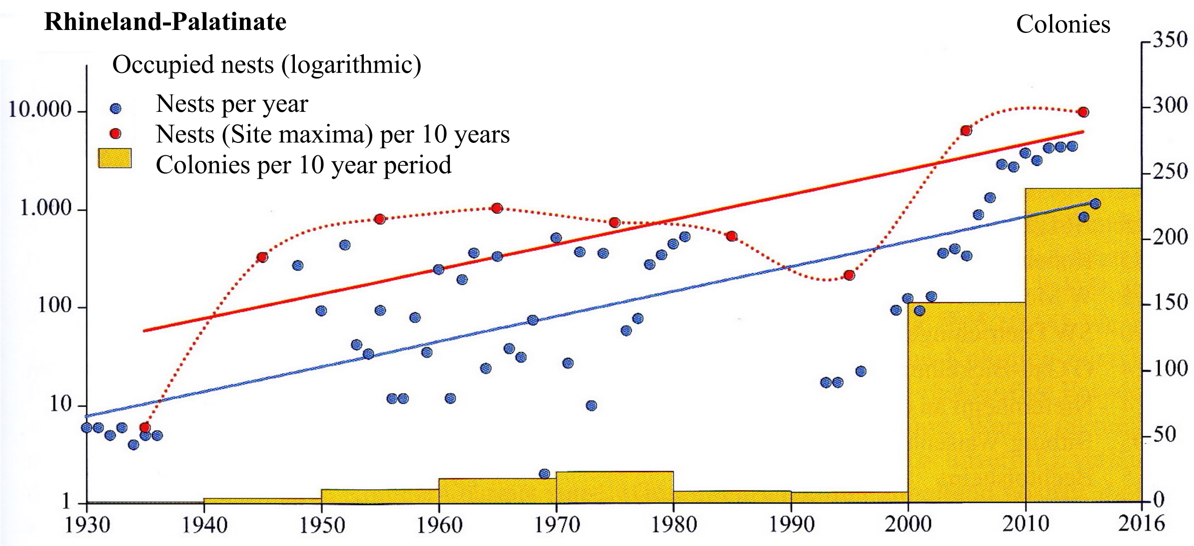

Figure 2: Population development of the rook in Rhineland-Palatinate (adapted Dietzen and Simon 2017)

Landau is one of the cities with many breeding pairs in Rhineland-Palatinate (Dietzen and Simon 2017). In 2017, five colony hotspots of the rook were identified by Bannas (2018): three schools (Otto-Hahn-Gymnasium, Pestalozzischule, Grundschule Godramstein) and two parks (Ostpark, Goethepark). While Otto-Hahn-Gymnasium and Pestalozzischule are located in the city centre of Landau, Grundschule Godramstein is situated in a small village which belongs to the municipality of Landau and borders directly on green spaces and vineyards. Ostpark and Goethepark are two parks quite close to the city centre of Landau. Data from these five hotspots show a strong overall increase in rook nests in Landau, from 29 nests in 2011 to 427 in 2018 (Bannas 2018).

That rooks often occur in urban areas (Keil 1988; Zimaroyeva et al. 2016) and that the number of urban breeding colonies of rooks is increasing is also true of other locations (Bayerisches Landesamt für Umwelt 2011; Fankhauser 1995; L.U.P.O. 2016; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015).

Andris and Westermann (2011) have studied rooks for several decades in Baden-Württemberg. It was not until the mid-1980s that a tendency emerged there for rooks to colonise cities to an increasing extent. The number of rural colony sites in Baden-Württemberg is declining drastically, while the number of colony sites in cities is growing. In 2010 95% of all rooks in

Baden-Württemberg were already breeding in towns with more than 5,000 inhabitants (Andris and Westermann 2011).

Figure 3: Rooks feeding in the vineyards of Landau

Thereby, it can be assumed that rooks nest especially in smaller towns where they have access to agricultural land and green spaces in the vicinity (Andris and Westermann 2011). Thus, the food supply can also be assumed to be guaranteed for most places in Landau particularly as rooks can often be seen feeding in the surrounding vineyards and fields (Figure 3).

However, it is not entirely clear why rooks move to cities. They may benefit from a milder climate in cities as well as from suitable breeding trees and lower enemy pressure (Dietzen and Simon 2017). Moreover, illegal persecution in rural areas, which has occurred in the past several times and is likely to occur today (Gschweng 2016), may be one of the reasons why the rooks are breeding in cities to an increasing extent (Stabsstelle Umwelt Lahr 2010).

2.2.2 Potential for conflict

Conflicts between humans and rooks occur in both rural (Dietzen and Simon 2017; Feare 1974) and urban areas (Bad Krotzingen Stadtverwaltung 2019; Bannas 2018; Dietzen and Simon 2017; Engelberth Hansen 2019; Fankhauser 1995; Fankhauser 2013; Gschweng 2016; Hölzinger 2014; Sepp and Dufner 2020; Stäbler 2019; Stabsstelle Umwelt Lahr 2010; Stadt Diepholz 2019; Trondheim Kommune 2014; Waikato Regional Council n.d.). Conflicts in the countryside can result from the agricultural damage caused by rooks (Bayerisches Landesamt für Umwelt 2011; Dietzen and Simon 2017; Feare 1974; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015). In cities, in particular noise caused by the rooks' calls and faeces have potential for conflict (Bannas 2018; Dietzen and Simon 2017; Fankhauser 1995; Schilling 2018; Wolsbeck 1989). Since rooks breed in colonies (Dietzen and Simon 2017; Svensson 2017; Wolsbeck 1989) which split up after breeding (Dietzen and Simon 2017), the conflict between humans and rooks in cities is greatest during the breeding season (Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Stabsstelle Umwelt Lahr 2010), i.e. between the beginning of March and June (Dietzen and Simon 2017).

The fact that many residents suffer greatly from the noise and faeces of rooks and that the conflict between humans and rooks is an emotional debate is confirmed by newspaper reports (e.g. Böckmann 2018, Böckmann 2019; Bonsen 2015; Höhl 2016; Kriesl 2016; Landauer CDU-Stadtratsfraktion will Saatkrähen abschießen lassen: „Belastend und gesundheitsgefährdend“ 2019; Meyer 2018; Problem mit Krähen: München rüstet auf 2018; Specks 2016; Vogel 2017; Weiper 2013; Zierz 2016), radio broadcasts (e.g. Stalbus 2018; WDR Kiraka) and television reports (e.g. BR 2016; SWR 2018) which highlight the various interests of different stakeholders both in Landau and in other places in Germany.

On the one hand, people insist that measures should be taken against the rook (Böckmann 2019; Bonsen 2015; Landauer CDU-Stadtratsfraktion will Saatkrähen abschießen lassen: „Belastend und gesundheitsgefährdend“ 2019; Weiper 2013; Zierz 2016). Usually, public places are the main focus of action. The city of Augsburg, for example, perceives a problem of hygiene on the grounds of the university hospital due to the faeces (Problem mit Krähen: München rüstet auf 2018), as does the city of Landau in some schoolyards (Bannas 2018; Böckmann 2019; Landauer CDU-Stadtratsfraktion will Saatkrähen abschießen lassen: „Belastend und gesundheitsgefährdend“ 2019). In addition, breeding rooks near schoolyards also lead to disturbance of lessons due to the calls of the rooks (Meyer 2018). However, not only hospitals and schoolyards are among the hotspots of conflict, but also cemeteries (Bayerisches Landesamt für Umwelt 2011; Bierl 2019; Sepp and Dufner 2020; Vogel 2017): for example visitors and funeral gatherings in Pritzwalk were disturbed by noise and faeces from about 600 to 700 breeding pairs at the cemetery (Vogel 2017). In addition, some people feel frightened by the large number of black birds (Bonsen 2015).

On the other hand, environmentalists argue that the rook is legally protected (NABU n.d.; Wilhelm 2018), that potential repellent measures are counterproductive (NABU n.d.) and that the increase in the number of rooks is only due to the fact that the rook population, once greatly reduced by humans, is slowly recovering (Kriesl 2016; NABU n.d.).

Emotional discussions take place not only in the media, but also at various events, for example, at a POLLICHIA talk given by Prof. Dr. Gerhard Reese in Landau in January 2020 (“Was haben Saatkrähen mit dem Klimawandel zu tun?”). He explained why it is sometimes difficult for humans to provide enough space for the environment illustrating that by using the example of the rook.

Moreover, the explosive nature of the conflict with the rook in Landau is clearly demonstrated by the fact that it is being used for the election campaign. For example, Bündnis 90 Die Grünen has included the subject of rooks in their election programme (Bündnis 90 Die Grünen n.d.).

Therefore, the city of Landau, initiated the research project in cooperation with the University of Koblenz-Landau, which led to this thesis.
In order to promote a constructive exchange between all stakeholders, such as city employees, ornithologists, and citizens, the city of Landau has set up a round table on the subject of rooks (Stadt Landau in der Pfalz Stadtverwaltung 2017).
Nevertheless, it remains a highly debated issue where no measure can satisfy all stakeholders. The measures that can be implemented to reduce the conflict between humans and rooks are described in the following chapter.

2.3 Conflict resolutions

Although the rook is protected under the European Birds Directive (European Union 2009) and under the Federal Nature Conservation Act (Deutscher Bundestag 2009), which is outlined in detail in Appendix I, in certain cases repellent measures can be undertaken. Moreover, the acceptance of the rook within the human population can be increased. Both issues are outlined in this chapter.

2.3.1 How to repel rooks

Repellent measures are used both illegally (Andris and Westermann 2011; Gschweng 2016; Hölzinger 2014; Krüger and Nipkow 2015) and legally (Deutscher Bundestag 2009; Gschweng 2016; Sepp and Dufner 2020; Stabsstelle Umwelt Lahr 2010) to counteract the conflict between humans and rooks.
There are countless examples of illegal attempts to repel rooks. These range from tree pruning and tree felling to shooting and poisoning of the animals (Andris and Westermann 2011; Gschweng 2016; Krüger and Nipkow 2015).
However, following a proper application and legal review, they are also being expertly repelled from locations with a particularly great potential for conflict (Gschweng 2016; Sepp and Dufner 2020; Stabsstelle Umwelt Lahr 2010). If a farmer's field is occupied by more than 50 birds, the farmer may suffer considerable damage (Andris and Westermann 2011). Then the farmer can submit an application to the Upper Nature Conservation Authority for lethal repellent measures, i.e. the shooting of a certain number of birds, which is customary in such a case (Andris and Westermann 2011).
Mainly used in cities, one of the more harmless repellent measures is the utilisation of an eagle owl dummy. Since movable eagle owl dummies, which residents can operate from the ground using a cord, have been installed in the castle park of Bad Krozingen, no more rooks nest there (Andris and Westermann 2011). Nevertheless, it is often reported that owl dummies did not

contribute to any change in the breeding behaviour of the rooks in the long term (Krüger and Nipkow 2015; Stabsstelle Umwelt Lahr 2010).
However, there are many more measures that have been used so far to repel rooks (Bayerisches Landesamt für Umwelt 2011; Engelberth Hansen 2019; Fünfstück and Rudolph 2011; Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Sepp and Dufner 2020; Stäbler 2019; Stadt Freiburg 2016). In Landau, for example, trees have been pruned and nests removed (Klöppel 2020).
Even if some repellent measures lead to local success, they can have negative consequences in the long run. Often, one colony splits up into several colonies occupying new sites and thus causes problems at new locations (Andris and Westermann 2011; Bitz 1990). For example, in a colony in poplars near Bad Krozingen, residents suffered not only from damage to the corn fields, but also from noise and faeces in gardens. As a result, about 50 poplars were felled, which reduced the size of the colony. However, the rooks not only colonised other surrounding trees, but also established a new sub-colony (Andris and Westermann 2011). Thus, the conflict was not reduced but intensified instead.
One problem with repellent measures may be the strong location fidelity to a breeding place described by Rörig (1900). Even if rooks were successfully repelled from a breeding site for one year by various measures, such as frequent shooting, the rooks often returned to the same location the next year (Rörig 1900).

Nevertheless, there are numerous other methods that are used with greater or less success locally:

- tree-cutting (Bayerisches Landesamt für Umwelt 2011; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Stäbler 2019)
- covering the treetops with nets (Sepp and Dufner 2020; Stadt Freiburg 2016)
- egg collection from nests (Sepp and Dufner 2020)
- removal of nests (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Sepp and Dufner 2020; Stäbler 2019; Stadt Freiburg 2016)
- nest splashing (Bayerisches Landesamt für Umwelt 2011; Fünfstück and Rudolph 2011)
- attaching balloons, tape etc. in the trees (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Sepp and Dufner 2020)
- use of approved lasers (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015)

- nightly illumination (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015)
- signal flares (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015)
- shot fired in the air (Bayerisches Landesamt für Umwelt 2011; Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015)
- repellents using odour of predators (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015)
- sound dummies (BirdGards) that imitate the calls of predatory birds (Krüger and Nipkow 2015; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015) or warning cries of the rooks (Bayerisches Landesamt für Umwelt 2011; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Sepp and Dufner 2020)
- flight of a falconer's bird of prey as a warning, without attacking the rooks (Bayerisches Landesamt für Umwelt 2011; Bierl 2019; Fünfstück and Rudolph 2011; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015)
- squirrel as natural enemies which feed on the rooks' eggs (Engelberth Hansen 2019)
- etc.

2.3.2 Increasing the acceptance of the rook among the public

In addition to repellent measures, another way to address the conflict is to improve acceptance of the rook among the population (Bannas 2018; Bayerisches Landesamt für Umwelt 2011; Gschweng 2016; Menzel 2020; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Roth 2011; Sepp and Dufner 2020). There are many cities that have already implemented (Menzel 2020) or are considering implementing various measures (Bannas 2018; Bayerisches Landesamt für Umwelt 2011; Gschweng 2016; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015).

The first step towards better acceptance among the public is transparency and public information about the problem and the status of various measures (Bayerisches Landesamt für Umwelt 2011; Gschweng 2016; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Sepp and Dufner 2020). Articles in newspapers and on websites, reports on radio and television (Sepp and Dufner 2020), but also activity in the social media can be useful in this regard. There are already flyers from various cities that provide information about rooks (e.g. Landesbund für Vogelschutz in Bayern e. V. n.d.; NABU and WAU e.V. n.d.; Roth 2011;

Stabsstelle Umwelt Lahr 2010; Stadt Rees Abt. Bauverwaltung und öffentliche Ordnung 2018; Stichmann 2016; Umweltamt Landau 2015).

In addition, information events such as talks or round tables help all interest groups to exchange information, which was done in Landau (Stadt Landau in der Pfalz Stadtverwaltung 2017; Vortrag in Landau: Was haben Saatkrähen mit dem Klimawandel zu tun? 2020) and other cities (Bayerisches Landesamt für Umwelt 2011). However, information events can be offered for children as well. Activities in playschools and schools or field trips with children and young people can increase the acceptance of the rook among future generations (Gschweng 2016). The integration of the subject of rook into the school curriculum could also contribute to this (Bannas 2018). Webcams could be fixed on breeding trees for pupils to observe the rooks' breeding behaviour live on a website (Gschweng 2016).

One of the pioneers of promoting acceptance of the rook among the public is the municipality of Ascheberg in Schleswig-Holstein, which implemented a rook nature trail in 2010 (Menzel 2020). On that tour, visitors are guided through the rooks' breeding site by a rook mascot called Gerda and learn about the rooks' behaviour (Menzel 2020). Several other cities have included the idea of a rook nature trail in their plans to increase acceptance among the population, for example the cities of Laupheim (Gschweng 2016) and Soest (Stichmann 2016). Bannas (2018) has also listed a rook nature trail as a possible measure for Landau.

Even setting up individual information boards can help to inform the public (Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015). There is also an information board on rooks in Landau. However, it is located at a former colony, which is no longer occupied, near the indoor swimming pool La Ola.

In contrast to repellent measures, which have a direct impact on the life of the rook, but which are sometimes difficult to implement and the success of which is not guaranteed, measures to increase acceptance within the public can be implemented directly. The idea is that a better knowledge of the rooks' behaviour could change people's attitudes, which would relax people directly affected and defuse the whole conflict between humans and rooks.

Consequently, the conflict between humans and rooks is caused by the increasingly more frequent choice of breeding grounds within cities and the resulting annoyance of residents because of noise and faeces. As the rook is protected under the Birds Directive, repellent measures such as tree pruning are only possible with a special permit. That is sometimes granted in certain places, such as near hospitals, playschools or schools. Moreover, repellent measures are rarely effective in the long term. In addition, it is important to provide information on the breeding behaviour of the rook to the public and to monitor and transparently communicate planned and implemented repellent measures.

In order to develop effective measures a detailed understanding of local breeding tree selection is necessary. Therefore, the aim of Part I of this thesis is to collect basic data on the distribution of rookeries and the genera of breeding trees in the Anterior and Southern Palatinate with a special focus on Landau and then to classify the collected data and incorporate them into data from previous years.

3 Mapping methodology

3.1 Study Area

The study area covers the Anterior Palatinate and Southern Palatinate, two of the four sub-regions of the Palatinate, which is located in the southeast of the federal state of Rhineland-Palatinate in southwest of Germany. Both areas are part of the Upper Rhine Plain and are strongly influenced by viticulture. They are bordered by Rheinhessen to the north, the Rhine to the east, the Palatinate Forest to the west and the border to France to the south.

Landau (Pfalz), 49°11'56.0"N 8°07'06.8"E, which has about 47,000 inhabitants and an area of about 8,000 ha, is examined in detail. A special feature is that the town is the largest wine-growing municipality in Germany (Stadt Landau in der Pfalz Stadtverwaltung n.d.). Moreover, with more than 22 ha of parks, Landau is characterised by many urban green areas. Those green spaces, as well as the avenues of the city, are planted with both native and exotic tree species with almost a quarter of all urban trees belonging to the Acer genus (Stadtverwaltung Landau in der Pfalz 2020).

3.2 Data collection

Data from the Society for Ornithology in Rhineland-Palatinate GNOR (Gesellschaft für Naturschutz und Ornithologie Rheinland-Pfalz e.V.) about rookeries from former years (GNOR 2015) as well as from an environmental sciences project by students of the University of Koblenz-Landau in 2018 (Mittelmeier and Marini 2018) served as a basis for mapping the colonies of the rooks in the Anterior and South Palatinate sub-regions. The data basis was shapefiles, which were analysed with QGIS (QGIS Development Team 2020), so that the colonies could be surveyed with the help of GPS data. For the analysis of the total amount of nests in Landau, nest numbers from Bannas (2018) were used in addition.

The formerly occupied sites were surveyed mainly from April 10th to 17th, 2020 and checked for current nests. In some places, the data collected was supplemented at a later date when further breeding trees were found or some tree genera were identified at a later date.
If occupied trees were found, the tree genus and the number of nests were noted. If the nests did not appear to be occupied, that was also recorded. If no more nests were found, the colony was mapped as abandoned.
For the urban areas of Landau the tree height and the diameter at breast height (DBH) were also determined, mainly by using the tree cadastre of the city of Landau (Stadtverwaltung Landau in der Pfalz 2020). The trees which could not be clearly assigned to any tree in the tree cadastre or which were not included in it were measured manually. The tree height was measured with the second stick method according to the American Forests champion trees measuring guidelines handbook (Leverett and Bertolette 2014) and the trunk diameter was calculated after measuring the trunk circumference.
The methodology and data basis of all collected data is summarised in Table 1.

Table 1: Methodology and data basis of collected data

Collected data	**Collecting methodology**	**Data basis**
Number of nests	Counting	(GNOR 2015; Mittelmeier and Marini 2018)
Tree genus	On-site inspection	(Stadtverwaltung Landau in der Pfalz 2020)
Tree height	On-site inspection and second stick method	(Stadtverwaltung Landau in der Pfalz 2020)
Tree DBH	On-site inspection and measurement of the trunk circumference	(Stadtverwaltung Landau in der Pfalz 2020)

3.3 Data analysis

The evaluations of the colony development were made with MS Excel (Microsoft Corporation 2020). For that purpose, several graphs were created, which compare urban and rural colonies, as well as the overall development at individual locations.
MS Excel (Microsoft Corporation 2020) was also used to analyse the distribution of tree genera among the breeding trees. For the comparison of all tree genera within the urban area of Landau

with the tree genera of the breeding trees, only those trees of the tree cadastre (Stadtverwaltung Landau in der Pfalz 2020) that are located in the immediate urban area of Landau were used, i.e. not in the surrounding villages or rural areas that also belong to the municipality of Landau. Tree height and DBH are graphically displayed in relation to the tree genera using R (RStudio Team 2020).

In order to examine the extent to which repellent measures had an influence on the development of the colonies in the study area, the data of the number of nests were assessed with relation to the repellent methods carried out. A list of repellent methods from 2010 to 2020 was provided by the SGD Süd, Department of Regional Planning, Nature Conservation, Building Regulations (Klöppel 2020).

For analysing the development of rookeries in addition to the self-collected data in 2020, data from GNOR (2015) and from the student project of the University of Koblenz-Landau (Mittelmeier and Marini 2018), which were already used to identify potential breeding sites, as well as information and nest numbers on the development in Landau from Bannas (2018) were used.

4 Results of the rookery mapping

4.1 Rook colonies in the Anterior and South Palatinate sub-regions and in Landau

In the Anterior Palatinate and South Palatinate, 50 colony sites known from previous years were checked, of which only 25 were current rookery sites in the year 2020 and an additional huge colony in Edenkoben was found, i.e. 26 colonies in total (364 breeding trees, 1,600 nests; Table 2). Of those colonies 23 rookeries (343 breeding trees, 1,521 nests) were located in urban areas and only 3 (21 breeding trees, 79 nests) in rural areas. Consequently, nowadays the majority of rooks in the Anterior and South Palatinate breed in cities and urban outskirts (Figure 4). Around Landau there was only one rural colony near Offenbach with six nests. The breeding rooks in the municipal area of Landau (143 trees, 682 nests) made up more than a third of all breeding rooks in the Anterior and South Palatinate sub-regions.

Table 2: Rookeries in the Anterior and South Palatinate sub-regions in 2020

City	**Colony**	**Urban/rural**	**Number of breeding trees**	**Number of nests**
Duttweiler	NW_Duttweiler	Rural	11	30
Edenkoben	SUEW_Edenkoben	Urban	63	308
Frankenthal	FT_Parkfriedhof	Urban	40	119
Frankenthal	FT_Neumayerschule	Urban	4	21
Frankenthal	FT_Philipp-Rauch-Str	Urban	36	91
Grünstadt	DUEW_Gruenstadt_Kirchheimer_Str	Urban	14	72
Grünstadt	DUEW_Gruenstadt_Auf_der_Wart	Urban	2	6
Lambsheim	RP_Friedhof_Lambsheim	Urban	4	51
Landau	LD_Neustadter_Str	Urban	4	8
Landau	LD_Gillet	Urban	13	52
Landau	LD_Reduitstr	Urban	3	21
Landau	LD_Schwanenweiher	Urban	16	179
Landau	LD_Marienring	Urban	6	55
Landau	LD_Goethepark	Urban	45	211
Landau	LD_Alter_Meßplatz	Urban	27	113
Landau	LD_Fort	Urban	11	21
Landau	LD_Lazarettstr	Urban	5	11
Landau	LD_An_den_Lerchenwiesen	Urban	2	3
Ludwigshafen	LU_Ebertpark	Urban	13	45
Ludwigshafen	LU_Bliesstr	Urban	2	18
Neustadt	NW_Grundschule_Ostschule	Urban	7	15
Obrigheim	DUEW_Obrigheim_Eisbach	Urban	7	24

Offenbach	SUEW_Bruehlgraben	Urban	3	5
Rheingoenheim	LU_Hoher_Weg	Urban	3	3
Roedersheim-Gronau	RP_Roedersheim-Gronau_Hauptstr	Urban	4	33
Speyer	SP_Deutsches_Forschungszentrum	Urban	23	82

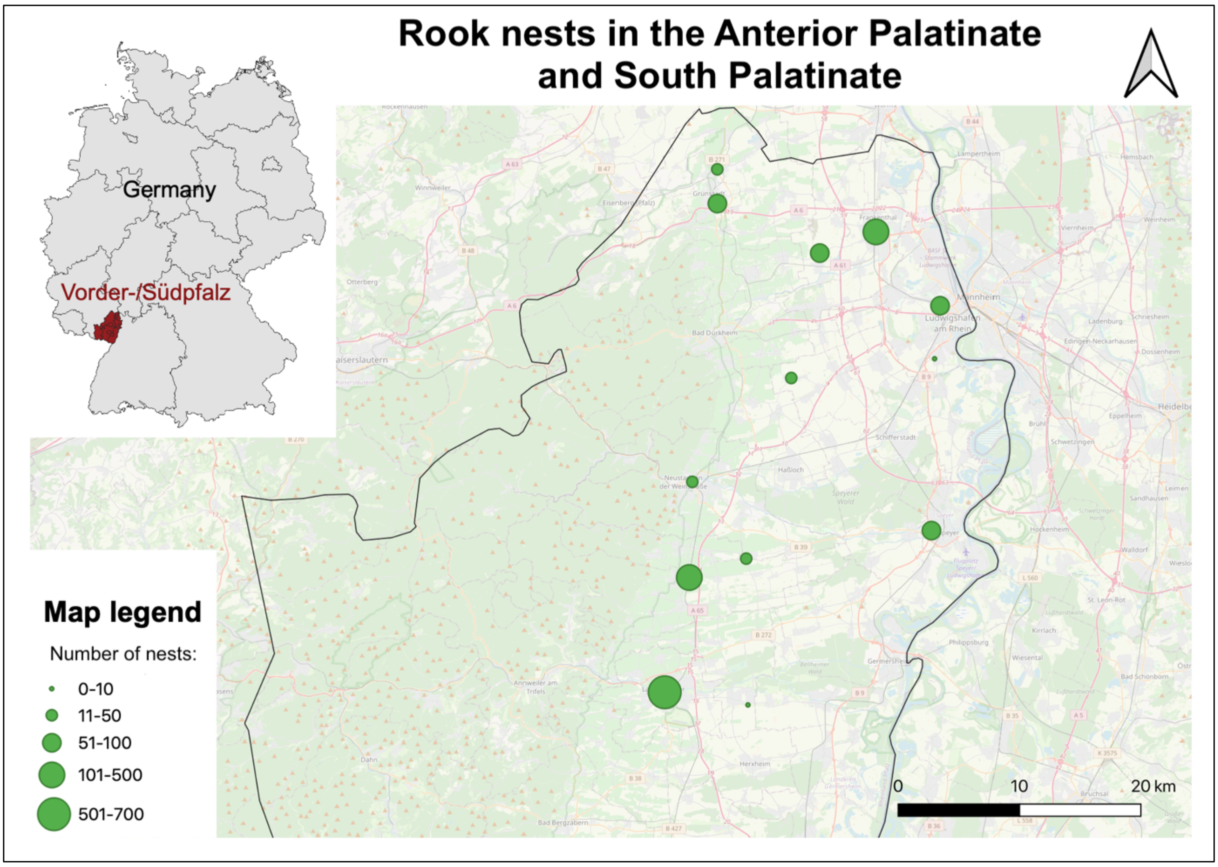

Figure 4: Number of rook nests in the Anterior Palatinate and South Palatinate in the year 2020 (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

Looking at the distribution of breeding trees in the city centre of Landau in detail, it is worthy of notice that 72 trees (411 nests) were located in the urban green spaces of Goethepark, Schillerpark, Schwanenweiher, and Fort and that the majority of breeding trees, also within urban green spaces, were located along traffic axes (Figure 5; Figure 6). Only the breeding trees in the Fort were about 100 m away from the nearest traffic axis (i.e. road, railway track). All other breeding trees were located within a radius of more or less 50 m from the nearest traffic axis.

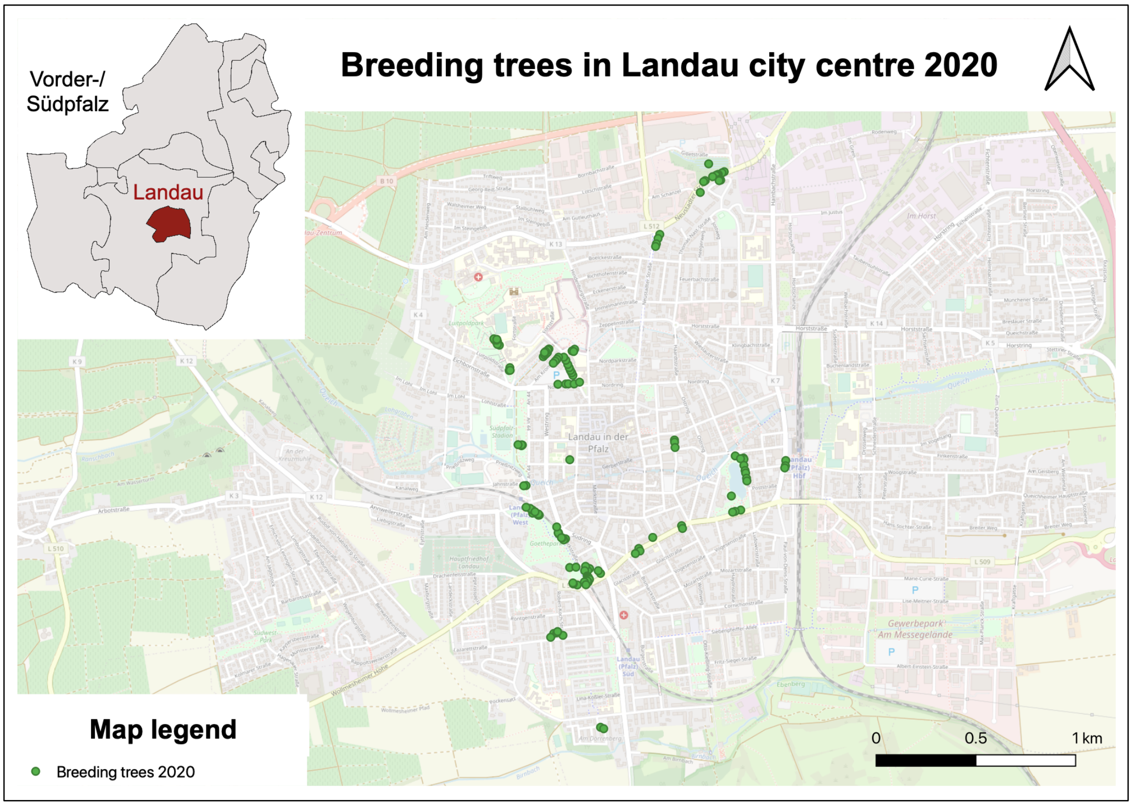

Figure 5: Breeding trees in the city centre of Landau in 2020 (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

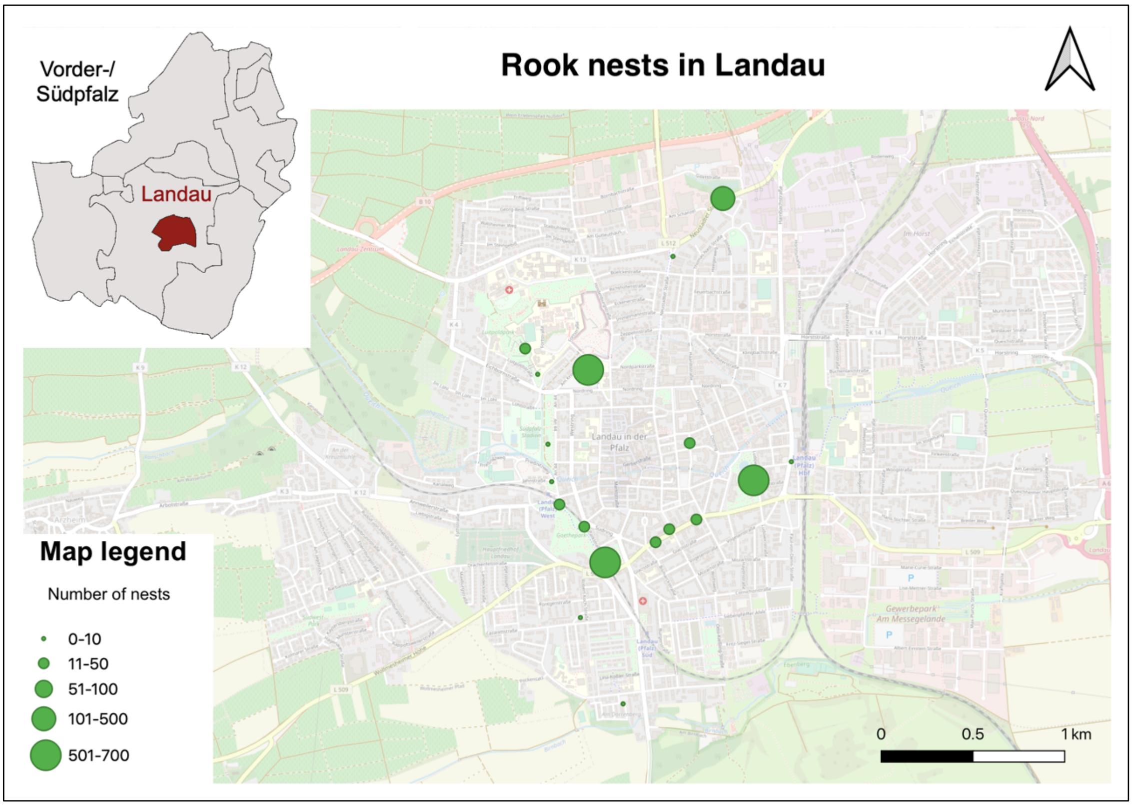

Figure 6: Number of rook nests in Landau in the year 2020 (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

4.2 Characteristics of rook breeding trees

4.2.1 Tree genus distribution

The tree genera distribution of the rooks' breeding trees shows that Platanus was the most common breeding tree in the Anterior and South Palatinate as well as in Landau. That is independent of whether one considers the absolute number of breeding trees (Figure 7a; Figure 8a) or the tree genera per nest (Figure 7b; Figure 8b). In that context, it must be taken into account that - as Landau is a part of the Anterior and South Palatinate - all breeding trees within Landau are also included in the calculation for the Anterior and South Palatinate.

However, the tree genera composition varies between the Anterior and South Palatinate and Landau. In addition to Platanus, Acer and Robinia were the most common tree genera in the Anterior and South Palatinate, whereas within Landau Platanus was followed by Acer, Fraxinus, Tilia, and Quercus. Thus, Acer was the second most common tree genus as well in the Anterior and South Palatinate sub-regions as well as in Landau itself.

But the ratio of tree genera does not only differ between the Anterior and South Palatinate sub-regions and Landau, it also depends on whether the calculation is done per breeding tree or per nest. In this respect, the data show that different tree genera have different numbers of nests. 44% of all breeding trees within Landau were Platanus hosting 69% and thus a large proportion of all nests (Figure 8b). The situation was similar for the Anterior and South Palatinate as a whole, with Platanus accounting for 50% of all breeding trees and hosting 58% of all nests in the study area (Figure 7). Within Landau Quercus also showed that tendency but at a lower level (breeding trees: 3%, nests: 7%). On the other hand, there were also tree genera that seem to have relatively few nests per tree. For example, 24% of all breeding trees in Landau were Acer, but those accounted for only 8% of all nests (Figure 8). Thus, when Acer is used for breeding, few nests appear to be established on a single tree. That was also the case with Fraxinus (breeding trees: 10%, nests: 6%) and Tilia (breeding trees: 8%, nests: 5%) in Landau. Furthermore, within Landau neither Robinia nor Populus and Aesculus were listed, whereas in the mapping of the entire Anterior and South Palatinate they made up a quite considerable proportion of the breeding trees with 12%, 6% and 4%.

For more detailed data on all breeding trees, a table is given in Appendix II.

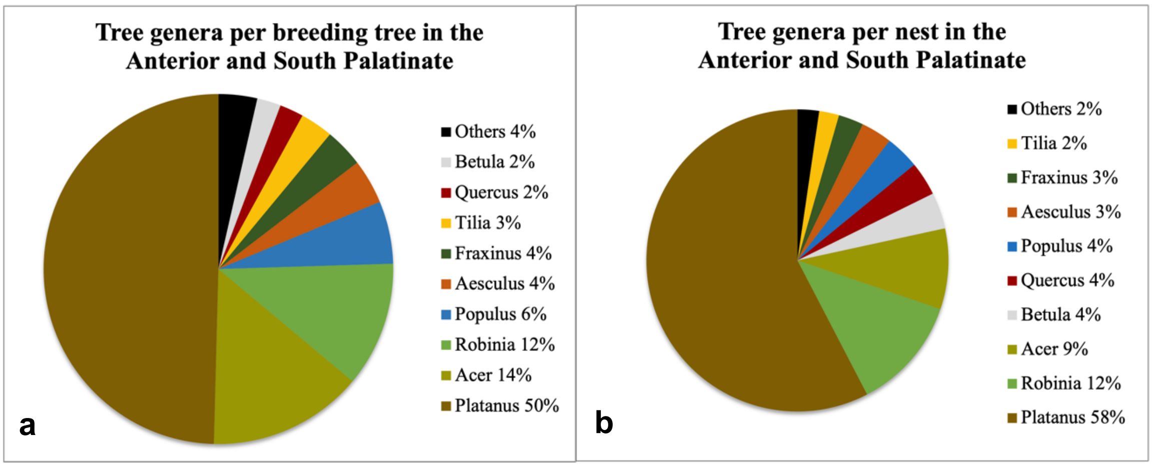

Figure 7: Breeding tree composition by genus of the Anterior and South Palatinate in the year 2020 calculated (a) per breeding tree and (b) per nest

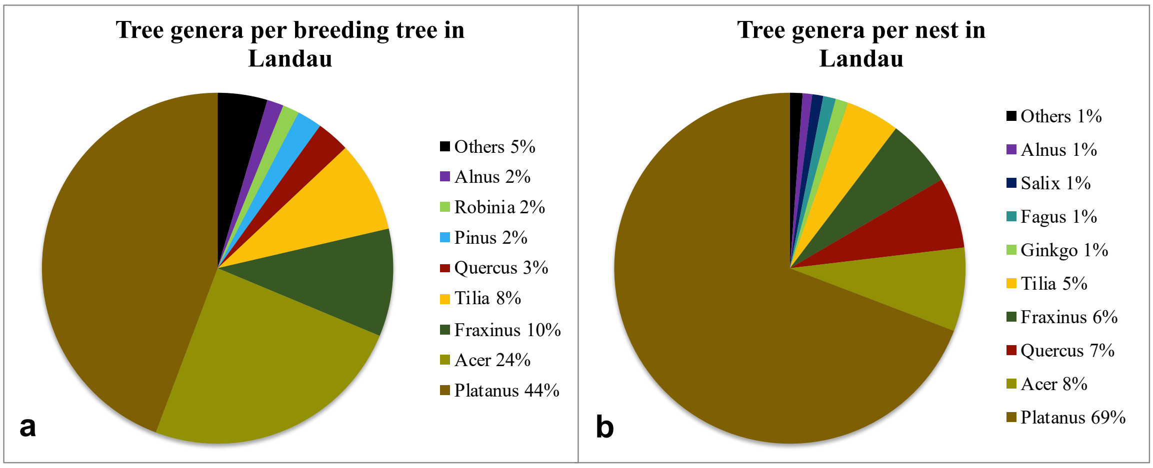

Figure 8: Breeding tree composition by genus of Landau in the year 2020 calculated (a) per breeding tree and (b) per nest

4.2.2 Diameter at breast height and breeding tree height

The DBH and tree height for the breeding trees in Landau according to tree genera is shown in Table 3. The minimum value of the DBH across all tree genera was 20.00 cm, the maximum value was 180.00 cm and the average was 64.52 cm. The minimum tree height of all 13 tree genera used by the rook for breeding in Landau was 10.00 m. The maximum was 28.00 m, while on average the breeding trees were 20.10 m high. However, there were large differences between the individual tree genera. While Betula had an average DBH of 30.00 cm, Fagus had an average DBH of 130.00 cm. And there were also great differences in tree height, with an average height of 18.00 m for Betula and Fagus and an average height of 26.00 m for Quercus.

Table 3: Minimum height, maximum height, average height, minimum DBH, maximum DBH and average DBH of all breeding trees in the city of Landau based on the mapping in 2020

Tree genus	Minimum height in m	Maximum height in m	Average height in m	Minimum DBH in cm	Maximum DBH in cm	Average DBH in cm	Tree number
Acer	10.00	28.00	18.38	20.00	80.00	41.72	32
Betula	18.00	18.00	18.00	30.00	30.00	30.00	1
Fagus	18.00	18.00	18.00	130.00	130.00	130.00	1
Fraxinus	14.00	22.00	17.62	20.00	70.00	38.08	13
Ginkgo	22.00	22.00	22.00	90.00	90.00	90.00	1
Gleditsia	22.00	22.00	22.00	70.00	70.00	70.00	1
Juglans	18.00	18.00	18.00	50.00	50.00	50.00	1
Pinus	22.00	24.00	22.67	60.00	60.00	60.00	3
Platanus	10.00	28.00	18.88	30.00	180.00	74.66	59
Quercus	24.00	28.00	26.00	70.00	130.00	110.00	4
Robinia	18.00	18.00	18.00	40.00	40.00	40.00	2
Salix	21.00	21.00	21.00	40.00	40.00	40.00	1
Tilia	16.00	26.00	20.73	30.00	110.00	64.36	11
All tree genera	10.00	28.00	20.10	20.00	180.00	64.52	130

In this regard, the question that arises is whether tree height and DBH are related to the number of nests.

The absolute numbers of nests indicate that most nests were on trees with a height of 16 to 20 m, while fewer nests were on trees of 10 to 15 m height. Most of the trees selected had a DBH between 41 and 50 cm (Appendix III). In addition, the scatter plot reveals that trees of a greater height hosted more nests (Figure 9a).

In contrast to tree height which has a unimodal distribution in the absolute nest numbers, DBH shows a bimodal distribution with one peak at a DBH of 51 to 60 cm and one peak at 121 to 130 cm. In this context, most trees were selected for breeding by rooks were between 16 and 20 m height (Appendix III). The number of nests increased in line with larger DBH (Figure 9b).

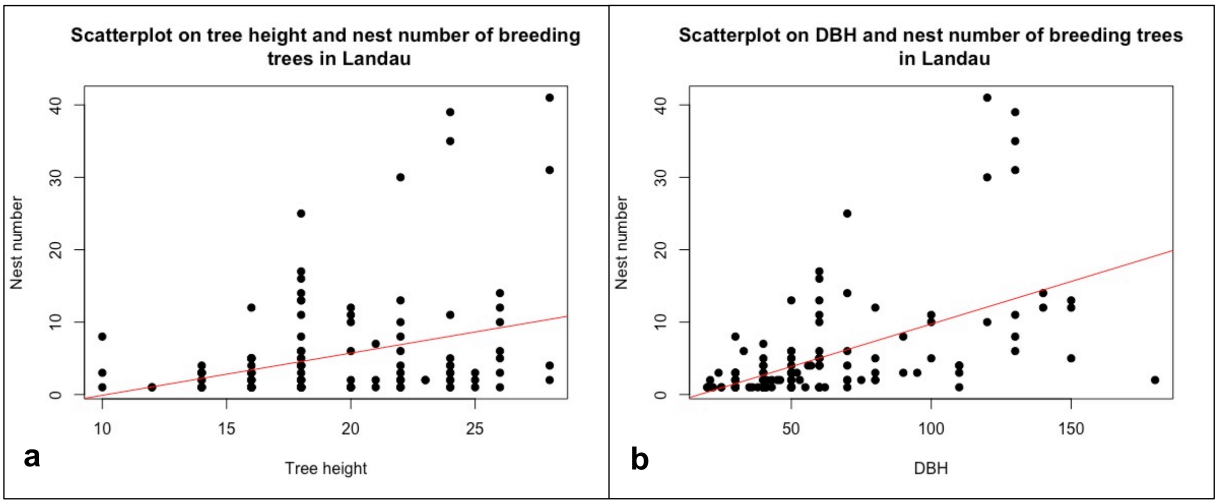

Figure 9: Correlation between (a) tree height and nest number and (b) DBH and nest number of breeding trees within Landau

5 Discussion of the rookery mapping

5.1 Rook colonies in the Anterior and South Palatinate sub-regions and in Landau

It is difficult to make a reliable statement on the population development of rooks within the Anterior and South Palatinate sub-regions based on nest numbers, as mapping is not carried out annually on an all-encompassing basis. Therefore, it can be assumed that the data presented in Table 4 are not complete. Based on the data, an increase in the overall population is likely since the number of nests increased (2010: 473, 2020: 1,600), although there is no substantial increase in the nest numbers from 2013 (1,542) to 2020 (1,600). The number of rural and urban colonies does not seem to have changed greatly over the years. However, nest numbers have decreased considerably in rural areas (2011: 288, 2020: 79) and increased rapidly in urban areas (2011: 321, 2020: 1,521). Why there were fewer nests in rural areas in 2020 (74) remains unclear. It could also be due to an incomplete census of the total population. However, although rural colonies still exist, their share of the total population has declined sharply since 2011 (47.29%) to 2020 (5.19%).

Table 4: Development of the rook population within the Anterior and South Palatinate sub-regions based on data by GNOR (GNOR 2015) and the own mapping in 2020

Year	**Total number of colonies**	**Number of urban colonies**	**Number of rural colonies**	**Number of nests**	**Number of nests in urban colonies**	**Number of nests in rural colonies**	**Percentage of rural colonies in %**	**Source of data**
2010	20	17	3	473	399	74	15.64	(GNOR 2015)
2011	25	18	7	609	321	288	47.29	(GNOR 2015)
2012	24	21	3	722	489	233	32.27	(GNOR 2015)
2013	30	25	5	1,542	1,267	275	17.83	(GNOR 2015)
2020	26	23	3	1,600	1,521	79	5.19	Own mapping

Nevertheless, it remains a matter of definition at what point a colony is to be considered an independent colony and when it is deemed to be an urban or a rural colony, as many breeding trees are often located on the outskirts of cities.

In any case, as presented in Table 5 in two of the three remaining rural colony sites of the formerly 15 (GNOR 2015) different sites used at times in previous years, the number of nests has decreased drastically from 2011, respectively 2012, (Obrigheim: 54, Offenbach: 27) to 2020 (Obrigheim: 30, Offenbach: 6). Only Duttweiler experienced an increase in the number of nests (2011: 36, 2020: 43). However, even there the numbers have dropped from 2013 (52) to 2020 (43). Therefore, the question is where the rooks that left the rural colonies have moved to.

Table 5: Comparison of nest numbers in rural colonies in the Anterior and South Palatinate sub-regions between 2011 and 2020 based on data from GNOR (GNOR 2015) and the own mapping in 2020

Colony	Location	2011	2012	2013	2020
Eisbach	Obrigheim	54	101	79	30
Outdoor swimming pool	Duttweiler	36	33	52	43
Brühlgraben	Offenbach	NA	27	NA	6

If development of the nest numbers at the urban breeding sites within the city of Grünstadt is compared with the nest numbers in the nearby rural colony by the Eisbach creek, which is presented in detail in Appendix IV, it is evident that some rooks previously breeding by the Eisbach might have moved to the city. However, the increase in breeding rooks in the city is much stronger and cannot only be explained by rooks that have moved there. Thus, other factors seem to be important as reasons for the increase in breeding rooks in urban areas.

This phenomenon of decreasing rural rook populations and increasing urban populations can also be seen in Landau and its surrounding villages. While there has been a strong increase in the number of nests within Landau up to 682 nests in 2020 (2011: 29 nests; Figure 10), the number has decreased in the surrounding villages. In 2020 no nests could be found at almost all previously known locations. Rook nests were not found in urban nor in rural areas of the villages within a radius of 5 km around Landau rook nests were found, except for one colony at the Brühlgraben in Offenbach, where six nests were still detected (Table 6).

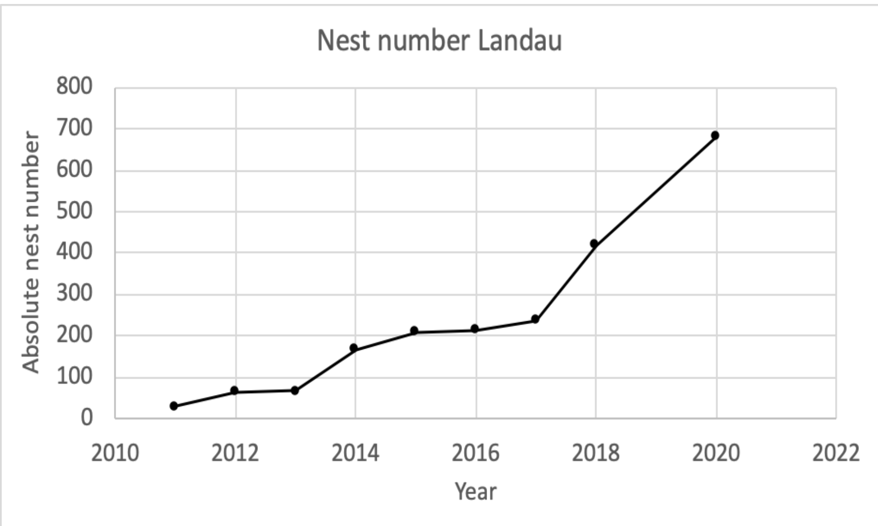

Figure 10: Development of rook nest numbers within Landau based on data by Bannas (Bannas 2018) and the own mapping in 2020

Table 6: Development of nest numbers in the villages around Landau from the year 2010 to 2020 based on data by GNOR (GNOR 2015) and own mapping in 2020

Location	2010	2011	2012	2013	2018	2020
Nußdorf	NA	NA	NA	66	12	0
Hochstadt	NA	NA	NA	5	NA	0
Dammheim	14	37	21	NA	NA	0
Offenbach	NA	NA	27	NA	2	6
Insheim	NA	NA	NA	53	NA	0
Wollmesheim	NA	NA	NA	NA	9	0
Queichheim	NA	10	NA	14	2	0

For Landau, just like for Grünstadt, it is still unclear where the additional rooks breeding in the city come from. One reason for the increase in urban breeding pairs might be rooks moving in from the surrounding rural areas. However, the increase of 653 nests in Landau from the year 2011 to 2020 is considerably larger than the number of all breeding pairs mapped since 2010 (less than 100) in the surrounding villages that belong to the urban area of Landau (GNOR 2015), which were no longer occupied in 2020 (Table 6). Thus, the increase in the urban rook population in Landau cannot be explained only by the decline of rural colonies. The natural population increase within the colonies would also have to be taken into account. As considering that aspect would go beyond the scope of this paper, it will not be discussed further.

The decline of rural colonies and the increase of colonies within cities were also observed in parts of Baden-Württemberg (Andris and Westermann 2011). As already mentioned in the theoretical background, in the mid-1980s rooks in that area began to breed within cities for the first time and in 2010 95% of all rooks were already breeding in towns with more than 5,000 inhabitants (Andris and Westermann 2011). It is also known that in the 19th and 20th centuries rooks bred mainly in rural areas in Rhineland-Palatinate (Dietzen and Simon 2017). Exactly as in Baden-Württemberg in 2010, 95% of all known rook nests in the Anterior and South Palatinate sub-regions in 2020 were located in urban areas (overall: 1,600; urban: 1,521; rural: 79). Thus, the proportion of rooks breeding in cities has increased greatly within the study area just as was demonstrated for various other regions in Germany (Bayerisches Landesamt für Umwelt 2011; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015).

Preference of rooks for breeding within cities

The question is, why rooks nowadays prefer cities instead of rural colony sites. There are several approaches to explaining this.

First of all, it is assumed that rooks have moved to cities to an increasing extent mainly due to (illegal) repellent measures in rural areas (Bayerisches Landesamt für Umwelt 2011; L.U.P.O. 2016; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015). However, Andris and Westermann (2011) contradict the hypothesis by arguing that many rural colony sites have slowly disappeared without visible disturbances. And even small disturbances result in colonies moving to cities instead of breeding in the surrounding rural landscape at suitable alternative sites. But if rural areas were clearly better suited as breeding habitats than urban areas, small disturbances would not be sufficient to displace rooks from rural areas and into cities. Moreover, for the most part there are mostly no efforts by rooks to colonise new sites in the rural landscape in general.

This argumentation leads to the antithesis by Andris and Westermann (2011) and the second explanatory approach, which is the greater pressure from predators in the countryside. This idea is supported by the fact that the natural predators of the rook, such as the northern goshawk (*Accipiter gentilis*), peregrine falcon (*Falco peregrinus*), eagle owl (*Bubo bubo*) and marten (*Mustelidae spp.*) are much more common in the countryside today than they used to be in former times (Andris and Westermann 2011), because the northern goshawk for example was hunted intensively in the past (NABU and LBV 2014). In cities, on the other hand, both the rook's offspring and the adult birds are quite safe from their natural enemies (Andris and Westermann 2011; L.U.P.O. 2016). However, the peregrine falcon is known to breed on buildings (Svensson 2017) and there are numerous reports from German cities of peregrine falcons breeding (e.g. Landeshauptstadt Dresden 2020; Stadt Gütersloh n.d.; Stadt Landshut n.d.; Stadt Mannheim n.d.; Stadtverwaltung Worms 2020), as well as of northern goshawks breeding in urban areas (NABU and LBV 2014) such as in Berlin (NABU 2009) or in Hamburg (NABU n.d.a). Nevertheless, the predator pressure for rooks within cities could be lower than in rural areas. However, that needs to be analysed further in particular for the study area in order to draw conclusions on the impact of predators on rook population development in Landau.

The third explanatory approach given in literature is a better food availability within cities for birds in general (Allatson and Connor 2020; Ciach and Fröhlich 2017; Rodewald and Kearns 2011; Tryjanowski et al. 2015). For rooks in Poland it has been verified that they move to the cities due to the food supply, as their natural food habitats in the rural environment have been destroyed (Jadczyk and Drzeniecka-Osiadacz 2013). However, since the rooks in Landau seem to search for food primarily in the surrounding fields and vineyards, based on food availability it seems questionable why they do not breed in those rural areas. Nevertheless, for a clear conclusion the foraging behaviour of the rooks in Landau would have to be investigated specifically, i.e. investigating the proportion of food that rooks find within cities. Food availability can also be related to microclimate as shown in a study by Rytkönen et al. (1993). This study observed that rooks in Finland find more food in warmer cities during frost, as the ground is less frozen there (Rytkönen et al. 1993). However, as frost is rare in the Anterior and South Palatinate sub-regions during the rooks' breeding season, that reason can be disregarded. The fourth explanation is a warmer microclimate due to the urban heat island (UHI) effect (Kalnay and Cai 2003; Santamouris 2013), as there are studies showing that the warmer microclimate within cities might be a reason for birds in general to breed there (Jadczyk and Drzeniecka-Osiadacz 2013; Partecke et al. 2004). As temperature is one of the main points of Part II of this thesis it is not discussed further in this chapter, just like artificial light, the fifth approach, which is also known to affect the behaviour of some bird species (Byrkjedal et al. 2012; Ciach and Fröhlich 2017; Dominoni et al. 2020).

Distribution within Landau

However, there has not only been a change in the distribution of urban colonies, but also within Landau a change in colony sites can be observed over the years (Figure 11). In 2020 all breeding trees within Landau were located to the west of the railway tracks running on a north-south axis. All breeding trees used in recent years to the east of the railway tracks were no longer occupied. Nevertheless, most of the colonies located in the western part that were used previously were still occupied in 2020, e.g. Goethepark and Schwanenweiher, while some colonies, e.g. Pestalozzischule, were not used as breeding sites in 2020. Thus, not all breeding sites within Landau seem to be used regularly, and breeding sites change over the years. The question is why the rooks no longer bred at certain sites in 2020.

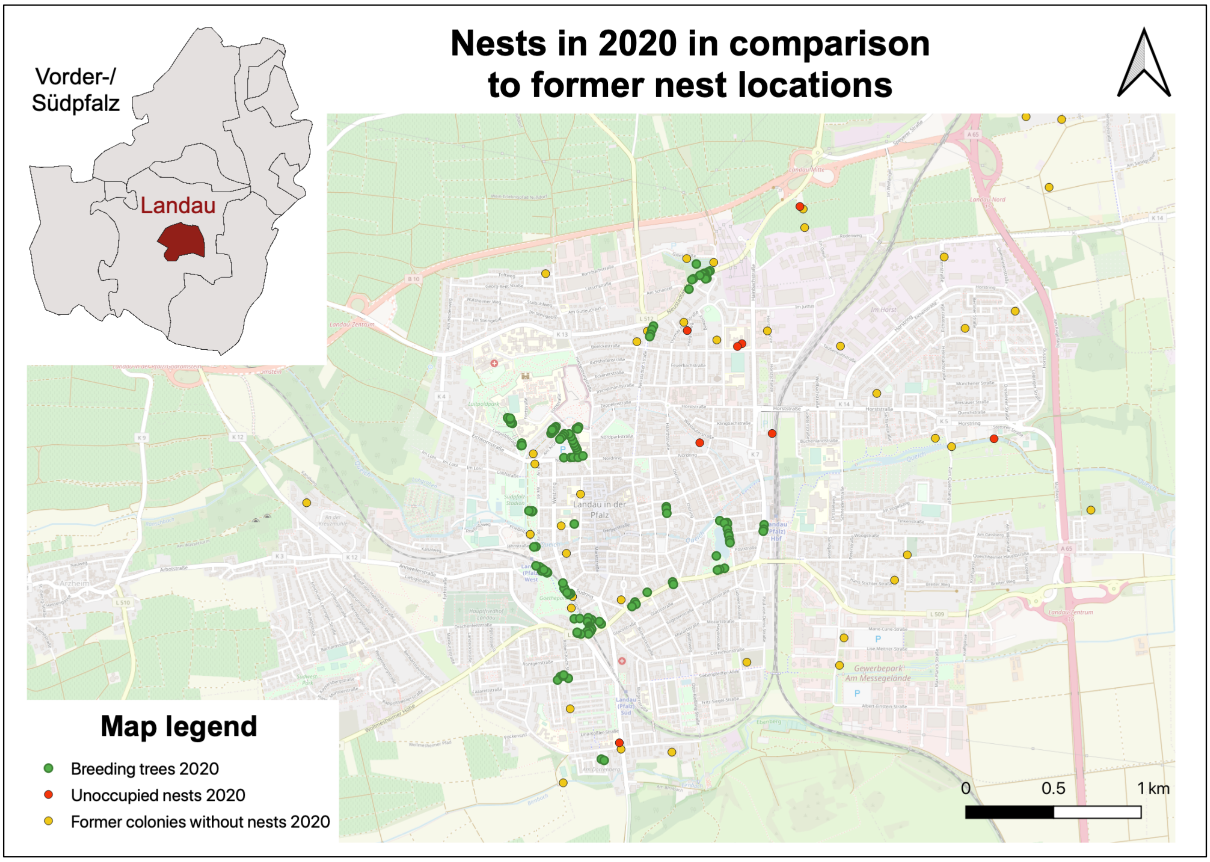

Figure 11: Breeding trees in 2020 (green, own data) in comparison to unoccupied nests (red) and formerly occupied (yellow) colonies (GNOR 2015; Mittelmeier and Marini 2018) within Landau (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

Success of repellent measures

Repellent measures may possibly be responsible for this development. A closer look at Bannas' (2018) data and the four hotspots (Pestalozzischule, Otto-Hahn-Gymnasium, Ostpark, Goethepark) within the city of Landau helps to verify this. Figure 12 shows that the rooks nearly completely disappeared from the school areas in 2020 (Pestalozzischule: 0, Otto-Hahn-Gymnasium: 2) due to repellent measures (Klöppel 2020), whereas the number of nests in the parks increased even further (Ostpark: 168, Goethepark: 155).

Since the nest numbers at Pestalozzischule and Otto-Hahn-Gymnasium dropped considerably from 2018 (Pestalozzischule: 60, Otto-Hahn-Gymnasium: 110) to 2020 (Pestalozzischule: 0, Otto-Hahn-Gymnasium: 2), the question is whether any repellent measures were implemented. According to the data of the SGD Süd (Appendix V) the crowns of the trees at Pestalozzischule and Otto-Hahn-Gymnasium were cut back in 2019, and that measure was already taken in 2014 at Pestalozzischule only (Klöppel 2020).

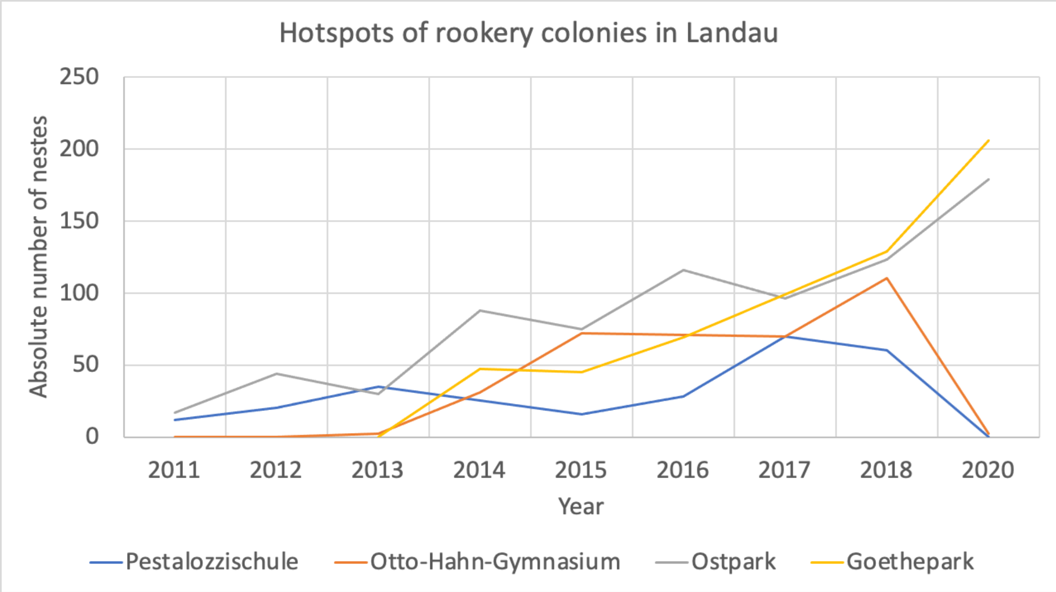

Figure 12: Development of the nest number at the four breeding hotspots of rooks in Landau based on data by Bannas (2018) and the own mapping in 2020

The tree cutting seems to have already been successful in 2014, as the nest numbers at Pestalozzischule already dropped at that time (2013: 35, 2015: 16). However, the nest numbers of Otto-Hahn-Gymnasium increased (2013: 2, 2015: 72), which could be because the rooks that previously nested at Pestalozzischule switched to the trees at Otto-Hahn-Gymnasium. In any case, the tree-cutting seems to have been successful for Pestalozzischule back in 2014.

However, from other locations it is known that tree-cutting leads to a successful short-term displacement of rooks, but in the long term, repopulation usually occurs (L.U.P.O. 2016; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Roth 2011) or it may also cause a splitting of colonies (Andris and Westermann 2011; Fünfstück and Rudolph 2011; Gschweng 2016; Sepp and Dufner 2020; Stabsstelle Umwelt Lahr 2010).

Repopulation also seems to have occurred at Pestalozzischule, as nest numbers increased sharply at both schools by 2018 (Pestalozzischule: 60, Otto-Hahn-Gymnasium: 110). However, since only two nests were found at Otto-Hahn-Gymnasium in 2020, the tree-cutting in 2019 seems to have been successful again, at least in the short-term. Whether repopulation will occur in subsequent years remains to be seen.

If a splitting of colonies due to repellent measures has taken place at those schools or at other places in Landau cannot be clearly determined either, as the general increase in the number of rooks led to new colonisation anyway. Therefore, the development of all sites must be monitored in the coming years to draw conclusions on this issue.

However, the number of nests in Goethepark and Ostpark has increased. Furthermore, in his elaboration Bannas (2018) recommended Alter Meßplatz as an alternative habitat to Pestalozzischule and Otto-Hahn-Gymnasium, which are approximately 200 m respectively 400 m south of Alter Meßplatz. However, no old nest numbers are available for Alter Meßplatz. Bannas (2018) only wrote about small colonies there. As there were 113 nests in 2020, it can be assumed that there has been an increase in colony size there as well. Therefore, it is possible that the rooks which were repelled from the schools have nested there. However, that assumption cannot be confirmed beyond any doubt, as the total numbers of breeding rooks in Landau have also increased. Thus, in addition to rooks repelled from the schools, birds might have moved in from outside the city or a natural increase in population could have caused the increase in the nest numbers in the parks.

Consequently, Landau has breeding sites that are stable over many years (e.g. Goethepark) and sites that are not stable, either due to repellent measures (e.g. Otto-Hahn-Gymnasium) or due to unknown causes (former colonies east of the railway tracks).

Rooks along traffic axes

In the distribution of breeding trees in Landau, it is striking that most of the breeding trees were located directly along highly frequented roads, such as Marienring, Neustädter Straße or at the parking spot Alter Meßplatz. When rooks were breeding within parks, there were almost no breeding trees in the centre of parks, but the trees were almost always located along roads or railway tracks on the edges of parks (Goethepark, Schwanenweiher). In Goethepark, for example, large Platanus trees in the park interior, which should be perfectly suitable as breeding trees based on tree genus, tree height and DBH, were not used as such. Instead, the rooks built nests on relatively young trees of Acer, Fraxinus and Robinia which are located in a wooded strip at the edge of the park along a railway track and not expected to be preferred by rooks for breeding.

Similar to the results in Landau, a study by Cooke et al. (2020) showed that rooks increase slightly in abundance near roads in Great Britain in contrast to most other bird species.

Studies on the effect of roads on other bird species most often investigated the threats arising from roads, which can be habitat loss associated with fragmentation (Benítez-López et al. 2010; Betts et al. 2006; Kociolek et al. 2011; Miller et al. 2018), collision with vehicles (Ascensão and Mira 2005; Benítez-López et al. 2010; Clevenger et al. 2003; Erritzoe et al. 2003; Kociolek et al. 2011), noise (Benítez-López et al. 2010; Forman and Deblinger 2000; Halfwerk et al. 2011; Kociolek et al. 2011; McClure et al. 2017; Peris and Pescador 2004; Reijnen and Foppen

1995; Rheindt 2003), artificial light (Amichai and Kronfeld-Schor 2019; Benítez-López et al. 2010; Ciach and Fröhlich 2017; Da Silva et al. 2015; Kempenaers et al. 2010; Kociolek et al. 2011; Nordt et al. 2013) and chemical pollution (Benítez-López et al. 2010; Getz et al. 1977; Grue et al. 1986; Kociolek et al. 2011).

However, as Morelli et al. (2014) pointed out in their review, there are also several positive effects of roads on birds, which are similar to the reasons for birds to move to urban areas presented above: the provision of food sources (Dean and Milton 2009; Lambertucci et al. 2009; Laursen 1981; Morelli 2013; Yamac and Kirazli 2012), reduced predator pressure (Silva et al. 2019; Yamac and Kirazli 2012; Zhou et al. 2020), warmer microclimate (Whitford 1985; Yosef 2009), the provision of nesting habitat along roads (Li et al. 2010; Morelli 2013) and prolonged diurnal activity due to street lights enabling more hours of foraging especially in the dark Scandinavian winter in Norway (Byrkjedal et al. 2012).

However, most of those studies examined roads and traffic axes in the open countryside or forests and not within cities, which would be more comparable to the rooks breeding along traffic axes in the urban area of Landau.

The studies by Zhou et al. (2020) and Kövér et al. (2015) showed that some birds prefer breeding along streets within cities. In the case of Scaly-breasted munia (*Lonchura punctulata*) an explanation for this is reduced enemy pressure (Zhou et al. 2020) and in the case of hooded crows (*Corvus corone cornix L.*) it is that the rows of trees along roads are similar to their natural habitat in the open countryside (Kövér et al. 2015). As rooks in rural areas also tend to breed in trees and forest strips along open agricultural land (Eislöffel 1995), that might be an explanation for rooks as well.

Thus, the phenomenon that birds prefer breeding along roads in cities does not only exist in Landau but is also described in the literature for various bird species. However, the causes for that are often only speculation and mostly remain unclear. Moreover, as there are differences in the effect of parameters connected to roads (e.g. artificial light) on different bird species, the reasons for breeding along roads within cities have to be investigated in particular for rooks in order to better understand the breeding tree selection of the rook within cities. That is done in Part II of this thesis.

5.2 Characteristics of breeding trees

Tree genera of breeding trees

As described in the theoretical background, rooks prefer Platanus and Populus as breeding trees (Andris 1996; Dietzen and Simon 2017; Eislöffel 1995; Olea 2009), since those genera are sufficiently large, have suitable ramifications (Bayerisches Landesamt für Umwelt 2011) and sprout late (Dietzen and Simon 2017; Eislöffel 1995). In line with the current literature, Platanus as one of the preferred breeding trees of rooks can be confirmed for the Anterior and South Palatinate sub-regions and for Landau. Populus, however, was not mapped as a breeding tree with above-average frequency in 2020. In the Anterior and South Palatinate only 6% of all breeding trees were Populus while no breeding tree of Populus was found within Landau. This low proportion of Populus among the breeding trees of the rook is remarkable, as earlier data from Dietzen and Simon (2017) for Rhineland-Palatinate showed that Populus accounted for a proportion of 44% (Figure 13). However, as the Anterior and South Palatinate is only a part of Rhineland-Palatinate, it must be taken into account that differences in tree genera composition between data from Dietzen and Simon (2017) and the author's own mapping in 2020 might also result from the different investigation areas.

Nevertheless, one possible explanation for the differences is the decline in nest numbers in rural areas. In the study area of this thesis many rural colonies, regardless of whether there were nests there in 2020 or not, are dominated by Populus, while inner-city locations or locations in cemeteries are often dominated by Platanus, which is in line with Olea's (2009) study area in Spain. As the data on breeding tree genera by Dietzen and Simon (2017) can be compared on a time scale with the breeding tree genera identified in this thesis, it can be assumed that the decline in Populus as a breeding tree is related to the decline of rural colonies and the increase in urban colonies. That assumption is supported by the fact that Populus dominated rural colonies in the Anterior and South Palatinate sub-regions in the previous years (GNOR 2015) and that the three rural colonies (Brühlgraben, Duttweiler, Obrigheim) mapped in 2020 consist of Populus only (Figure 14b). Moreover, at 2% the share of Populus in all tree genera within the urban area of Landau (only the trees within the city of Landau are taken into account without the rural catchment area and the villages belonging to the municipality of Landau) was comparatively low, thus supporting the assumption that Populus is the dominating tree genus in rural areas (Figure 15).

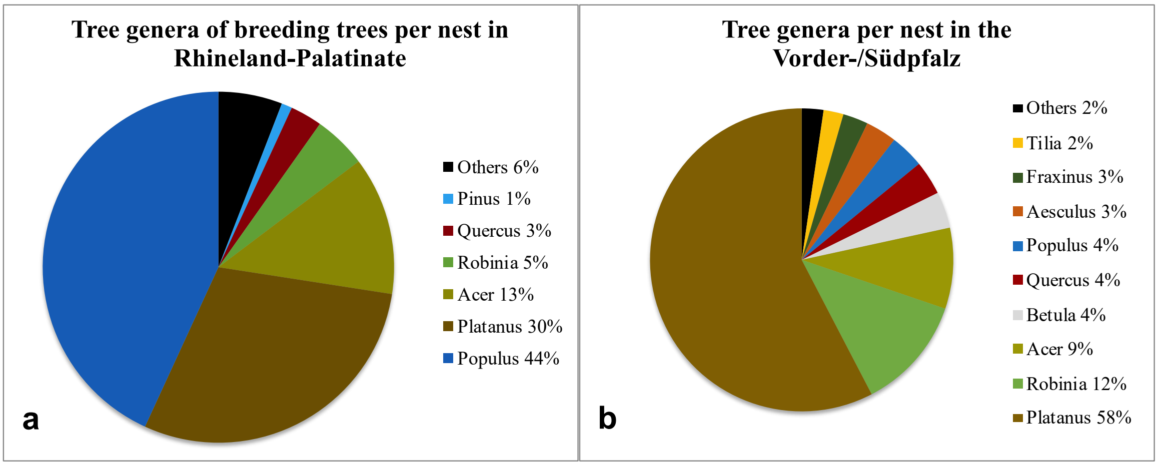

Figure 13: Tree genus distribution per nest for Rhineland-Palatinate (adapted by Dietzen and Simon Dietzen and Simon 2017) and the tree genus of the Anterior and South Palatinate sub-regions in 2020)

While the rural colonies in the Anterior and South Palatinate sub-regions consisted of 100% Populus (Figure 14b), the distribution of breeding trees in cities was dominated by Platanus, with a proportion of 44%, followed by a large number of other tree genera (Figure 14a). The fact that cities are home to a wide variety of tree genera, which is confirmed by the tree cadastre (Stadtverwaltung Landau in der Pfalz 2020), could explain that (Figure 15). Nevertheless, even in rural areas there are tree genera other than Populus (Stadtverwaltung Landau in der Pfalz 2020).

Comparing the tree genera distribution of breeding trees within Landau with the data of the tree cadastre (Figure 15), it becomes obvious that only 3% of all trees in the urban area of Landau are Platanus (Stadtverwaltung Landau in der Pfalz 2020), but 69% of all rook nests within Landau were located on Platanus (Figure 8b). Moreover, according to the tree cadastre (Stadtverwaltung Landau in der Pfalz 2020), with almost a quarter of all trees within Landau (Figure 15) Acer accounts for a larger share of all tree genera compared to other tree genera such as Fraxinus or Tilia. That could be the reason why Acer was used comparatively often as a breeding tree in Landau (Figure 8a).

Thus, the presence of a tree genus in large numbers seems to be a reason why that tree genus, e.g. Acer, is often used as a breeding tree. Nevertheless, some tree genera, e.g. Platanus, seem to be specifically selected by rooks as breeding trees, although they occur in lower numbers than other tree genera.

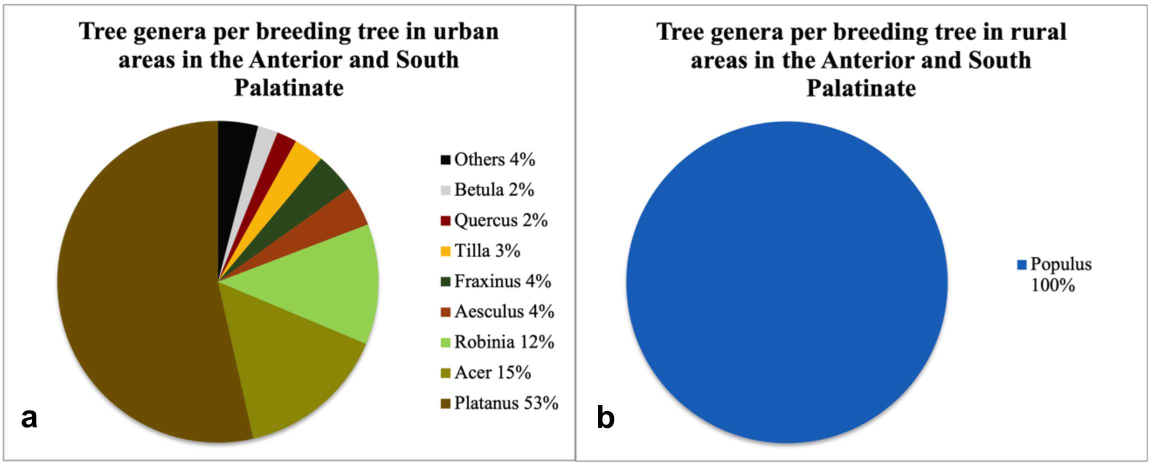

Figure 14: Tree genera per breeding tree for (a) urban areas and (b) rural areas (Brühlgraben, Duttweiler, Obrigheim) in the Anterior and South Palatinate sub-regions based on the mapping in 2020)

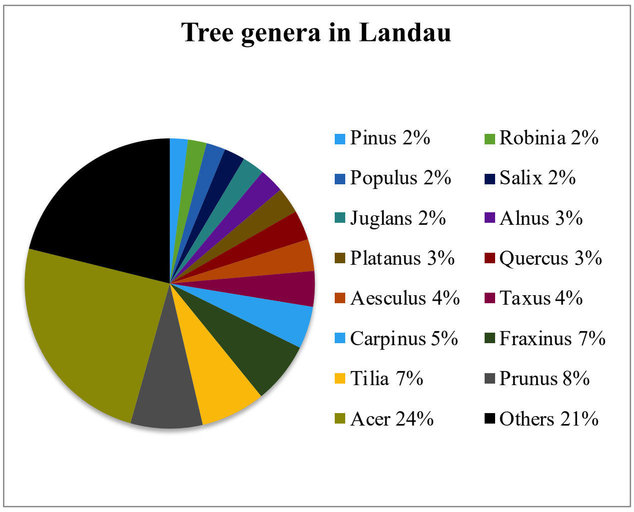

Figure 15: Tree genera distribution in Landau based on the tree cadastre (Stadtverwaltung Landau in der Pfalz 2020), while only the trees within the city of Landau are taken into account without the rural catchment area and the villages belonging to the municipality of Landau

In the literature, the rook's preference for certain tree genera is explained on the one hand by better conditions for nest-building in terms of easily breaking branches (Dietzen and Simon 2017), and on the other hand by better protection from predators, ensured by late sprouting tree genera (Dietzen and Simon 2017; Eislöffel 1995). Nevertheless, within Landau rooks occasionally used trees of genera other than Platanus and Populus, although trees of those preferred genera that were not used for breeding were available close to trees of other genera used for breeding. Hence, assumed advantages of Platanus and Populus, such as better protection from enemies due to late sprouting trees, no longer seem to be decisive in breeding tree selection at these sites. That might be because there is a lower enemy pressure in cities in general (Andris and Westermann 2011) or because factors other than selection of certain tree genera reduce enemy pressure better or otherwise increase breeding success.

DBH and tree height

An additional question is whether not only the tree genus but also the DBH and height of trees are important factors for the breeding tree selection of the rook. Even though there were large variations in minimum (Δ_{minDBH} = 110.00 cm, $\Delta_{minheight}$ = 14.00 m), maximum (Δ_{maxDBH} = 140.00 cm, $\Delta_{maxheight}$ = 10.00 m) and mean ($\Delta_{meanDBH}$ = 140.00 cm, $\Delta_{meanheight}$ = 8.38 m) DBH and tree height between the tree genera within Landau, for the most part the samples of the individual tree genera were too small to make tree genera-specific statements. Nevertheless, minimum values can be determined for all tree genera overall with 20.00 cm DBH and 10.00 m tree height.

However, in terms of both DBH and tree height, rooks used a wide range for breeding with regard to all tree genera overall. In this context, trees with a DBH of 21 to 60 cm and a height of 16 to 20 m accounted for the largest proportion of breeding trees. That seems to be partly related to the availability of trees of this size within Landau. Only 10% of all trees in Landau have a DBH greater than 60 cm, with 39.31% of all trees having a DBH of less than 21 cm (Stadtverwaltung Landau in der Pfalz 2020). A similar situation can be observed for tree height. While only about 5% of all trees are taller than 20 m, almost 85% are smaller than 16 m (Stadtverwaltung Landau in der Pfalz 2020). Thus, availability can explain why fewer trees with greater DBH and height are used. On the other hand, the fact that trees with a small DBH and low tree height are used less often does not necessarily seem to be because of availability. Thus, it can be assumed that trees must have a certain minimum DBH and height to be suitable as breeding trees.

Even though most tree genera (e.g. Fagus, Quercus) were only represented by a few individuals among the breeding trees in Landau, Platanus and Acer with 59 and 32 individuals respectively showed that there seem to be differences in DBH and tree height among breeding trees of different tree genera. The DBH of breeding trees of Platanus (DBH_{minPb} = 30.00 cm, DBH_{meanPb} = 74.66 cm) and Acer (DBH_{minAb} = 20.00 cm, DBH_{meanAb} = 41.72 cm) differ greatly, but Platanus ($height_{minPb}$ = 10.00 m, $height_{meanPb}$ = 18.88 m) and Acer ($height_{minAb}$ = 10.00 m, $height_{meanAb}$ = 18.38 m) are quite similar in tree height. According to the tree cadastre (Stadtverwaltung Landau in der Pfalz 2020) Platanus (DBH_{meanPc} = 47.02 cm) in Landau generally have a larger DBH than Acer (DBH_{meanAc} = 33.34 cm). Nevertheless, the difference in DBH between breeding trees of Platanus and Acer (Δ_{DBHb} = 32.94 cm) was greater than between both genera in general in Landau (Δ_{DBHc} = 13.68 cm). Consequently, rooks seem to prefer a larger DBH for Platanus while they already use Acer that have a smaller DBH as

breeding trees. Thus, with the help of a larger sample of breeding trees of the individual tree genera, genus-specific thresholds of DBH and tree height could be developed.
One possible explanation for the different suitability of various DBH and tree heights may be that rooks breed in colonies and thus there have to be many branch ramifications suitable for nesting at one site. Since the data of this thesis show that trees with larger DBH and greater height host more nests, it can be assumed that those trees have more suitable branch ramifications. Thus, rooks might either prefer trees with a smaller DBH and thus fewer ramifications situated very close to each other (e.g. Goethepark along the railway track) or trees with a particularly large DBH (e.g. Schwanenweiher) which can host lots of nests at once.
Two explanations can be assumed for a difference in DBH and tree height of breeding trees between different genera. First, the crown structure may vary between different genera and thus the number of suitable branch ramifications might differ. In addition, it might be due to the distribution of tree genera within the city, i.e. the fact that Platanus are often planted as single specimens or at a greater distance from one another, e.g. on parking areas, while Acer often grow close to each other in small forest strips (Stadtverwaltung Landau in der Pfalz 2020). Thus, Acer of small size might provide more suitable branch ramifications in a given area than Platanus of the same size, as they are further apart from each other. However, these are only assumptions that should be investigated further.
The fact that DBH is also connected with breeding tree decision in other bird species is verified by a study on the scaly-breasted munia which showed that its breeding trees, which are also often located along roads, have a larger DBH than non-breeding trees (Zhou et al. 2020).

Consequently, rooks prefer some tree genera as breeding trees (Platanus), while others seem to be increasingly used for breeding due to their great availability within Landau (Acer). Moreover, trees seem to need a certain tree height and DBH to be suitable as breeding trees for rooks whereby the thresholds might depend on the tree genus. Based on the breeding trees in Landau, the minimum for tree height is 10.00 m and for DBH it is 20.00 cm of all tree genera together. However, as there seem to be differences between the genera, in order to determine reasonable thresholds each tree genus should be defined separately, whereby a larger sample is needed for each tree genus. Thus, further research is needed in this regard.

6 Intermediate Conclusion

In accordance with existing literature, a decline in rural colonies and an increase in urban colonies of the rook can be observed in the Anterior and South Palatinate sub-regions as well as in Landau. With 682 nests in Landau in 2020, the number has increased by 263 nests within the last two years (2018: 419), which is an increase of 62%. However, further research is needed to determine the reasons for this increase, as rooks moving in from the abandoned rural colonies cannot be the only reason. Due to the growing number of rooks in Landau, the conflict between humans and rooks within the city is increasing and, therefore, repellent measures have already been implemented in some places. At Pestalozzischule and Otto-Hahn-Gymnasium tree-pruning was successful, at least in the short-term. It remains to be seen whether it will be effective in the long-term.

Moreover, this thesis confirms that tree genus is important for the rooks' breeding tree selection, as rooks prefer Platanus in particular. The preference for Populus mentioned in literature could not be proven for the overall study area, which is assumed to be due to the decline of rural colonies as all rural colonies in 2020 were dominated by Populus. In addition to the tree genus, breeding tree selection and the nest numbers on individual trees depend on DBH and tree height, as trees below a DBH of 20.00 cm and a height of 10.00 m are not used as breeding trees within Landau. Thereby, it seems reasonable that breeding tree selection is based on crown condition and number of suitable branch ramifications, which might correlate with DBH and tree height. On the one hand this investigation shows strong preference of rooks for Platanus; on the other hand it shows that in some cases other factors seem to be more important than the tree genus. Thus, planting Platanus at sites chosen as alternative breeding sites for rooks by urban planning and removing Platanus at sites where rooks should not breed might not be a successful solution overall. Therefore, additional factors determining the breeding tree selection of rooks have to be identified in order to heighten the probability of selected and prepared alternative sites being accepted by rooks. In this context, Part II of this thesis is a first step. During the mapping of breeding trees in Landau, it was evident that many breeding trees were located along roads or railway tracks, which has already been noted in other cities (Bitz 1990). For this reason, factors that might influence the breeding tree selection of rooks along traffic routes were explored. That led to the idea of investigating whether temperature, artificial light and noise are important in breeding tree selection within Landau, the results of which are presented in Part II of this thesis.

Part II - Influence of temperature, artificial light at night (ALAN) and noise on breeding tree selection

In Part II of this thesis, the influence of temperature, artificial light at night (ALAN) and noise on the breeding tree selection of rooks is investigated. An influence of those three factors on breeding tree selection can be assumed based on the mapping of the nests described in Part I, since many of the breeding trees are located along traffic routes.

7 Theoretical background of the effect of temperature, ALAN and noise on breeding site selection

In general, birds choose breeding sites where they expect to have the greatest breeding success. In this context, breeding success is a trade-off of a variety of factors, such as breeding tree species (Dietzen and Simon 2017; Eislöffel 1995; Olea 2009), food supply (Czarnecka and Kitowski 2013; Gloutney and Clark 1997; Welbers et al. 2017), predator pressure (Andris and Westermann 2011; Dietzen and Simon 2017; Silva et al. 2019; Yamac and Kirazli 2012), interspecific (Halfwerk et al. 2016) and intraspecific (Olea 2009) competition, but also of temperature (Carroll et al. 2015; Carroll et al. 2018; Hovick et al. 2014; Kulaszewicz and Jakubas 2018; Lloyd and Martin 2004), ALAN (Hennigar et al. 2019; Jong et al. 2015; Molenaar et al. 2006; Russ et al. 2017) and noise (Bayne et al. 2008; Halfwerk et al. 2016; Hennigar et al. 2019; Liu et al. 2020; Peris and Pescador 2004).

Thus, the influence of temperature, ALAN and noise on breeding behaviour and breeding success has already been investigated for various bird species. Observations were made in the natural habitat, often determining the abundance of bird species and individuals (e.g. Ciach and Fröhlich 2017; Peris and Pescador 2004). But since numerous other factors can also influence the abundance of birds (Hennigar et al. 2019), such as the risk of collision with cars (Benítez-López et al. 2010; Erritzoe et al. 2003) or interspecific competition (Halfwerk et al. 2016), such studies are always associated with a certain degree of uncertainty in the interpretation of the results. Accordingly, experimental studies in which individual birds are deliberately exposed to noise, for example, can help to investigate the effect of only one factor (e.g. Halfwerk et al. 2016; Liu et al. 2020; McClure et al. 2017).

7.1 Temperature

Temperature can affect the development of embryos of different bird species in the eggs and the survival rate of nestlings (Barrett 1980; Bennett et al. 1981; Clauser and McRae 2017; Coe et al. 2015; Grant 1982; Guthery et al. 2001; Tapper et al. 2020; Walsberg and Voss-Roberts 1983; Webb 1987), whereby the optimal breeding temperature (Webb 1987) and thus also the optimal ambient temperature at breeding sites differs between species (Appendix VI).

Rytkönen et al. (1993) examined the breeding success of rooks according to temperature in northern Finland, showing that higher temperature was associated with higher breeding success. In that context, the researchers compared the breeding success over six years (1987-1992) correlating it with weather data from Ruukki, which is 25 km north of the study area. The investigations revealed that breeding success was related to the weather and in particular to mean temperatures during nesting. Breeding success was lowest at about 5.5 °C and highest during the greatest mean temperature recorded of about 9 °C. The reason for higher breeding success was most likely that in colder springs when the ground is frequently frozen, not enough earthworms, the main food source for nestlings, can be found (Rytkönen et al. 1993). The fact that higher food supply due to a milder microclimate within cities leads to rooks moving to cities was also shown for wintering rooks (Grüll 1981; Jadczyk and Drzeniecka-Osiadacz 2013). Reasons might be that rooks within cities are sometimes fed by humans (Jadczyk and Drzeniecka-Osiadacz 2013) and that rooks can feed on human-supplied birdseed or food scraps (Grüll 1981). In northern Finland the mean temperatures are generally much colder than in Landau. Mean temperatures in May 2020 varied between 5.5 °C and 9 °C in Ruukki (Rytkönen et al. 1993). The mean temperature in May at the meteorological station in Bad Bergzabern, which is located about 15 km to the southwest of Landau, was warmer with 14.9 °C (Agrarmeteorologie RLP 2020).

Although no study is known to have investigated the effect of temperature on nest site selection of rooks in a climate similar to Landau before, it can be assumed that rooks prefer warmer locations. Compensating for temperature fluctuations requires energy (Whitford 1985). Parental behaviour, such as shading the eggs from solar radiation (Clauser and McRae 2017; Lloyd and Martin 2004) or certain construction and orientation of nests (Gloutney and Clark 1997; Lloyd and Martin 2004; Skowron and Kern 1980), cannot compensate for all temperature fluctuations (Carroll et al. 2018; Clauser and McRae 2017; Coe et al. 2015; McClintock et al. 2014). Thus, on the one hand it can be assumed that birds adapt their breeding period to temperature (Jong et al. 2018) and, on the other hand, choose nest sites with a suitable microclimate to keep the energy costs low (Carroll et al. 2018). Therefore, the study area and the local climatic conditions are decisive in determining whether warmer or colder sites are preferred compared to the surroundings. Thus, it can be assumed that rooks are more likely to breed in warm locations compared to their surroundings than in cold ones. This is supported by the fact that rooks are known to breed increasingly within cities, also in Germany (Andris and Westermann 2011; Bayerisches Landesamt für Umwelt 2011; Dietzen and Simon 2017; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015). Cities generally have a warmer microclimate than rural areas, among other things because the proportion of sealed surfaces is very high and those heat up more than vegetation patches in rural areas (Kalnay and Cai 2003; Santamouris 2013; Whitford 1985). Thus, Dietzen and Simon (2017) regard the milder microclimate within cities compared to rural areas as one reason why rooks increasingly breed in cities. Moreover, within Landau rooks often breed along transport axes, often roads, even if they breed within parks. Hence, they are highly exposed to sealed surfaces and thus seem to specifically search for warmer temperatures. In general, birds might reduce energy costs by staying close to warm streets (Whitford 1985).

Nevertheless, different bird species are energetically most efficient at different temperatures (Whitford 1985). The lower critical temperature is often between 22 °C and 23 °C (Kendeigh 1969; King 1964; Whitford 1985) whereas the upper temperature limit for lethality is at about 47 °C (Carroll et al. 2018; Guthery et al. 2005; Kendeigh 1969). Thus, many bird species that prefer colder nesting sites or have greater breeding success at colder sites are breeding in warm or hot climatic conditions (Carroll et al. 2018; Lloyd and Martin 2004), while bird species that breed in colder conditions tend to choose warmer nesting sites to save energy for warming the eggs and hatchlings (Kulaszewicz and Jakubas 2018; Rytkönen et al. 1993). In this context, it is difficult to compare studies in order to clarify how strong the effects of certain temperature differences are and at what point a site is described as being colder or warmer. That depends to a great extent on the climate in the study area (Appendix VI), the measurement period (night/day/both, short-term/long-term) and the methodology, i.e. nest temperature vs. ambient temperature (Carroll et al. 2018; Hovick et al. 2014; Imlay et al. 2019; Lloyd and Martin 2004) or ambient temperature of meteorological stations vs. breeding success (Facey et al. 2020; Rytkönen et al. 1993). Nevertheless, the climatic conditions in Landau during breeding season might be considered to be a colder climate. The breeding season of rooks in Landau is from March to June (Dietzen and Simon 2017) and in 2020 the mean temperatures measured at the meteorological station in Bad Bergzabern were between 7.2 °C (March) and 18.1 °C (June) with an overall mean of 13.5 °C (March-June) and with the lowest temperature of -2.2 °C (April) and a maximum value of 28.8 °C (June; Agrarmeteorologie RLP 2020). Thus, the temperatures are well below 38.3 °C, which are the temperatures faced by birds that prefer colder breeding sites (Carroll et al. 2018). However, there are also species that have higher breeding success at cooler nesting sites, although the ambient temperature is similar to that of Landau. But that is due to other factors linked to temperature, as in the case of Barn swallows (*Hirundo rustica*), to prey abundance depending on precipitation and temperature (Facey et al. 2020).

Although it can thus be assumed that high breeding success at a certain temperature also affects nest site selection, it appears that birds such as the Chestnut-collared longspur (*Calcarius ornatus*) prefer nesting sites with higher temperatures, even though the chicks do not thrive as well there (Lloyd and Martin 2004), similarly to the Scaled quail (*Callipepla squamata*), which chooses cooler nesting sites, although their breeding success is higher at warmer sites (Carroll et al. 2018). Consequently, sometimes factors other than temperature seem to be more important in nest site selection, which also has to be discussed with regard to the rook. Therefore, the next chapter presents the effects of another factor associated with urban habitat, which is ALAN.

7.2 Artificial light at night (ALAN)

As the circadian clock of birds is adapted to the seasonal day-night rhythm predicated on light and darkness (Amichai and Kronfeld-Schor 2019; Da Silva et al. 2015; Dominoni et al. 2013), ALAN often leads to altered behaviour (Amichai and Kronfeld-Schor 2019; Aulsebrook et al. 2020; Byrkjedal et al. 2012; Da Silva et al. 2015; Dawson et al. 2001; Dominoni et al. 2013; Dominoni et al. 2020; Dwyer et al. 2013; Holveck et al. 2019; Jiang et al. 2020; Jong et al. 2015; Jong et al. 2018; Kempenaers et al. 2010; Lambrechts et al. 1997; Leveau 2020; Nordt et al. 2013; Poesel et al. 2005; Raap et al. 2015; Russ et al. 2014; Russ et al. 2017; Santos et al. 2010; Titulaer et al. 2012; Welbers et al. 2017). Changed behaviour during the breeding period can also influence breeding success (Amichai and Kronfeld-Schor 2019; Kempenaers et al. 2010; Lambrechts et al. 1997; Poesel et al. 2005) and consequently also nest site selection (Hennigar et al. 2019; Russ et al. 2017).

However, no study was found on the influence of ALAN on rooks' breeding success or breeding site selection. Only one study is known to have examined rooks, among others, in relation to ALAN: Ciach and Fröhlich (2017) have investigated the extent to which bird species composition during winter is altered by several factors (buildings, food sources, forests, greenery, landfills, light, noise, open areas, pollution, roads, waters). Bird species and individuals were counted on 56 sample plots. Rooks were one of the species occurring most

often in the sample plots (frequency: 84%). In contrast to noise, ALAN positively affected bird density. However, that study did not examine the influence of ALAN during the breeding season and on breeding site selection, as it was conducted in winter. Consequently, ALAN could have had an even greater positive impact than during the breeding season in spring due to the short winter days (Ciach and Fröhlich 2017). Furthermore, no detailed result on the abundance of the rook and the influence of the different factors on its occurrence is presented. Nevertheless, as rooks occurred with a high frequency in the sample plots it can be assumed that rooks tend to seek ALAN rather than avoid it.
That is exactly what can be assumed based on the mapping in Part I as well. In Landau, rooks breed conspicuously often along roads that are exposed to high levels of ALAN due to street lighting. Thus, although no previous study investigating this aspect is known, it can be assumed that ALAN has a positive effect on nest site selection of rooks.

However, the effect of ALAN on other bird species has been investigated a great deal. In that context, many birds show a prolonged period of activity due to the illumination at night (Amichai and Kronfeld-Schor 2019; Da Silva et al. 2015; Dominoni et al. 2013; Jiang et al. 2020; Leveau 2020; Russ et al. 2014; Welbers et al. 2017), whereby some species do not show prolonged activity (Welbers et al. 2017). Thus, ALAN can prolong the time periods during which diurnal birds can search for food (Dwyer et al. 2013; Leveau 2020; Russ et al. 2014; Santos et al. 2010). In addition, ALAN can lead to more food being available if the birds' prey is attracted by ALAN (Welbers et al. 2017). However, the sleep quality of some bird species is impaired (Aulsebrook et al. 2020; Jiang et al. 2020; Raap et al. 2015). Resulting lower melatonin concentrations in birds exposed to ALAN lead to shorter sleep and researchers assume that fitness is negatively affected by that (Jiang et al. 2020). Even so, the sleep of some species is less impaired by amber light than by white light (Aulsebrook et al. 2020). However, due to shorter sleep and birds becoming active earlier in the morning they also start singing earlier (Da Silva et al. 2015; Kempenaers et al. 2010; Nordt et al. 2013). The start of dawn singing can affect the choice of mating partners (Kempenaers et al. 2010; Poesel et al. 2005). Nevertheless, in a few cases bird species in ALAN-exposed areas neither sing earlier nor are they affected in their singing behaviour (Da Silva et al. 2015).
ALAN not only has an impact on the day-night rhythm of birds, but also on their annual rhythm, as birds use the duration of brightness to estimate the length of the day and thus the season (Titulaer et al. 2012). Consequently, when exposed to ALAN some birds start laying eggs earlier than birds that are not exposed to ALAN (Jong et al. 2018; Kempenaers et al. 2010), as

the birds exposed to ALAN might assume it to be later in the season. Nevertheless, there are also bird species that do not show earlier laying dates of eggs (Jong et al. 2015). ALAN can also lead to altered behaviour later in the breeding season (Titulaer et al. 2012). Titulaer et al. (2012) assume that great tits believe it is already later in the year due to the extended day length caused by ALAN, citing that as the reason for mother birds to fly out to find food for the nestlings at a more frequent rate during the second nestling phase, because the birds assume they are under time pressure. That time pressure arises because the time window in which birds can breed is usually comparatively short, as it is adjusted to the best possible food availability (Kempenaers et al. 2010; Lambrechts et al. 1997). Thus, breeding success can be reduced if the breeding period and the abundance of food no longer coincide, when birds start egg laying earlier (Lambrechts et al. 1997).

Moreover, ALAN not only has a direct influence on the day-night and annual rhythms of the birds, but also an indirect effect on their breeding success by influencing predator pressure. For instance, in the case of the European blackbird (*Turdus merula*), nests exposed to more ALAN were destroyed by predators more often (Russ et al. 2017).

Accordingly, ALAN also has an impact on the breeding site selection of some birds (Hennigar et al. 2019; Russ et al. 2017), whereby it depends on the species whether birds prefer to breed at sites exposed to ALAN (Russ et al. 2017) or avoid breeding exposed to ALAN (Hennigar et al. 2019; Molenaar et al. 2006), or whether ALAN even has no effect on breeding site selection (Jong et al. 2015).

The European blackbird is a bird species that prefers to breed at sites exposed to ALAN (Russ et al. 2017). ALAN influenced the date of egg laying, predation risk, number of successful nests and thus nest site selection. Nest sites that were exposed to more ALAN were chosen by European blackbirds more often and daily nest survival was higher at those sites (Russ et al. 2017). Russ et al. (2017) suggest that the greater breeding success at illuminated sites is due to lower enemy pressure.

To be able to assess the influence of ALAN on rooks, it is important to know the wavelength range in which rooks perceive light. In general, different wavelengths are perceived by the eye with different brightness (Schnapf et al. 1987). The extent to which certain wavelengths are perceived depends on the structure of the eye and on the number of photoreceptors, rods and cones. Unlike many bird species (Goldsmith 2006), rooks cannot perceive ultraviolet wavelengths (Odeen and Hastad 2003). Moreover, the values of wavelength of maximum absorbance calculated by Odeen and Håstad (2003) in the short wavelength range for the hooded crow with 406 nm and the western jackdaw (*Corvus monedula*) with 408 nm are quite similar to those of humans with 426 nm (Merbs and Nathans 1992).

The sensitivity of the photoreceptors is described by the spectral sensitivity function (Schnapf et al. 1987). Figure 16 presents the spectral sensitivity functions of different species and, as a comparison, the one of humans as well as the CIE Ph function (Saunders et al. 2008). The CIE Ph curve, which was developed by the International Commission on Illumination (Goodman et al. 2016), shows the photopic function of humans at 555 nm (Saunders et al. 2008). Figure 16 shows that the variations between species are not very large.

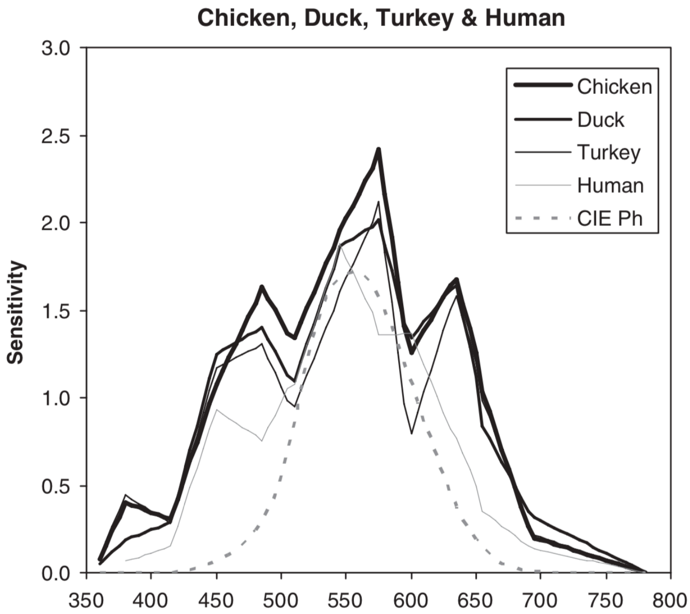

Figure 16: Spectral sensitivity functions of different bird species in comparison to the one of humans (Saunders et al. 2008)

For those reasons, it can be assumed that - for an approximation of the light influence on breeding tree selection of the rook - the usual wavelength measuring range of measuring instruments, which is usually adapted to the visible ranges for humans (Saunders et al. 2008), is appropriate.

However, since ALAN and noise often occur simultaneously, often it is not clear whether the investigated effects on changed behaviour, breeding success and nest site selection are due to ALAN or whether noise is actually the cause (Amichai and Kronfeld-Schor 2019; Kempenaers et al. 2010; Nordt et al. 2013). For this reason, it is important to incorporate the effect of noise on breeding success and breeding site selection.

7.3 Noise

Noise can affect the singing behaviour of birds (Brumm 2004; Brumm and Todt 2002; Cynx et al. 1998; Da Silva et al. 2015; Dorado-Correa et al. 2018; Kempenaers et al. 2010; Nordt et al. 2013; Oberweger and Goller 2001; Potash 1972; Singh et al. 2019; Slabbekoorn and den Boer-Visser 2006), because noise can cause masking of bird songs (Brumm 2004; Potvin et al. 2014; Schroeder et al. 2012; Swaddle and Page 2007). Masking occurs when a sound is overlaid by another sound so that the original sound is no longer heard (Moore and Glasberg 1986). Masking effects also occur in natural habitats, e.g. due to waterfalls or the songs of other birds (Brumm 2004; Dubois and Martens 1984). Birds affected by masking due to urban noise react in a similar way to birds struggling with natural noise (Brumm 2004). Masking can complicate communication between birds (Brumm 2004; Lucass et al. 2016; Potvin et al. 2014; Schroeder et al. 2012; Swaddle and Page 2007), because they can no longer hear each other. Thus, mate search (Brumm 2004; Swaddle and Page 2007), communication with and care for chicks (Lucass et al. 2016; Schroeder et al. 2012) or the effectiveness of alarm calls may be impaired (Potvin et al. 2014). Furthermore, it could also increase the likelihood of being detected by enemies (Brumm 2004; Quinn et al. 2006). All of this can be assumed to affect breeding site selection. Therefore, some bird species adapt to traffic noise e.g. by starting singing earlier (Hennigar et al. 2019; Nordt et al. 2013).

In order to be able to determine whether the rook's choice of breeding site can also be influenced by masking, the frequency with which rooks communicate has to be identified. Røskaft and Espmark (1982) determined 20 different rook calls, which involved various different frequencies and also depended on the individual. The majority of the caws were in the range of 1 to 2 kHz. This is consistent with investigations of a breeding rookery in Switzerland, Bern, showing a frequency of 1.3 to 2.5 kHz (Fankhauser 1995). However, some individuals had a tonality of up to 8 kHz (Røskaft and Espmark 1982). As urban noise occurs mainly in low frequencies below 2 kHz (Mahn 2011; Potvin et al. 2014; Slabbekoorn and Peet 2003) the higher frequencies of up to 8 kHz might be an adaptation to avoid masking. Several studies showed that birds that sing at higher frequencies are more tolerant of urban noise (Cardoso et al. 2020; Francis et al. 2011). However, although most studies show that birds switch to higher frequencies to avoid masking (Dubois and Martens 1984; Francis et al. 2011; Juárez et al. 2020; Slabbekoorn and den Boer-Visser 2006; Wood et al. 2006), some birds also switch to lower frequencies (Potvin et al. 2014). However, it must be taken into account that urban noise also occurs at higher frequencies above 2 kHz (Mahn 2011). The fact that traffic noise primarily takes place at the lower frequencies means it is quieter in higher frequency range. For example,

if a street with 3 - 12 passing cars per minute is examined, a sound with a frequency of 1 kHz occurs at a volume of 60 dB, but a sound with a frequency of 5 kHz only has a volume of about 45 dB (Mahn 2011). While a bird communicating at 1 kHz has to sing louder than 60 dB, a bird communicating at a frequency of 5 kHz only has to sing louder than 45 dB.
Thus, another adaptation to urban noise is increasing the volume of communication to drown out the ambient noise according to the Lombard effect (Brumm 2004; Brumm and Todt 2002; Cynx et al. 1998; Dorado-Correa et al. 2018; Singh et al. 2019). In this context, it has been demonstrated that bird species with a greater body size tend to communicate with greater volume (Cardoso 2010). However, singing is energetically costly (Oberweger and Goller 2001) and hence increasing volume during singing in order to overcome masking increases the energetic costs for birds (Brumm 2004). Thus, a natural high volume of rooks' calls or an ability to increase volume could inhibit strong impairment by noise. With a mean volume of 64.1 dBA rook calls are not as loud as passing cars (69.3 dBA) or lorries (73.7 dBA; Fankhauser 1995). At 7 a.m. the mean traffic noise was 55 dBA (Fankhauser 1995). Even if this might depend on the traffic load, it can be assumed that rooks are quite tolerant of noise along roads, because the volume of their communication seems to allow them to communicate despite traffic noise. That assumption is supported by the fact that rooks have a comparatively large body size, which is an indicator of birds that increase their volume to overcome masking (Cardoso 2010).

In addition to the frequently altered behaviour of the birds, physiological impacts caused by noise are also reported for various bird species (Marler et al. 1973; Potvin 2017). Canaries which were experimentally exposed to noise reacted with partial deafness and - when exposed over a longer period of time - with inability to communicate at high frequencies (Marler et al. 1973). Thus, adapting to urban noise by changing to higher frequencies is no longer possible and might reduce fitness of birds in noisy urban environments.
Such physiological changes are not related to masking of the bird communication, but to the ability to perceive certain frequencies, to hear and to be harmed by the direct noise. Thus, it is important to determine the frequencies that rooks perceive. Since rooks communicate in a range of 1 to 2.5 kHz (Fankhauser 1995; Røskaft and Espmark 1982), but sometimes up to 8 kHz (Røskaft and Espmark 1982), it can be assumed that they can hear that frequency range. Nevertheless, it is questionable what other frequencies rooks can perceive beyond that. There is no known study that examined the hearing ability of the rook in particular, but there are a few studies on the hearing of other *Corvidae spp.* (Cohen et al. 1978; Jensen and Klokker 2006). The hooded crow can perceive sounds best between 700 Hz and 2.8 kHz (Jensen and Klokker

2006) and the blue jay (*Cyanocitta cristata*) have its best hearing ability at a frequency of 2 kHz (Cohen et al. 1978).
Studies on the hearing of other bird species show similar results (Jackson 2012; Appendix VII). With a cut-off for the hearing range set at 60 dB (Heffner et al. 2016; Hill 2017; Hill et al. 2019), no wavelengths above 11 kHz can be perceived by the investigated species (Cohen et al. 1978; Gall et al. 2011; Heffner et al. 2013; Heffner et al. 2016; Hill et al. 2014; Hill 2017; Jensen and Klokker 2006; Okanoya and Dooling 1987; Strawn and Hill 2020). However, since some of those studies investigated a limited frequency range, the hearing range in such studies only has an upper limit. In addition, some of the values were derived from the audiograms, so the values are only a rough guideline.

Thus, noise can reduce fitness by masking the birds' communication (Brumm 2004; Lucass et al. 2016; Potvin et al. 2014; Schroeder et al. 2012; Swaddle and Page 2007), by affecting feeding (Quinn et al. 2006) and mating (Swaddle and Page 2007) or by leading to physiological changes (Marler et al. 1973; Potvin 2017), all of which might influence breeding success.
An effect on breeding success has been shown for great tits (*Parus major*); in natural breeding habitats exposed to noise close to a highway, clutches were smaller and had fewer chicks (Halfwerk et al. 2011). Furthermore, experimental studies show that breeding success of some species is reduced when birds are exposed to noise after having chosen a breeding site (Mulholland et al. 2018; Schroeder et al. 2012), whereas breeding success of other species is not affected (Mulholland et al. 2018; Walthers and Barber 2020). Rheindt (2003) explains this with the different singing frequencies of different species and with species that communicate at high frequencies avoiding breeding exposed to traffic noise. However, some birds also seem to get used to traffic noise (Brumm 2004; Harms et al. 1997).

Therefore, the effect of noise on breeding site selection depends on the bird species, with some species avoiding noise (Bayne et al. 2008; Francis et al. 2009; Halfwerk et al. 2016; Hennigar et al. 2019; Liu et al. 2020) while other species prefer to breed at sites that are more intensively exposed to noise (Francis et al. 2009; Halfwerk et al. 2016; Hennigar et al. 2019).
However, no studies on the influence of noise on nest site selection of rooks could be found. Only one study is known that investigated the effect of noise on the abundance of rooks, among others, in winter in Poland, but not during the breeding season (Ciach and Fröhlich 2017). Only the nocturnal noise between 10 pm in the evening and 6 am in the morning was considered. Noise negatively affected the abundance of species and individuals. The rook was among those

birds occurring most frequently (frequency: 84%) within the sample sites (Ciach and Fröhlich 2017). However, no detailed information is provided on the effect of noise on rooks, since only the bird assemblage was investigated. Nevertheless, since rooks occurred with a high frequency at the sample sites it can be assumed that they do not avoid noise.

This suggestion is supported by the result from Part I of this thesis showing that within Landau many rooks breed along transport axes, mainly streets. Thus, it can be assumed that rooks within Landau are also exposed to a comparatively high noise level caused by traffic.

In any case, detailed investigation to test this assumption is necessary.

7.4 Hypothesis derivation

Based on the results of Part I and the literature presented above, the hypotheses regarding the influence of temperature, ALAN and noise on breeding tree selection of rooks, which is presented in the following, is to be tested with the aid of this thesis.

(1) Effect of temperature on breeding tree selection of rooks

As presented above, studies on different bird species show that temperature influences breeding success by affecting the development of eggs and chicks. Parent birds create the necessary temperature within the nest by adapting their behaviour when the temperature is too cold or too warm, which can increase additional energy costs. In order to keep those costs as low as possible, parent birds look for breeding sites that have the best suitable ambient temperature, while the preferred temperature varies between different bird species. Bird species that occur in colder climates tend to breed at warmer sites in comparison to the ambient temperature or randomly selected sites and vice versa, which has also been shown for rooks in Finland (Rytkönen et al. 1993).

Although no study has investigated the influence of temperature on the breeding success or breeding tree selection of rooks in similar climatic conditions to Landau, the birds can be assumed to prefer warmer breeding sites, as it is known that rooks now breed within cities to an increasing extent and one reason for this mentioned in literature is the milder microclimate within cities. That assumption is supported by the fact that temperatures in Landau overall tend to be colder rather than warmer during the breeding phase in spring and consequently warmer individual nest locations can be assumed to reduce the energy expenditure of the parent birds.

For these reasons, it is hypothesised that higher temperatures prevail at manually selected rook breeding trees (Bm – in the following called “breeding trees”) compared to manually selected non-breeding trees (Nm – in the following called “reference trees”) and randomly selected non-breeding trees (Nr – in the following called “random trees”), i.e. that the mean temperature (°C) at 3 m height at breeding trees is higher than at reference trees or random trees (Table 7).

(2) Effect of ALAN on breeding tree selection of rooks

ALAN can change activity phases, sleep, singing and feeding behaviour of some bird species, as well as the abundance of predators. All this can affect mating, date of oviposition, development of chicks and thereby breeding success and thus breeding site selection. Although many bird species are negatively affected by ALAN, there are also bird species which are positively affected by ALAN, such as the European blackbird, which has higher rates of nest survival when exposed to ALAN (Russ et al. 2017).

This preference for breeding exposed to ALAN is also assumed for rooks, since at least during winter rooks are not repelled by ALAN (Ciach and Fröhlich 2017). In addition, the mapping in Part I of this thesis shows that rooks in Landau breed increasingly along traffic routes and the breeding trees are thus expected to be exposed to street lighting.

Consequently, the hypothesis to be tested is that breeding trees are exposed to a higher light level than reference trees or random trees, i.e. that the mean illuminance (lx) at breast height of Bm is higher than that of reference trees or random trees (Table 7).

(3) Effect of noise on breeding tree selection of rooks

Noise affects birds in particular by impairing their communication due to masking, but whether and to what extent communication is affected is species specific. Communication is important for recognising alarm calls from conspecifics, for mating and raising the hatchlings. In addition to impaired communication, negative physiological effects caused by noise, e.g. deafness, changed feeding behaviour and altered predation pressure can affect breeding success and thus breeding site selection. However, some birds have developed methods of communication to adapt to high noise levels, such as changing the frequency or increasing the volume.

There was no study found investigating the effect of noise on rooks’ breeding tree selection. However, rooks in particular communicate at frequencies of 1 to 2.5 kHz. As road noise mainly involves frequencies below 2 kHz, it can be assumed that their communication is affected by masking. Nevertheless, it was shown that wintering rooks are not repelled by noise (Ciach and Fröhlich 2017). Moreover, Fankhauser (1995) revealed that rooks communicate with a high volume, i.e. 64.1 dBA in the mean, while traffic noise at 7 am was measured as 55 dBA. Consequently, it can be assumed that the rooks’ communication is not impaired, because their volume enables them to communicate despite traffic noise. As the mapping of Part I of this thesis additionally indicates that rooks often breed along traffic routes in Landau and thus exposed to traffic noise, this thesis tests the hypothesis that breeding trees are exposed to a higher noise level than reference trees or random trees, i.e. the mean noise level (dB) at the height of 3 m for Bm is higher than for reference trees or random trees (Table 7).

Table 7: Hypotheses to be tested (Bm: manually selected breeding trees, Nm: manually selected non-breeding reference trees, Nr: randomly selected non-breeding trees)

Variable	Hypothesis	Hypothesis with direction	Operationalised hypothesis	Statistical hypothesis
Temperature	Breeding tree selection of rooks is affected by temperature	Bm are exposed to higher temperatures than Nm or Nr	The mean temperature (°C) at 3 m height for Bm is higher than for Nm or Nr	H_1: $\mu_{Bm, temp} > \mu_{Nm, temp}$ or $\mu_{Bm, temp} > \mu_{Nr, temp}$
Light	Breeding tree selection of rooks is affected by ALAN	Bm are exposed to a higher light level than Nm or Nr	The mean illuminance (lux) at breast height for Bm is higher than for Nm or Nr	H_1: $\mu_{Bm, light} > \mu_{Nm, light}$ or $\mu_{Bm, light} > \mu_{Nr, light}$
Noise	Breeding tree selection of rooks is affected by noise	Bm are exposed to a higher noise level than Nm or Nr	The mean noise level (dB) in 3 m height for Bm is higher than for Nm or Nr	H_1: $\mu_{Bm, noise} > \mu_{Nm, noise}$ or $\mu_{Bm, noise} > \mu_{Nr, noise}$

8 Material and methods of the measurements

8.1 Study area

While the mapping of the nests in Part I of this thesis took place in the entire area of the Anterior and South Palatinate, the investigation of the effect of temperature, ALAN and noise on the breeding tree selection of the rook was only carried out within the city of Landau (49°11'56.0 "N 8°07'06.8 "E), without taking the surrounding villages that belong to the municipality of Landau into account. Thus, the study area is limited by the B10 to the north, by the A65 to the east and by the Ebenberg nature reserve to the south. In the west, the district of Wollmesheimer Höhe is still part of the study area, but the villages of Wollmesheim and Arzheim are no longer included.

8.2 Data Collection

8.2.1 Tree selection

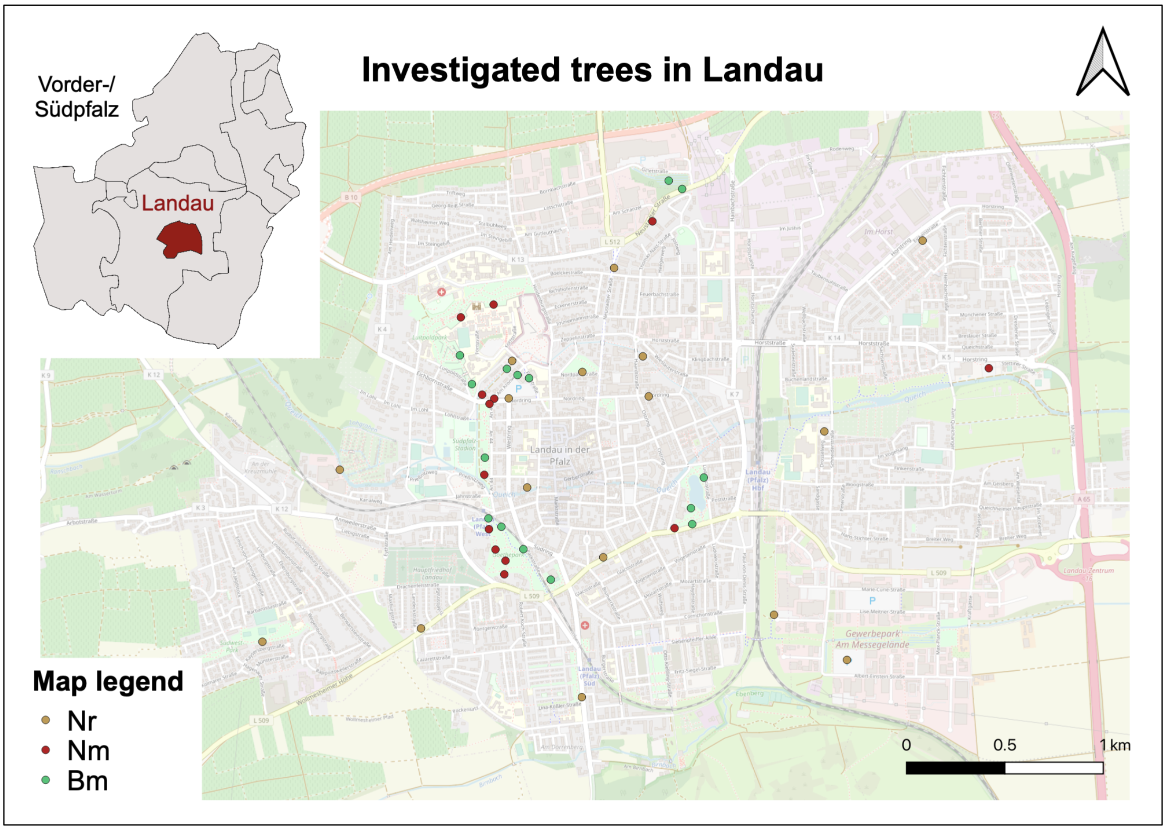

Figure 17: Investigated trees in Landau grouped by Bm, Nm, and Nr (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

For the measurements of temperature, ALAN and noise, 15 breeding trees (Bm1-Bm15) and 13 non-breeding reference trees (Nm1-Nm13) were manually selected. In addition, 16 non-breeding trees (Nr1-Nr16) were randomly selected (Figure 17). The tree selection was based on the investigations of tree genus, tree height and DBH of rook breeding trees within Landau presented in Part I of this thesis. When sampling reference trees and random trees, only trees of a tree genus used by rooks for breeding within Landau and with a tree height of at least 10 m and a DBH of at least 20 cm were considered.

Manual tree selection of breeding trees and reference trees

Breeding trees and reference trees were selected manually because their locations give rise to questions regarding why breeding trees are used for breeding by rooks and reference trees are not. Random trees were randomly selected so as to have a sample of non-breeding trees in addition to reference trees, selected only based on the criteria of tree genus, tree height and DBH. The selection of trees is described in detail below. The selection of breeding trees and reference trees was based on the observations during the mapping that some trees appeared to be well suited as breeding trees (in terms of tree genus, tree height and DBH) but, unlike other trees, they were not used for breeding. On the other hand, trees were also noticed that were used as breeding trees although they did not appear to be obviously predestined for that. The detailed reasons for selection of breeding trees and reference trees is explained in the following, whereby the trees are assigned to six groups: (1) Gillet, (2) Fort, Bürgergraben and Alter Meßplatz, (3) Schillerpark, (4) Goethepark and Sovoyenpark, (5) Schwanenweiher and (6) La Ola.

(1) Gillet

The group of investigated trees named after the Gillet DIY store is located in the northern part of Landau mainly along Neustädter Straße (Figure 18). Neustädter Straße is one of the main connecting roads to the B10 federal road, which leads to the A65 motorway, which in turn connects Landau with the

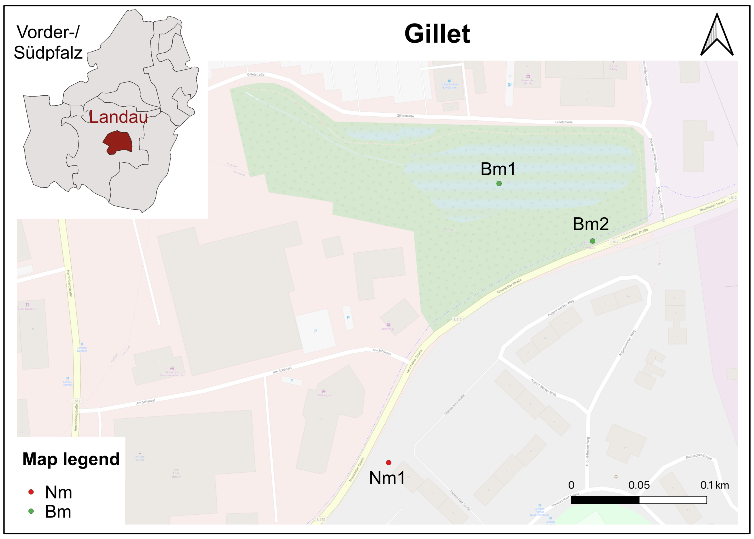

Figure 18: Bm and Nm at Gillet (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

surrounding larger cities of Ludwigshafen to the north and Karlsruhe to the south. That makes Neustädter Straße one of the busier roads in Landau. In some sections, there are Platanus planted at regular intervals along the road, which make up the largest proportion of the breeding trees in this group. The colony comprises 13 breeding trees with 52 nests. However, although there seems to be enough space for additional nests on the Platanus along Neustädter Straße, seven breeding pairs use a Salix that is 70 m away from the road in a rainwater catchment basin, which is why this tree was chosen for investigation as Bm1. For comparison with Bm1, one Platanus used for breeding along Neustädter Straße was chosen as well (Bm2). Further southwest along Neustädter Straße, the trees along the road are no longer used as breeding trees. That raises the question of whether temperature, ALAN and noise differ here compared to Bm1 and Bm2. Therefore, a Tilia was chosen for investigation (Nm1).

(2) Fort, Bürgergraben and Alter Meßplatz

Alter Meßplatz is a parking lot surrounded by Platanus close to the city centre of Landau. Of the 41 Platanus around the car park, 16 trees are used as breeding trees for a total of 109 nests. On the basis of the current literature, it would be assumed that the rooks first occupy all trees of Platanus there before they move to other tree genera close by. Although there are several plane trees at Alter Meßplatz that are not used for breeding yet, some rooks breed along Bürgergraben and in the Fort on trees of other tree genera. Bürgergraben is 60 m linear distance from the nearest breeding tree at Alter Meßplatz, and the two breeding trees in the Fort are respectively 130 m and 300 m linear distance from the nearest breeding tree at Alter Meßplatz.

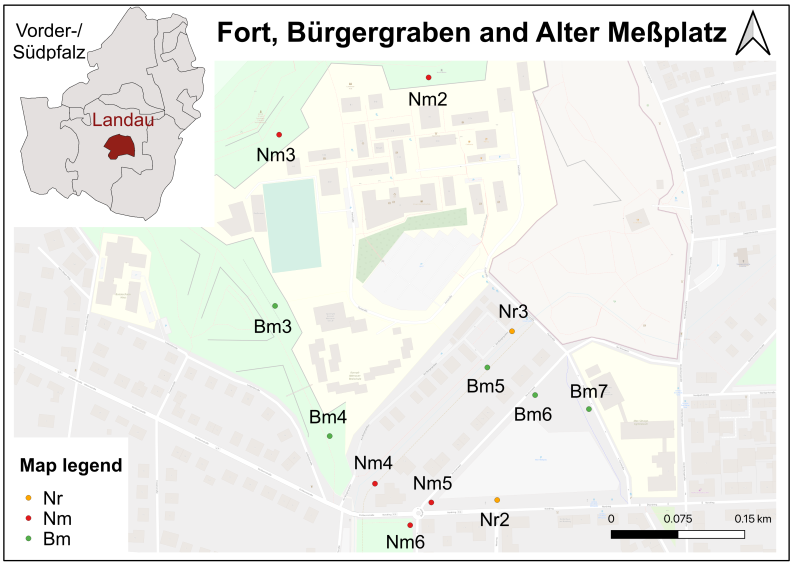

Figure 19: Bm and Nm at Fort, Bürgergraben and Alter Meßplatz (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

Therefore, at Alter Meßplatz two breeding trees (Bm6, Bm7) and one Platanus located in the southwest (Nm5) which was not chosen for breeding were selected for investigation to determine whether differences in temperature, ALAN and noise can explain why not all Platanus around Alter Meßplatz are used for breeding by rooks (Figure 19).

Bürgergraben is a small canal bordered by a narrow strip of woodland, with parallel footpaths and houses with gardens on either side. There are breeding trees in the northeastern part of Bürgergraben, a total of 8 with 11 nests. Of those breeding trees, a Fraxinus, Bm5, was selected to test whether temperature, ALAN and noise differ in comparison to Nm5 at Alter Meßplatz. As there are no trees used as breeding trees in the southwestern part of Bürgergraben, a Fraxinus, Bm4, was selected there to check whether there are differences compared to the ones used as breeding trees to the northwest at Bürgergraben (Figure 19).

The Fort is an inner-city wooded area surrounding the university campus with many footpaths running through it. The colony in the Fort contradicts the hypothesis of this work assuming that rooks breed in particular along traffic routes, especially because with the Platanus at Alter Meßplatz in the vicinity of the Fort there still seem to be enough potential breeding trees available. The colony in the Fort consists of 11 breeding trees with a total of 21 nests. Three breeding trees (4 nests) are located relatively far to the southeast at the edge of the Fort and 8 trees (17 nests) in the centre of the Fort, comparatively far away from roads. Since the question arises why the rooks breeding there do not use the free Platanus at Alter Meßplatz, breeding trees (Bm3, Bm4) were selected at both sites in the Fort for comparison with Nm5 at Alter Meßplatz. In addition, to determine whether temperature, ALAN and noise can explain why the rooks decided to breed in the eastern part of the Fort, two Acer (Nm2, Nm3) were selected for comparison with Bm3 and Bm4 (Figure 19).

Moreover, this group includes another non-breeding tree (Nm6), which is known to have been used as a breeding tree in previous years, giving rise to the question of why other trees are now preferred by rooks for breeding (Figure 19).

(3) Schillerpark

Schillerpark is a narrow park close to the city centre with an area of 2.2 ha. In the southern part of the park there are four breeding trees with a total of 5 nests. Although the breeding trees are located inside the

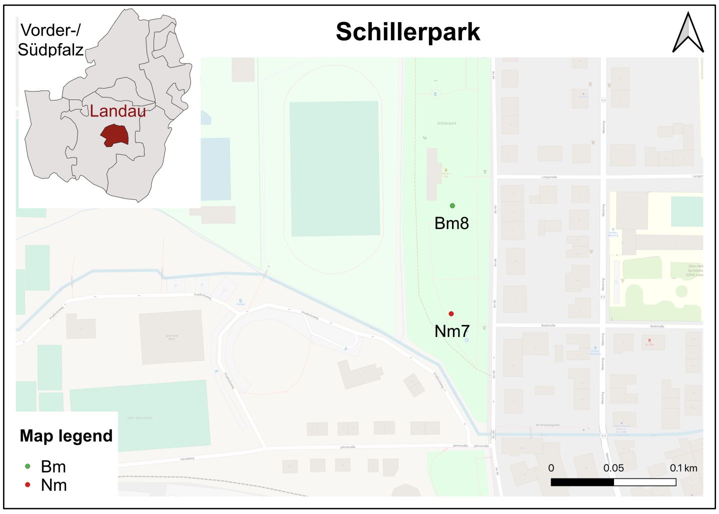

Figure 20: Bm and Nm in the Schillerpark (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

park, they are barely 40 m away from the nearby road. However, as it is a bicycle road, it is only used to a limited extent by car traffic and is therefore not particularly highly frequented. The breeding trees are located right next to the Schillerpub, a popular restaurant. Assuming that rooks prefer locations that are exposed to more noise as breeding sites, the question arises whether the noise from the Schillerpub has an effect on breeding tree selection. Therefore, one of the breeding trees has been selected for further investigations (Bm8). Since three of the four breeding trees are Pinus, a Pinus further south in Schillerpark and thus further away from the Schillerpub has been selected as a non-breeding tree (Nm7; Figure 20).

(4) Goethepark and Sovoyenpark

Goethepark is only 120 m linear distance south of Schillerpark. With an area of 5.5 ha, Goethepark is larger and also wider than Schillerpark. Westbahnstrasse, a busy inner-city road that borders Goethepark to the north, runs between the two parks. there is a railway track adjacent to the park to the east and the highly frequented Schloßstraße lies to the south of the park. To the west, the park is bordered for the most part by residential areas with houses and gardens. Sovoyenpark, which is much smaller with an area of 1 ha, is southeast of Goethepark, on the other side of the railway tracks. Goethepark and Sovoyenpark together account for 38 breeding trees with a total of 194 nests.

A Platanus used for breeding (Bm9) located at the northern end of Goethepark on Westbahnstrasse was investigated (Figure 21). Two Platanus located further inside Goethepark are similar to Bm9 in size and DBH, but are not used as a breeding trees and were thus investigated (Figure 22). One (Nm8) is located 50 m and the other (Nm10) even 230 m further inside the park. Furthermore, Nm8 is located at a similar distance from the railway tracks and a highly frequented road as a Platanus used as a breeding tree in Sovoyenpark, which was therefore also investigated

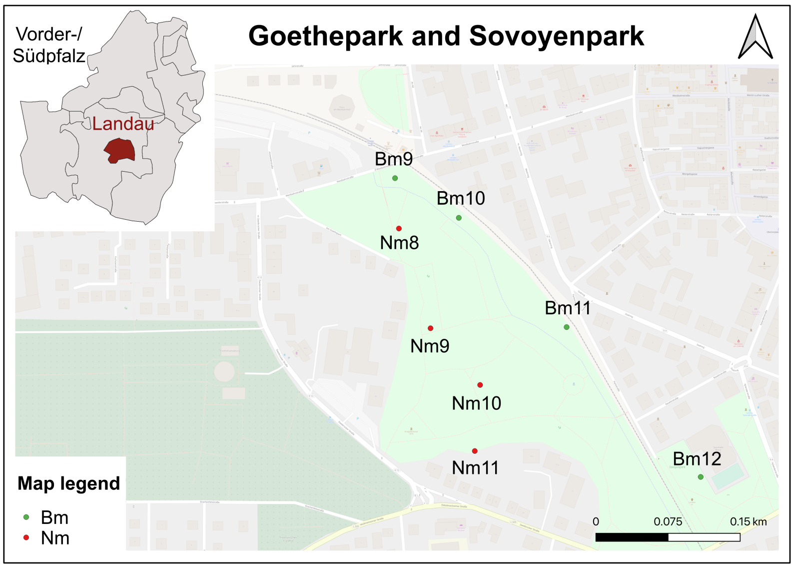

Figure 21: Bm and Nm in the Goethepark and Sovoyenpark (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

(Bm12). It is questionable whether the factors temperature, ALAN and noise can explain why Nm8 and Nm10 are not used as breeding trees compared to Bm9 and Bm12.

In addition to the four Platanus, four Acer were selected for further investigation. Two Acer (Bm10, Bm11) that are located at different sites along the railway tracks on the eastern edge of Goethepark were selected (Figure 21). The values for temperature, ALAN and noise of those two Acer are compared with an Acer (Nm9) that is located in the interior of the park and with an Acer (Nm11) that is located similarly to Bm10 and Bm11 in a wooded edge strip of the park, not adjacent to the railway tracks but instead to gardens of residential houses.

Figure 22: (a) Bm 9, (b) Bm10 and (c) Nm8 in the Goethepark

(5) Schwanenweiher

Schwanenweiher is a lake in Ostpark (3.5 ha). The lake is surrounded by green areas with many large solitary trees. Of those trees, 13 are used by the rook as breeding trees and are home to a total of 168 nests. As there is a lake in the centre of the park, almost all trees in the park are fairly close to roads. However, the Platanus occupied by the most nests are located along the heavily frequented Rheinstraße, one of which was selected for further investigation (Bm14; Figure 23). A little further west on the

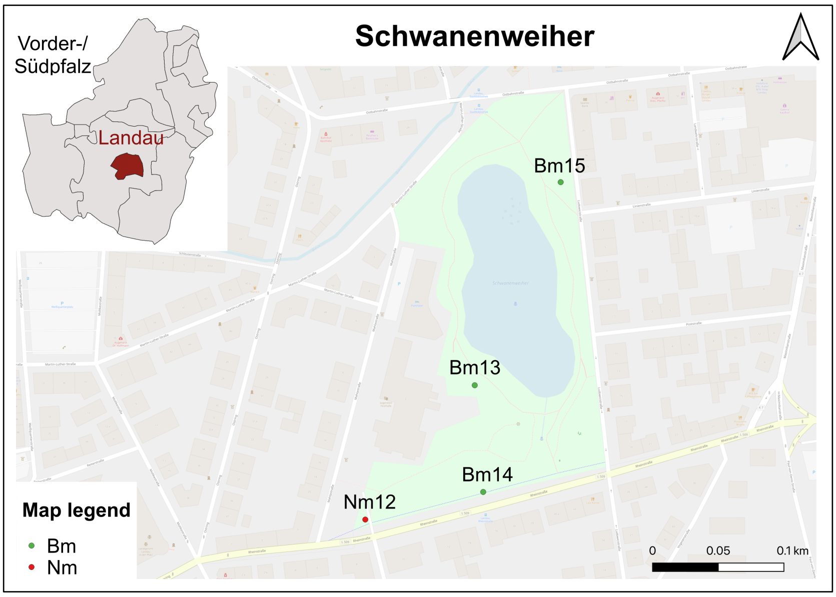

Figure 23: Bm and Nm at Schwanenweiher (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

Rheinstraße there is a Quercus (Nm12) that is not used as a breeding tree and was investigated to determine if temperature, ALAN or noise can explain that. In addition, a Platanus (Bm15) on the eastern edge of the park along Ludowicistraße was investigated, as well as a Platanus (Bm13) located behind the festival hall. That Platanus is located a little further away from a road, which is why it is to be compared with Bm13 and Bm14 to check if there are any differences in temperature, ALAN and noise.

(6) La Ola

There are 12 Platanus at the parking lot of the La Ola indoor swimming pool, all of which are not used by rooks as breeding trees. Parking lots with Platanus are often used as breeding sites, for example in Ludwigshafen at the car park on Industriestrasse. Therefore, a non-breeding tree (Nm13) was selected here for closer examination (Figure 24).

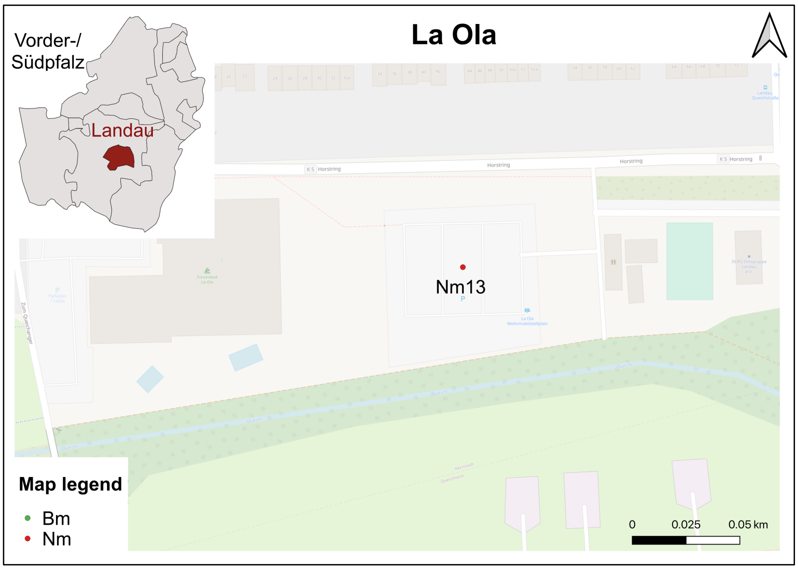

Figure 24: Bm at the indoor swimming pool La Ola

Tree selection of random trees

In addition to breeding trees and reference trees, 15 random trees were also selected for investigation. The tree selection of the random trees was done randomly using QGIS (QGIS Development Team 2020). Only trees of genera already used as breeding trees in Landau and trees with a height of at least 10 m and a DBH of at least 20 cm were taken into consideration. The random selection of the trees did not take into account (1) the manually selected trees (breeding trees, reference trees), (2) places where repellent measures have been carried out since 2010 according to the data from the SGD Süd (Klöppel 2020; Appendix V) and (3) trees affected by crown pruning, because those trees did not have suitable tree ramifications for nest building.

An adjustment of the random tree selection was only necessary in Badstraße, where random selection using QGIS chose a tree of Platanus affected by crown pruning. Therefore, the suitable tree of Platanus that is nearest to the randomly selected tree was chosen for investigation, in that case a tree on the opposite side of the street.

Table 8: Tree genera selection of the trees chosen for investigation based on the tree genera distribution of breeding trees in Landau determined in Part I of this thesis

Grouping	**Tree genus**	**Number of breeding trees in Landau**	**Percentage of the total number of breeding trees in %**	**Number of trees per 15 breeding trees**		**Actual number of trees taken**
	Platanus	58	44	6.6		7
	Acer	32	24	3.6		4
	Fraxinus	13	10	1.5		2
	Tilia	11	8	1.2		1
Group 1	Quercus	4	3	0.45	1.35	1
	Pinus	3	2	0.3		
	Alnus	2	2	0.3		
	Robinia	2	2	0.3		
Group 2	Fagus	1	1	0.15	0.9	1
	Ginkgo	1	1	0.15		
	Gleditsia	1	1	0.15		
	Juglans	1	1	0.15		
	Salix	1	1	0.15		
	Betula	1	1	0.15		
Total						16

According to the percentage distribution of the tree genera of all breeding trees in Landau (Table 8), 7 Platanus, 4 Acer, 1 Fraxinus and 1 Tilia were randomly selected with the QGIS command "Random selections within subsets". In addition, Alnus, Pinus, Quercus and Robinia were grouped together, as each tree genus accounts for between 2% and 3% of all breeding trees. From that group one tree was randomly selected with the QGIS command “Random selection”. Likewise Betula, Fagus, Ginkgo, Gleditsia, Juglans and Salix, which each make up 1% of all breeding trees, were combined into one group and one random tree was selected here as well. The percentage of tree genera in the total number of breeding trees of rooks in Landau was converted to 15 trees to be selected. The results were rounded so that in the end 16 random trees were selected using QGIS (Table 8).

8.2.2 Temperature measurement

For measuring the temperature, ONSET HOBO UA-002-08 Pendant Temperature/Light 8K Data Loggers were used. The HOBO data loggers were attached to the tree trunk at a height of approximately 3 m together with the AudioMoth data loggers that measured noise. The temperature was measured over a period of seven days from Saturday, September 5th to Thursday, September 10th, 2020. A measurement was taken every 15 minutes. The weather during the measurement period was summery, often with daily temperature highs of well over 20 °C and few clouds, often clear skies and hardly any rain.

8.2.3 ALAN measurement

A Voltcraft Luxmeter MS-1300 was used for measuring ALAN. The spectral sensitivity range of the luxmeter is shown in Figure 25 (Voltcraft 2008). The measuring range respectively the resolution of the luxmeter is 0.01 to 50,000 lx with an accuracy of ±10% plus 10 digits in the measuring range below 10,000 lx. The measuring range of 200 lx was used for the measurements for this thesis. The sampling frequency of the luxmeter is 1.5Hz.

The measurement was conducted on Wednesday, September 30th, 2020, from 8:10 pm to 11:40 pm with clear skies and almost a full moon. For all trees examined the measuring direction was upwards according to the methodology of Russ et al. (2017) on four sides (north, east, south, west) of the trunk at chest height during the night. Although it can be assumed that the headlights of cars have little influence at nest height in the treetop, no values were taken when cars were passing.

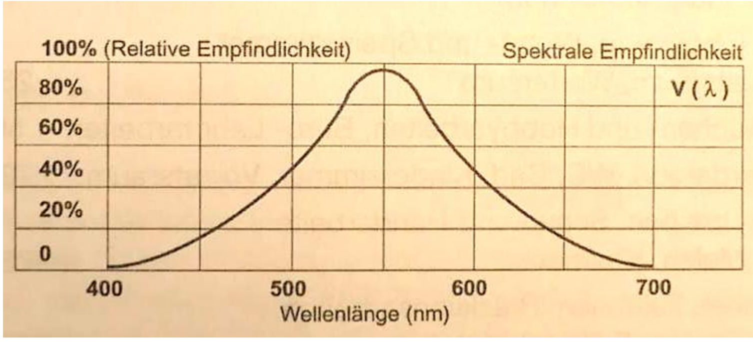

Figure 25: Spectral sensitivity of the Voltcraft Luxmeter MS-1300 (Voltcraft 2008)

In addition to the data collected with the luxmeter, data from the town of Landau was used to determine the light colour of the street lamps that are closest to the trees under investigation, and descriptive analyses were carried out to assess whether that factor might have an influence on the choice of breeding trees. The data on luminous colour originates from a personal communication with Ulrike Heck (2020), while the position of the street lights is taken from the Geoportal (Stadt Landau in der Pfalz Stadtverwaltung 2020) and the distance to the examined tree was measured with QGIS (QGIS Development Team 2020). The type of street light was derived from the Geoportal (Stadt Landau in der Pfalz Stadtverwaltung 2020) and from own observations.

8.2.4 Noise measurement

AudioMoth data loggers were used to record the noise. They were fitted with three AA lithium batteries and one SanDisk Extreme microSDHC 32GB 100MB/s A1 C10 V30 UHS-I U3. The AudioMoth data loggers were attached to the tree trunk at a height of approximately 3 m together with the HOBO data loggers that measured the temperature. The loggers were protected from rain by a plastic cover (Figure 26).

To determine the measurement range to be recorded with the AudioMoths, the literature on frequencies of the rooks' communication as well as on the hearing range of other bird species presented previously provided a guideline. As rooks communicate between 1 and 8 kHz (Fankhauser 1995; Røskaft and Espmark 1982) and at a level of 60 dB SPL no wavelengths above 11 kHz can be perceived by other bird species (Cohen et al. 1978; Gall et al. 2011; Heffner et al. 2013; Heffner et al. 2016; Hill et al. 2014; Hill 2017; Jensen and Klokker 2006; Okanoya and Dooling 1987), a measuring range up to 16 kHz seemed to be sufficient. Due to the Nyquist theorem, twice the kHz value has to be selected to measure the frequencies to be

examined (Hill et al. 2019). Moreover, Hill et al. (2019) recommend 48 kHz for measuring the soundscape with an AudioMoth. Therefore, the sample rate was set to 48 kHz.
According to Hill (2019) the gain was set to medium in accordance with the default settings. The recording duration was set to 55 sec and the sleep duration to 5 sec, to ensure that the data was stored properly (Wildlife Acoustics 2020). The advanced settings were adopted according to the default settings of the AudioMoth device.
In order to obtain a representative picture of the noise, the measurement was carried out continuously over four days, from Monday, September 7th to Thursday, September10th, 2020, from 00:00 to 24:00 hours.

Figure 26: An AudioMoth device fixed to one of the trees with a HOBO logger hanging from it

8.3 Data Analysis

For the analysis of the temperature data, only data during the twilight and night-time hours from 6 pm to 6 am were used to avoid effects of direct solar radiation, which varies between different locations and might have distorted the measured values. However, two data loggers failed during the measurements. Consequently, there are no data for Nm10 and Nr13 and thus those loggers were excluded from the analysis. The data was read out with HOBOware (Onset Computer Corporation 2020), exported to MS Excel and prepared there (Microsoft Corporation 2020) and then analysed and plotted with R (RStudio Team 2020).

The data on ALAN was documented and prepared for further statistical analysis with MS Excel (Microsoft Corporation 2020) and statistically analysed and plotted with R (RStudio Team 2020).

Although frequencies up to 48 kHz were measured, when analysing noise only frequencies of up to 16 kHz were considered in the analysis of the data because the aim of this thesis is to consider only the frequencies that are part of the rooks' communication and perceived by rooks, because only those frequencies may play a role in the selection of breeding trees.
The analysis was performed with kaleidoscope Pro (Wildlife Acoustics 2020). SPL Analysis was used to select Min SPL, Mean SPL and Max SPL within the following 1/3 Octave Bands: 19.7 Hz, 24.8 Hz, 31.2 Hz, 39.4 Hz, 49.6 Hz, 62.5 Hz, 78.7 Hz, 99.2 Hz, 125.0 Hz, 157.5 Hz, 198.4 Hz, 250.0 Hz, 315.0 Hz, 396.9 Hz, 500.0 Hz, 630.0 Hz, 793.7 Hz, 1000.0 Hz, 1259.9 Hz, 1587.4 Hz, 2000.0 Hz, 2519.8 Hz, 3174.8 Hz, 4000.0 Hz, 5039.7 Hz, 6349.6 Hz, 8000.0 Hz, 10079.4 Hz, 12699.2 Hz and 16000.0 Hz. Afterwards, the data was processed with MS Excel (Microsoft Corporation 2020) and evaluated and graphically displayed with R (RStudio Team 2020).
Since some of the Audiomoth devices stopped measuring after a certain period of time, only the first 2 days (48 hours) were used for the analysis of the noise level instead of four days (96 hours). Moreover, the following trees had to be excluded from the analysis of the noise data due to missing and defective data: Nm7, Nr2, Nr5, Nr6, Nr7, Nr9, Nr10, Nr11, Nr12 and Nr13.

To test the hypotheses, the three groups of breeding trees, reference trees and random trees were compared by using an ANOVA, thus comparing the mean values of the groups. Checking the assumptions of an ANOVA, the Shapiro-Wilk Test (Field et al. 2013) showed normal distribution for temperature, but not for ALAN and noise, which also becomes clear in the histograms (Appendix VIII). Variance homogeneity was tested with Levene's Test (Field et al. 2013) and was given for temperature, ALAN and noise, which is also illustrated in the Residuals vs. Fitted Plots (Appendix IX). Since not all data was normally distributed, a permutation test with 10,000 permutations was performed to determine significancy (Anderson and Braak 2003). Moreover, in case of a significant result of the ANOVA a Tukey Post-hoc-Test was conducted to identify significant differences between groups (Field et al. 2013).

A logistic regression model was created to show graphically at which values of ALAN and noise it can be assumed that a tree is a potential breeding tree of the rook according to the criteria ALAN and noise. Reference trees and random trees were summarised as non-breeding trees (N) and compared to the breeding trees (B).

For all tests a significance level of 0.05 was chosen.

Outliers were identified with Cook's Distance (Field et al. 2013; Appendix X). However, as all outliers are plausible and most likely not the result of incorrect measurements, they were not excluded.

In order to classify the results, the three variables temperature, ALAN and noise were checked for correlations.

The R script is provided in Appendix XI.

9 Results

The temperature of random trees was 0.4 °C higher than the temperature of breeding trees and reference trees ($F_{2,39} = 2.68$, $p = 0.081$).

At 1.64 lx the difference in light levels between breeding trees and random trees was significant ($F_{2,41} = 3.16$, $p = 0.046$, Nm-Bm: $p = 1.00$, Nr-Bm: $p = 0.08$, Nr-Nm: $p = 0.11$).

The main difference between Bm and other trees was the >5dB higher mean noise level (Figure 27). However, only the difference between Bm and Nr was significant ($F_{2,30} = 3.87$, $p = 0.038$, Nm-Bm: $p = 0.12$, Nr-Bm: $p = 0.05$, Nr-Nm: $p = 0.78$). The probability of a rook breeding at a given site increased from about 20% at noise levels <25 dB at that site to about 90% at >45 dB (Figure 28).

Temperature, ALAN and noise showed medium positive correlations with each other (Figure 29).

Appendix XII is giving a detailed table with all values of temperature, ALAN and noise measured.

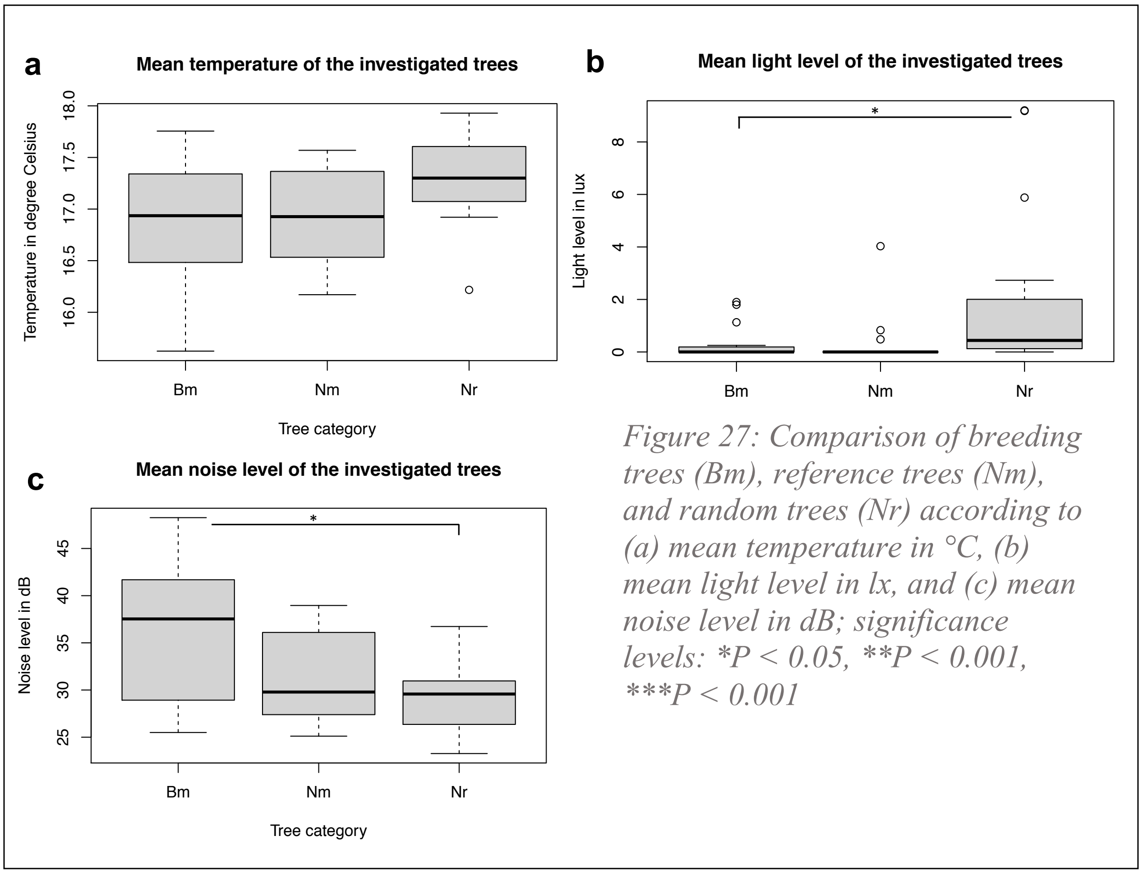

*Figure 27: Comparison of breeding trees (Bm), reference trees (Nm), and random trees (Nr) according to (a) mean temperature in °C, (b) mean light level in lx, and (c) mean noise level in dB; significance levels: *P < 0.05, **P < 0.001, ***P < 0.001*

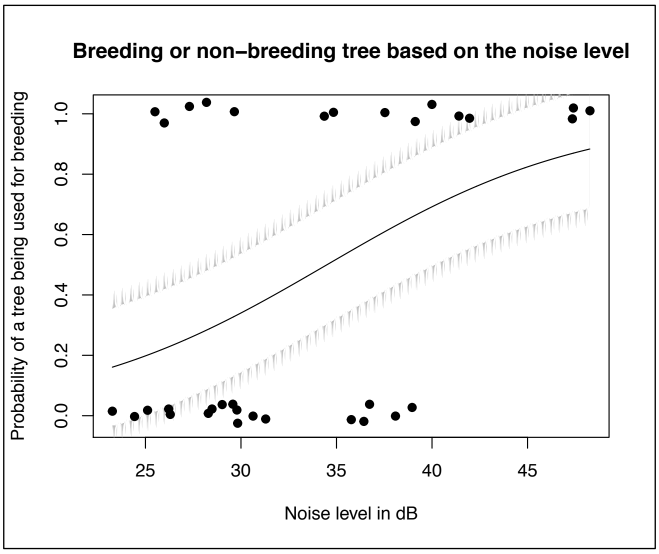

Figure 28: Noise level indicating when a tree becomes a potential breeding tree

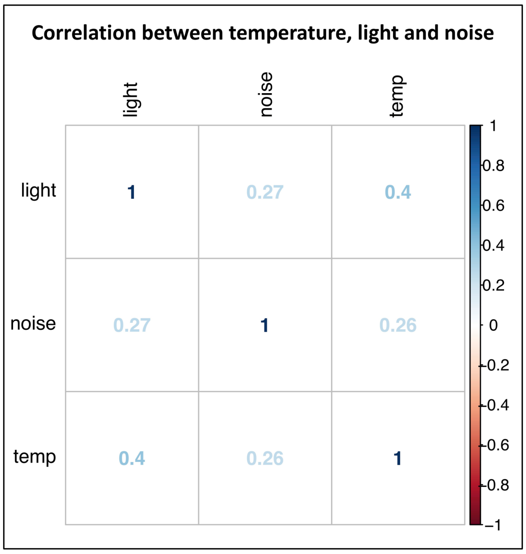

Figure 29: Correlation between the independent variables temperature, light, and noise

10 Discussion of the results of the measurements

Of the three variables investigated, noise had the greatest effect on the breeding tree selection of the rook in Landau, whereas temperature had no effect.

10.1 Temperature

There is no significant difference between breeding trees and reference trees or random trees. Thus, the hypothesis that rooks prefer trees exposed to higher temperatures for breeding has to be rejected.

It can be assumed that temperatures do not vary much in the whole city of Landau. The trees examined are distributed over the whole city, and the minimum and maximum mean night temperatures differ only by 2.31 °C. Those small variances in temperature at different breeding sites might be compensated by the nest design, as is known from other bird species (Gloutney and Clark 1997; Mainwaring et al. 2014; Skowron and Kern 1980). Nevertheless, the results show that there are variations in temperatures between different locations within Landau. As expected, the trees with the highest mean night temperatures per sample group were located along streets, while those with the lowest mean night temperatures were located in urban green spaces. That is also obvious in Figure 30, which shows that urban green spaces are less affected by urban heat island effects than streets and residential areas. Some breeding trees are in red areas, i.e. areas highly affected by UHIs (e.g. Bm14), whereas others are in yellow (e.g. Bm12) or green (e.g. Bm3) areas and thereby less affected by UHIs. However, the question arises whether a larger sample would have led to a different result. Since breeding trees along roads as well as in urban green spaces were investigated, the data could cancel each other out, so that no significant differences can be identified. It is possible that more breeding trees are located in warmer areas than in colder ones in total. However, that is only speculation and would need to be tested by investigating all breeding trees within Landau. Nevertheless, breeding trees of rooks in general are located at sites with different temperatures, although rooks would have the opportunity to predominantly choose warmer locations for breeding, as there seem to be enough potential breeding trees located in warmer areas. Consequently, the results suggest rooks do not choose breeding trees exposed to higher temperatures in particular.

Other factors, such as predation, can be more important than temperature in breeding tree selection as is assumed for Chestnut-collared Longspurs (*Calcarius ornatus*), which prefer nest sites that face southeast and are therefore exposed to higher temperatures, although the chicks grow up more slowly in those nests (Lloyd and Martin 2004).

However, the statement by Dietzen and Simon (2017) that the milder climate within cities is the reason for the rook to breed in cities, which had reinforced the hypothesis that rook breeding trees are exposed to higher temperatures than non-breeding trees can neither be proven nor confirmed by the present study, as it remains unclear what temperatures prevail in non-urban areas.

Nevertheless, the question is to what extent the results of this thesis are in line with existing literature.

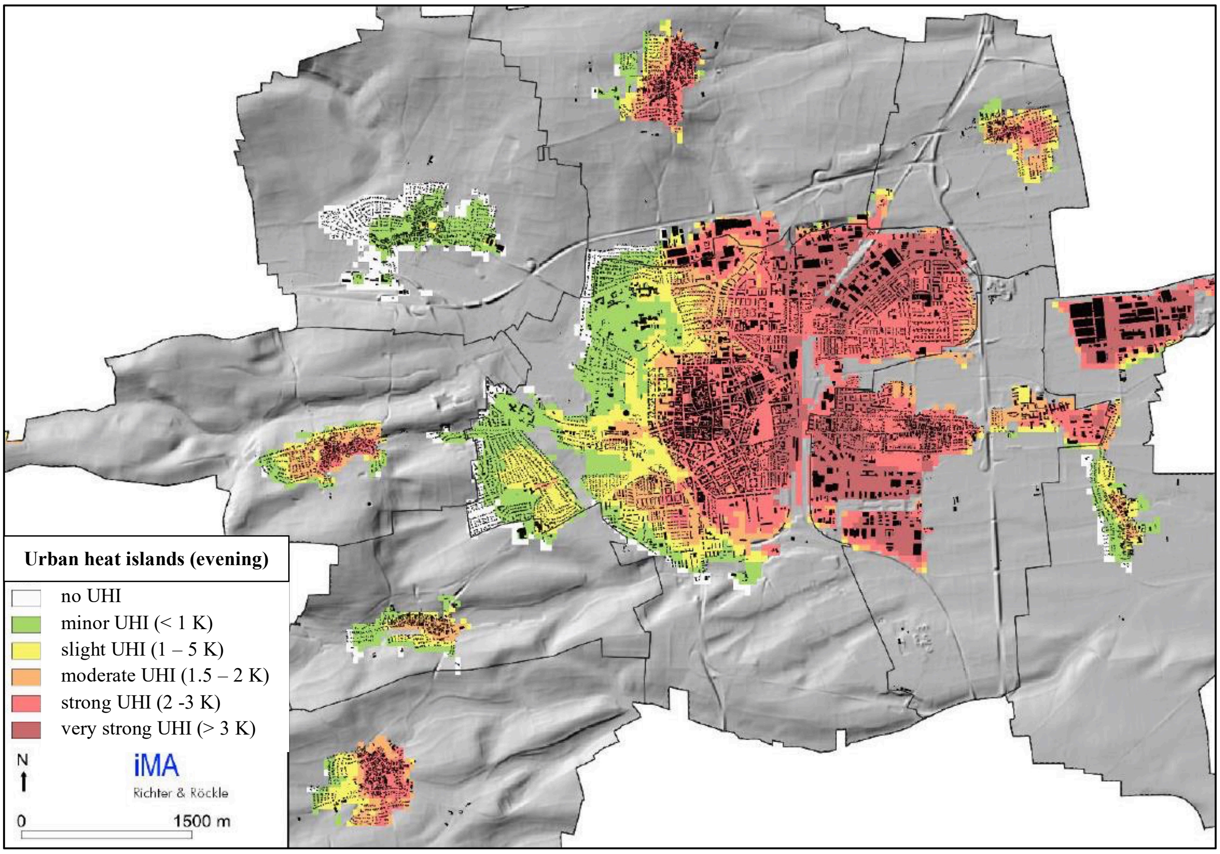

Figure 30: Temperatures in the urban area of Landau - figure created in the process of the urban climate analysis Landau 2019 and taken from Weigel and Sauer (2020), adapted

In this context, the comparability of the results of this thesis with results of other studies is problematic due to study areas in different climates, other bird species studied, different measurement methodologies or other study questions. Nevertheless, some conclusions regarding the results of this thesis can be drawn from existing literature, which are discussed in the following.

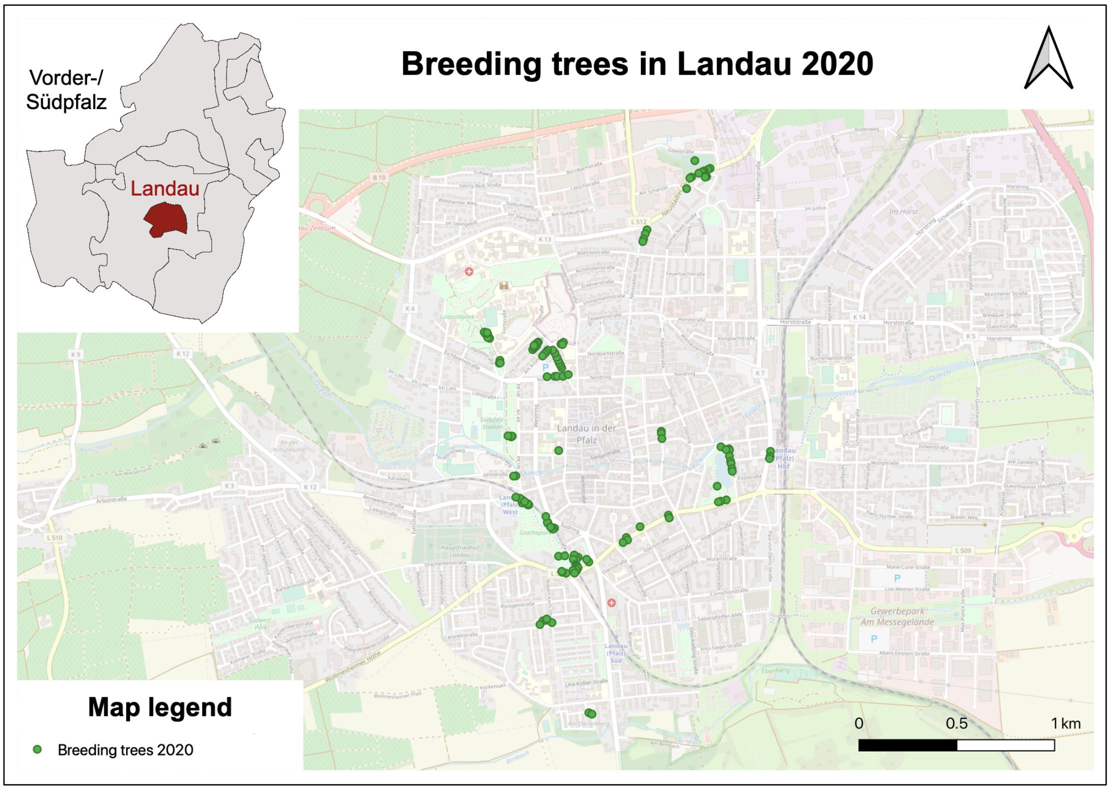

Figure 31: Breeding trees in Landau in the year 2020 (Basemaps: Bundesamt für Kartographie und Geodäsie 2020 and OpenStreetMap 2020)

There was only one study found that investigated the impact of temperature on breeding success of the rook. The study area investigated by Rytkönen et al. (1993) was located in northern Finland and rooks had a higher breeding success at higher temperatures due to better food availability. The reason for reduced food availability was frozen ground (Rytkönen et al. 1993). However, the risk of frozen ground during the breeding season in Landau is much lower than in northern Finland. Moreover, it was observed that rooks in Landau fly primarily to the surrounding vineyards and fields in search of food. Thus, milder temperatures within the city do not seem to be connected with food availability.

However, this shows that studies conducted under other climatic conditions are difficult to compare with the results of this thesis. Of the studies presented in the theory, the one by Facey et al. (2020) is the most comparable to Landau in terms of temperatures (min. 6.8 °C, max. 23.8 °C, mean 15.4 °C). They determined that breeding success of Barn swallows is higher at colder temperatures. As an explanation, the scientists assume that insects that serve as food are found in higher densities at colder temperatures and thus provide an easy food source (Facey et al. 2020). However, this thesis did not investigate breeding success, but the rook's

choice of breeding site in relation to temperature. Thus, the extent to which temperature can influence the rook due to weather fluctuations is not the research question of this thesis.
Nevertheless, the studies of Facey et al. (2020) and of Rytkönen et al. (1993) show that the influence of temperature on breeding success can be related to fluctuations in food availability due to temperature. For that reason, foraging behaviour and food availability for the rook as a consequence of temperature fluctuations or temperature differences between different breeding sites and thus the effect on breeding success and breeding site selection would have to be investigated for Landau.
In addition, different methodologies for measuring temperature can examine different research questions and lead to different results. Both studies (Facey et al. 2020; Rytkönen et al. 1993) did not use detailed data from the breeding sites as a data source for the temperature, but instead data from a meteorological station located 1.5 km away from the study area (Facey et al. 2020), or temperature data measured at an airport 15 km away from the study area (Rytkönen et al. 1993). However, this thesis has measured the temperature of breeding and non-breeding trees within Landau and thus compares the microclimate of different locations within a city. Thus, when using meteorological data it is not the microclimate that is examined, but temperature differences on a much larger scale.
Nevertheless, some of the studies presented previously have investigated the microclimate by comparing nest temperature with outdoor temperature (Carroll et al. 2018; Hovick et al. 2014; Imlay et al. 2019; Lloyd and Martin 2004). Although, in this thesis it was not the temperature inside the rooks' nests that was measured but at the breeding trees, the methodology of this thesis is most comparable to the study by Hovick et al. (2014). The researchers investigated operative temperature in relation to the ground-nesting greater prairie chicken (*Tympanuchus cupido*) in Oklahoma, USA. Operative temperature in addition to air temperature includes radiation, wind and humidity (Dzialowski 2005; Hovick et al. 2014). The operative temperature inside the nest was compared to several measurements across the landscape. The scientists showed that the temperatures within the landscape where the greater prairie chicken breeds differed by as much 23 °C when the air temperature was over 30 °C. Thus, at higher air temperatures, the temperatures measured in successful nests were 6 °C colder on average than at other sites measured in the landscape (Hovick et al. 2014). However, temperature fluctuations within Landau are not as great, which could be the reason why the temperature in Landau had no effect on the breeding tree selection of rooks in contrast to Hovick et al. (2014).
Nevertheless, Gloutney and Clark (1997) have also shown that measuring the operative temperature can be appropriate, i.e. insolation is taken into account.

Gloutney and Clark (1997) demonstrated that temperature between nest sites of mallards (*Anas platyrhynchos*) and blue-winged teals (*Spatula discors*) in comparison to unoccupied potential nest sites do not differ, while insolation at the nest sites is lower than at the unoccupied sites, which indicates that blue-winged teals seem to prefer nest sites exposed to less insolation. Nevertheless, it does not seem that rooks avoid insolation, since rooks deliberately use tree genera as breeding trees that sprout late, such as Platanus. Therefore, rook nests on Platanus can be assumed to be exposed to more insolation than nests on other tree genera.

But it is not only different study questions, climatic zones or methodologies that make it difficult to compare the results of this thesis on the rook with studies on other bird species; the different biology of the birds might also influence the results. Unlike rooks, most of the bird species on which the effect of temperature on breeding success or breeding site selection has been studied are ground-nesting birds (Carroll et al. 2018; Hovick et al. 2014; Lloyd and Martin 2004). Maybe this is because measuring the temperature in the nest and monitoring breeding success is easier with ground-nesting birds than for example with rooks, which breed in treetops (Dietzen and Simon 2017).
However, such differences in breeding biology may also influence temperature differences at various breeding sites. For example, Hovick et al. (2014) demonstrated that - at air temperatures of over 30 °C - the vegetation structure on the ground, in this case tallgrass prairie, was the reason for temperature differences of up to 23 °C at various sites within the study area. In addition, various studies on ground nesting birds have shown that the orientation of the nest is crucial for the effect of temperature on breeding success, i.e. how much radiation reaches the nest (Lloyd and Martin 2004; With and Webb 1993). Whether the orientation of the nest in the crowns of breeding trees is also specifically selected by rooks with regard to temperature still has to be investigated. Consequently, this gives rise to the question of the extent to which temperature at breast height on the trunk is representative of the temperature to which individual nests in the crown are exposed, as the vegetation structure of the crown and insolation might also affect the microclimate of the nests.

Therefore, it is difficult to compare the results of the influence of temperature on breeding success and breeding site selection of the various different studies with each other and with the results of this thesis. No study that is comparable to this thesis in terms of bird species, climate zone and methodology could be found. Nevertheless, some conclusions can be drawn from the existing studies regarding the results of this thesis and especially regarding unresolved questions that should be investigated in future studies. Firstly, the influence of temperature on breeding success is often related to food availability, which is not assumed for the rook in Landau, but would need to be investigated further. Secondly, taking into account the microclimate within the crown due to vegetation structure and radiation could increase the significance of the results, whereby measurement of the operative temperature should also be considered.

10.2 ALAN

ALAN can influence both breeding success (Amichai and Kronfeld-Schor 2019; Kempenaers et al. 2010; Lambrechts et al. 1997; Poesel et al. 2005) and breeding site selection (Hennigar et al. 2019; Russ et al. 2017), which is also shown by the results of this thesis indicating that - in contrast to the hypothesis - rooks avoid trees exposed to ALAN for breeding. With a difference of 1.64 lx, random trees are exposed to significantly more ALAN than breeding trees. Therefore, the hypothesis that breeding trees are exposed to more ALAN than reference trees or random trees has to be rejected.

It is important to consider whether this result is influenced by the tree selection. The question of why trees in the interior of parks are not used as breeding trees has arisen frequently, so many reference trees are located in the interior of parks, whereas the corresponding breeding trees are located along roads. Thus, the result that breeding trees are not exposed to more ALAN than reference trees is surprising.

However, the fact that trees in the park interior are less affected by ALAN than those along streets is supported by the results of this thesis. Two of the three trees exposed to the most ALAN of each group were located along streets (Bm14, Nm12), while only Nm13 is located within a park directly next to a street lamp. 20 of the 44 trees investigated are not exposed to ALAN at all, i.e. 8 of 15 breeding trees, 10 of 13 reference trees and 2 of 16 random trees. Nearly all of those trees are located in urban green spaces. However, it is striking that Nm1 is not exposed to any ALAN according to the measurement although it is located along Neustädter Straße. That is because the tree is located in a small strip of forest along the road and surrounded by bushes, so the ALAN value measured at breast height around the trunk was 0.00 lx. However, the value in the crown might be higher.

ALAN is investigated in this thesis because it is assumed that ALAN is higher along transport axes. However, the trees located along the railway track in Goethepark are not exposed to

ALAN just like those located inside the park, because street lights are found in particular along roads and not along railway tracks. Thus, ALAN cannot be the reason for breeding trees located along railway tracks.

The ALAN level to which trees are exposed to depends strongly on the distance to the closest street light. Thus, one tree such as Nr13, which is located directly next to a street light, can influence the result of the entire group, which gives rise to the question of how representative the samples are. If the mean distance to the nearest street light is compared within the groups, it is shorter for random trees ($\mu_{Nr,\ distance\ light} = 17.53$ m) than for breeding trees ($\mu_{Bm,\ distance\ light} = 25.73$ m) and reference trees ($\mu_{Nm,\ distance\ light} = 35.15$ m). Thus, a larger sample would increase the validity of the results considerably.

Consequently, according to the results of this thesis, ALAN cannot explain why reference trees are not used as breeding trees. However, the results of this thesis suggest that rooks tend to choose trees that are exposed to less ALAN for breeding, since breeding trees are exposed to significantly less ALAN than random trees.

Furthermore, the question is how large the significant difference in the mean values of ALAN actually is. The difference in the mean value between breeding trees and random trees is 1.64 lx. Kybar et al. (2017) showed that a full moon results in an illuminance of 0.05 to 0.1 lx. According to DIN EN 1838 emergency lighting has to ensure an illumination of 1 lx (Fördergemeinschaft Gutes Licht 2016) whereas directly under a street lamp the value is 10 lx (Fördergemeinschaft Gutes Licht 2014). Thus, since many of the trees investigated are exposed to 0.00 lx and the 1.64 lx difference reflects the difference between the mean values of all trees in the two groups of breeding trees and random trees, the difference is comparatively large.

The question is to what extent the result of this thesis, i.e. rooks avoiding ALAN in breeding tree selection, can be integrated into the existing literature.

The impact of ALAN on rook behaviour, breeding success and rook breeding site selection is largely unexplored and only the study by Ciach and Fröhlich (2017) investigated the influence of ALAN on the abundance of different bird species, including rooks. Nevertheless, studies on other bird species may provide indications and explanations why the rook in Landau seems to prefer breeding trees that are less exposed to ALAN than randomly selected sites.

Ciach and Fröhlich (2017) have shown in their study that the abundance of birds in winter generally correlates positively with ALAN, taken from the Light Pollution Map of Microsoft Bing Maps (MBM 2015) whereby the researchers examined rooks, among others. The results of this thesis contradict the results of Ciach and Fröhlich (2017) and thus also the hypothesis of this thesis. Since the study of Ciach and Fröhlich (2017) does not provide any details on the rook and on the different values of ALAN, it is difficult to discuss the causes and differences compared with this thesis. However, Ciach and Fröhlich (2017) conducted their study in winter and not during the breeding season. Therefore long, dark winter nights might possibly increase the number of birds and also rooks that choose areas exposed to ALAN, which is also suggested by the researchers. Moreover, during the breeding phase, other factors could be more important for the choice of breeding sites than ALAN, which is not important in winter, e.g. protection of chicks from enemies. Thus, it is crucial to compare the results of this thesis with studies on other bird species during the breeding phase.

There are several studies on bird species that investigate the effect of ALAN on breeding site selection (Hennigar et al. 2019; Jong et al. 2015; Russ et al. 2017). The study by Hennigar et al. (2019) shows that some bird species were repelled by light, while others were attracted. By means of an experimental study in which sample plots in an undisturbed forest in Canada were exposed to light during the breeding season, scientists investigated how light affects species composition and abundance. In that context, the researchers used the lamp of the model GLUX-RGB18W-S40B-MCL (Hennigar et al. 2019). That lamp has 525 lumens and a beam angle of 40° (superbrightleds.com n.d.). As the lamp was located at a height of 4.3 m (Hennigar et al. 2019) on average, the area on the ground was illuminated with 74.93 lx (WSH GmbH n.d.). 74.93 lx is much brighter than a common street light, as those illuminate the ground with 10 lx (Fördergemeinschaft Gutes Licht 2014). Thus, it can be assumed that the effect of light during the experiment of Hennigar (2019) was much stronger than the effect caused by street lighting, which was investigated in this thesis.
Most birds in the study were not attracted by light and – of six bird species examined in detail - one was repelled, i.e. Swainson's thrush (*Catharus ustulatus*; Hennigar et al. 2019). Hennigar et al. (2019) explained the fact that - contrary to the researchers' expectations - most birds were not attracted to light by the circumstance that the study was conducted in the forest, where the light was attenuated by vegetation and may not have been powerful enough. Nevertheless, as the light in the experiment was much more powerful than that of a street light, the effect of the vegetation during the experiment might be neglected when comparing the results of the study to those of this thesis. Hennigar et al. (2019) assume that Swainson's thrush avoids light because it specialises in living in forests (Whitaker and Montevecchi 1999) and may thus be more sensitive to changing habitat conditions (Bonier et al. 2007) or because it searches for food on

the ground (Holmes and Recher 1986; Holmes and Robinson 1988), whereby Swainson's thrush might thus be more affected by light than the bird species that forage in the leaf canopy (Hennigar et al. 2019). However, as rooks breed in rural areas as well as within cities, they do not seem to specialise in dark habitats. Rooks also forage on the ground (Dietzen and Simon 2017; Rörig 1900), but they seem to forage primarily in the surrounding vineyards and fields, which are not directly illuminated. Thus, although Swainson's thrush also avoids light, the explanations provided by Hennigar (2019) cannot explain why rooks prefer breeding trees exposed to less ALAN.

Although the European blackbird is attracted by ALAN and not repelled, the study by Russ et al. (2017) is the one that is most comparable with the methodology and results of this thesis for three reasons: (1) the study was conducted under natural conditions and not experimentally, (2) the study area is a city and (3) just like the rook, European blackbirds breed in nests and are not cavity-breeders.

The European blackbird nests are exposed to a wide range of ALAN with some nests exposed to almost no ALAN at all and some nests located in the highly illuminated city centre (Russ et al. 2017), just like rook nests within Landau. In this context, nests of European blackbirds that were destroyed or depredated were exposed to significantly more ALAN than nests exposed to less ALAN, although in their sample European blackbird nests tend to be found in lighter rather than darker areas (Russ et al. 2017). Thus, many European blackbirds do not breed at the sites that would be most appropriate for breeding success according to the level of ALAN. That could also be the case for the rook within Landau, as there are breeding trees both exposed and not exposed to ALAN. However, it is not clear beyond any doubt whether rook breeding success is impaired by ALAN and. thus, whether rooks breeding on trees exposed to more ALAN have less breeding success. Further studies are necessary to determine this.

However, when discussing the results, it is necessary to take into account that in different studies the data on ALAN come from different sources. Russ et al. (2017), for example, used street lighting data to calculate how much light the breeding sites that were studied are exposed to, following the methodology of Nordt and Klenke (2013). Thus, those results should be quite comparable with those of this study. However, Ciach and Fröhlich (2017), on the other hand, took the data on ALAN from the Light Pollution Map of Microsoft Bing Maps (MBM 2015). Those data are thus on a much larger scale compared to the detailed measurements of the breeding trees as carried out in this study. Thus, the methodology of Ciach and Fröhlich (2017) is suitable for large-scale comparisons of breeding habitats, but difficult to compare with the smaller-scale results of this thesis where breeding trees in a city, which may be only a few hundred metres apart, are compared.

Nevertheless, as rooks in Landau -unlike the European blackbird - tend to breed in darker locations, the question is to what extent rooks might be impaired by ALAN or why they might not benefit from ALAN.

In the case of the European blackbird, Russ et al. (2017) reason that the choice of brightness at breeding sites is a trade-off between the danger posed by shy nocturnal predators, which are more likely to be a danger in dark locations, and avian predators, which are more likely to target open nests illuminated brightly. As the tendency of the results of this thesis shows that breeding trees are exposed to less ALAN than random trees, the reason could possibly be that the predator pressure on rooks is lower in darker areas than in illuminated areas.

The rook’s natural predators include the northern goshawk, peregrine falcon, eagle owl and marten (Andris and Westermann 2011). Of those, the northern goshawk (Blakey et al. 2020) and peregrine falcon (Kettel et al. 2016) are both diurnal raptors, whereas the eagle owl (Svensson 2017) and marten (Roy et al. 2019) are nocturnal. Thus, as some of the rook’s predators are diurnal and some are nocturnal, it can be assumed that predation pressure is somehow affected because ALAN extends the natural length of day by illuminating the night. Therefore, it is possible that predator pressure by diurnal raptors, i.e. northern goshawk and peregrine falcon, is increased in areas affected by ALAN because their activity period might be extended. It has already been observed that Peregrine falcons hunt and feed their chicks at night-time in urban areas (DeCandido and Allen 2006; Kettel et al. 2016). Hence, the effect of ALAN on the hunting behaviour of the northern goshawk, peregrine falcon, eagle owl and marten has to be investigated in order to obtain an overall assessment of the effect of ALAN on the breeding tree selection of rooks.

Other reasons that could reduce breeding success at sites exposed to high levels of ALAN and thus lead to rooks breeding more at dark sites are a prolongation of the activity phase (Amichai and Kronfeld-Schor 2019; Da Silva et al. 2015; Dominoni et al. 2013; Jiang et al. 2020; Leveau 2020; Russ et al. 2014; Welbers et al. 2017) and the associated impairment of sleep (Aulsebrook et al. 2020; Jiang et al. 2020; Raap et al. 2015). But the extent to which ALAN influences the activity phase of rooks in Landau remains unclear.

Moreover, the extended activity phase and thus longer periods of foraging time for diurnal birds in illuminated areas (Dwyer et al. 2013; Leveau 2020; Santos et al. 2010) might be an advantage for bird species that forage in the immediate vicinity of their nests, e.g. for the great tit with a territory size of up to 2 ha (Krebs 1971; Wilkin et al. 2006). In contrast, rooks search for food within an area of 30 to 300 ha (Czarnecka and Kitowski 2013; Griffin and Thomas 2000), whereby rooks in Landau can be observed foraging especially in the surrounding vineyards and fields and returning to the city at twilight. Thus, an increase in the ability to search for food longer at the breeding site due to ALAN does not to seem to be as important for rooks as for blue tits.

However, nothing is known about the effect of ALAN on the sleeping and feeding behaviour of rooks nor on changed predation pressure, and consequently on rooks' breeding success. All of that would have to be investigated for an all-encompassing assessment of the effect of ALAN on the choice of breeding trees by rooks.

Furthermore, the question is whether the factor that influences the choice of breeding trees is not brightness as such but rather luminous colour, because it is a known fact that luminous colour can have an influence on the behaviour of birds (Aulsebrook et al. 2020; Hennigar et al. 2019; Jong et al. 2015; Zhao et al. 2020). However, the information provided by the municipal planning and building control office of Landau on the luminous colour of the street lighting closest to the trees studied (Heck 2020) shows that there is no discernible tendency for luminous colour to influence breeding tree selection. The luminous colours within the groups of breeding trees ($\mu_{Bm,}$ = 3133 K), reference trees ($\mu_{Nm,}$ = 3167 K) and random trees ($\mu_{Nr,}$ = 3118 K) differ only slightly. Even when comparing pairs of breeding trees and reference trees where it remains questionable why one tree is occupied and the other is not, such as Bm2 and Nm1 (both 4000 K) or Bm6/Bm7 and Nm5 (all three 3000 K) or Bm12 and Nm8 (both 3000 K), no differences in luminous colour are detectable (Appendix XIII).

In addition, the question is also how much light actually reaches the crown at nest height. It may be that less light reaches the nests and that the difference between breeding trees and random trees measured at nest height might not be significant. Therefore, the conclusion that rooks prefer breeding trees that are exposed to less ALAN would be wrong. All street lights in the town are shielded on top (Heck 2020), which means that probably relatively little light reaches the nests. However, there are isolated street lighting systems mounted at a greater height centrally above the roadway, called middle street light in Appendix XIII. It is possible that more light from those street lights may reach nests in the vicinity.

But it is not only the height of the street light and the distance between the tree and the street light that is decisive, but also whether the area in between is open or whether the light is shielded by houses or trees. Thus, it is clear that the collection of the data presented in Appendix XIII can only be an initial small contribution to the discussion about the extent to which luminous colour influences the breeding behaviour of the rook.

In order to obtain clear results as to whether ALAN has an influence on breeding tree selection, more detailed investigations are needed, especially how much light actually reaches the rooks' nests and can thus actually influence the choice of breeding tree.
Neither luminous colour nor changes in feeding behaviour seem to be the reason why rooks in Landau prefer breeding trees that are less exposed to ALAN than random trees. Increased enemy pressure due to ALAN seems to be a possible explanation. However, all those possible reasons are only assumptions and possible explanations, especially on the basis of other studies on other bird species, and further research is needed to clarify the extent to which ALAN influences the breeding tree selection of the rook in Landau and what the underlying causes are. Whether more definite conclusions regarding the influence of noise on the breeding tree selection of the rook in Landau can be drawn is discussed in the following chapter.

10.3 Noise

The fact that noise can influence the choice of breeding sites for birds (Francis et al. 2009; Halfwerk et al. 2016; Hennigar et al. 2019; Liu et al. 2020) is also demonstrated by the results of this thesis, as rooks in Landau prefer breeding trees that are exposed to more noise than non-breeding trees, whereby the difference between breeding trees and reference trees ($\Delta_{\mu Bm-\mu Nm}$ = 5.25 dB) is not significant, but it is significant between breeding trees and random trees ($\Delta_{\mu Bm-\mu Nr}$ = 7.35 dB). Thus, the hypothesis that breeding trees are exposed to more noise than reference trees or random trees is the only hypothesis that can be accepted.
The circumstance that reference trees tend to be less exposed to noise than breeding trees could be because reference trees are located more often in the interior of parks and thus further away from roads. The fact that reference trees are nevertheless exposed to more noise than random trees shows that in Landau there are numerous potential breeding trees in locations that are exposed to less noise and are not used as breeding trees. However, although breeding trees and random trees both have only few trees within urban green spaces and thus most trees are along main roads, minor roads and railway tracks (Table 9), noise is significantly higher at breeding trees. Consequently, rooks really seem to choose breeding trees that are exposed to more noise, whereby noise depends on the traffic load.

However, the majority of the AudioMoths that failed during the noise measurement were intended to measure noise at trees in the random tree group (Table 9). Thus, there is no data on four of five random trees located along main roads. Consequently, the defective AudioMoths could have distorted the result, making the difference between breeding trees and random trees more significant. Nevertheless, data was collected for one random tree located on a main road and for five random trees along smaller roads.

Table 9: Location of investigated breeding trees along main roads (Landstraße, Kreisstraße), minor roads and railway tracks and within urban green spaces - the measuring devices failed for the trees the ID of which is crossed out, so no data was available

Main roads	Minor roads, railway tracks	Urban green spaces
Bm2, Bm14	Bm4, Bm6, Bm7, Bm9, Bm10, Bm11, Bm12, Bm13, Bm15	Bm1, Bm3, Bm5, Bm8
Nm1, Nm4, Nm5, Nm6, Nm12, ~~Nm13~~	-	Nm2, Nm3, ~~Nm7~~, Nm8, Nm9, Nm10, Nm11
~~Nr2~~, ~~Nr7~~, Nr8, ~~Nr11~~, ~~Nr12~~	Nr1, Nr3, Nr4, ~~Nr5~~, ~~Nr6~~, ~~Nr9~~, ~~Nr10~~, Nr15, Nr16	~~Nr13~~, Nr14

A larger sample would have been able to compensate for the failed AudioMoths better and would increase the meaningfulness of the results. Nonetheless, the result shows that there are many other potential breeding trees exposed to less noise than selected breeding trees, thus suggesting that rooks prefer trees exposed to more noise for breeding. However, it is questionable whether there is a causal relationship between breeding tree selection and noise or whether the rook benefits from other factors along roads and therefore accepts noise.

However, no other study is known to have investigated the influence of noise on rook breeding site selection and only one study, that of Ciach and Fröhlich (2017), is known to have investigated the effect of noise on rooks at all. Nonetheless, comparisons with the results of studies on other bird species can help to interpret and discuss the results of this thesis.
Results of the investigations of the effect of noise on the abundance of different bird species, among others the rook, conducted during winter by Ciach and Fröhlich (2017) show that birds in general avoid noise. As rooks were one of the species with the highest abundance in the

sample plots it can be assumed that rooks were not repelled by noise, although detailed information on the effect of noise on rooks is not given in the study. The results of this thesis also support the conclusion that rooks are not repelled by noise, since the breeding trees of rooks in Landau are exposed to significantly more noise than randomly selected trees. Thus, the results of this thesis are consistent with two of the studies presented in the theoretical background, which show positive effects of noise on breeding site selection of other bird species (Francis et al. 2009; Halfwerk et al. 2016).

The study by Halfwerk et al. (2016) suggests that interspecific competition would also have to be examined and taken into account for an overall assessment of the choice of breeding trees by rooks. Blue tits (*Cyanistes caeruleus*) bred in nest boxes exposed to noise more often than in quiet control nest boxes and more than the great tits, which were investigated at the same time. The researchers assume that the reason is the more dominant great tits prevail in the choice of nesting place and occupy the nest boxes that are not exposed to noise (Halfwerk et al. 2016). Thus, it is questionable which more dominant bird species the rook could compete with in the choice of breeding trees.

Francis et al. (2009) showed that one reason for birds to choose habitat exposed to noise may be less masking of some bird species' communication or masking of the birds' predators. This could be a reason why rooks also prefer breeding trees exposed to noise. Francis et al. (2009) conducted an experimental study in the field in a mainly forested area of investigation in Mexico where gas is extracted. The researchers examined the abundance of breeding birds in one study area where compressors made noise and in a comparison area where they were quiet. That revealed that the density of birds was the same at both locations, although the species composition differed with 21 species on the noisy plot and 32 species on the quiet comparison plot. 3 bird species only occurred in the area exposed to noise and 14 bird species only in the quiet area. In this context, Francis et al. (2009) examined the black-chinned hummingbird (*Archilochus alexandri*) and the house finch (*Carpodacus mexicanus*) in greater detail. 92% of all individuals of the black-chinned hummingbird and 94% of all individuals of the house finch nested in the noise-exposed area, with both species together accounting for 31% of all breeding birds in the noise-exposed area, which shows that both species prefer to breed exposed to noise. Francis et al. (2009) explain that on the one hand with the presumption that the species may be less affected by masking in comparison to other birds and on the other hand with reduced enemy pressure in the noise-exposed area.

Urban noise mainly occurs at lower frequencies (Potvin et al. 2014; Wood et al. 2006) and might not impair the two species, because black-chinned hummingbirds communicate within a frequency range of 1.5 to 12 kHz (Francis et al. 2009; Rusch et al. 1996), while house finches adapt by communicating at higher frequencies (Fernández-Juricic et al. 2004; Francis et al. 2009).
However, rook calls are mainly at frequencies between 1 and 2.5 kHz (Fankhauser 1995; Røskaft and Espmark 1982) and occasionally at 8 kHz (Røskaft and Espmark 1982). Thus, unlike the black-chinned hummingbird (Francis et al. 2009) rooks do not appear to be optimally adapted to urban noise in terms of their frequency range, although they occasionally seem to switch to higher frequencies.

However, besides changing the frequency (Dubois and Martens 1984; Francis et al. 2011; Juárez et al. 2020; Potvin et al. 2014; Slabbekoorn and den Boer-Visser 2006; Wood et al. 2006), increasing the volume is another strategy to avoid masking (Brumm 2004; Brumm and Todt 2002; Cynx et al. 1998; Dorado-Correa et al. 2018; Singh et al. 2019). As it is known that passerines with a larger body size are more likely to adapt in that way (Cardoso 2010), it might be a possible adaptation for the rook as well. However, no measurements were carried out on the volume of rook calls within Landau. Nevertheless, the calls are perceived as loud by residents, which is one of the major conflicts between humans and rooks in general (Bannas 2018; Dietzen and Simon 2017; Fankhauser 1995; Schilling 2018; Wolsbeck 1989). Therefore, Fankhauser (1995) measured the volume of the rook's communication as well as the volume of traffic noise in Bern, Switzerland. Since his research goal was to investigate how loud rook calls are for human hearing compared to traffic noise, he used an A weighting filter in his measurements. Rooks' calls were not as loud as traffic noise (Fankhauser 1995). However, the calls of rooks might be louder than of other bird species that avoid noise. In the city of Bern Fankhauser (1995) showed that the mean level pf rook calls was 64.1 dBA. Thus, the question is whether the rook's calls are louder than those of other birds that avoid noise. No measurements with an A weighting filter to determine dBA values of other songbirds occurring in German cities were found. However, the alarm calls of great tits in the laboratory were 22 dB without noise and 70 dB when exposed to noise (Templeton et al. 2016). But as those values were measured in dB and not dBA, without a doubt they cannot be compared to the values on the rook's communication presented previously (WM Baden-Württemberg n.d.). Moreover, it must be taken into account that Fankhauser (1995) examined the totality of the communication of several rooks in the field, whereas Templeton et al. (2016) only indicate the alarm calls of great tits in the laboratory. Firstly, this means that the average volume of rook alarm calls might be louder than the volume of the entire communication. Secondly, calls of several rooks might be louder than of one individual bird. In any case, the question is how loud the rook's natural volume is without traffic noise, because the rook might naturally have a louder call compared to the great tit and may thus need to increase its volume less. Since singing expends energy, Brumm (2004) assumes that increasing the volume expends even more energy. Thus, it could be hypothesised that great tits are able to reach a similar volume as rooks or even higher, but that they need to expend more energy to do so. Since they want to save energy, it can be assumed that they avoid noise, while rooks in contrast do not have to invest as much energy as great tits and thus do not avoid breeding exposed to noise.

However, further studies are necessary in order to be able to specifically state whether rooks naturally communicate with a higher volume than bird species that avoid noise and whether rooks adapt to noise by increasing volume.

Besides the fact that black-chinned hummingbirds and house finches are likely to be less affected by masking, Francis et al. (2009) was able to show that predation pressure is lower in the noise-exposed study area, both for black-chinned hummingbirds and house finches. In the noise-exposed plot, 13% of the nests were depredated, while in the quiet comparison plot 32% of the nests were depredated (Francis et al. 2009). Francis et al. (2009) determined that the cause of this was the predator, the scrub-jay (*Aphelocoma californica*), which itself avoided noise because it itself could be affected by masking. Whether the danger from predators is lower at breeding sites exposed to noise is therefore likely to also be determined by the frequency range of the predator's communication. This raises the question of which frequencies the rook's predators use to communicate.

The eagle owl and peregrine falcon are among the avian predators of the rook (Andris and Westermann 2011) and both can communicate at high frequencies (Jurisevic and Sanderson 1994; Mollet 2019).

Mollet (2019) studied the communication of a pair of eagle owls in Switzerland. Most of the communication was male and female singing or female croaking. While the singing took place in the low frequency ranges up to about 2 kHz, the croaking of the female covered a wider range of frequencies, sometimes up to more than 10 kHz (Mollet 2019). Thus, the majority of communication took place in the low frequency ranges and could therefore be affected by masking. However, individual eagle owls are characterised by different individual calls (Lengange 2005), so frequencies might vary between individuals to some extent.

For the peregrine falcon, Jurisevic and Sanderson (1994) determined that the alarm vocalisations have a mean frequency of 9.5 kHz. In a later study on a female, Jurisevic (1998) showed that the primary frequency range of communication is between 1.8 and 5.3 kHz, with a minimum of 1.2 and a maximum of 9.2 kHz. Thus, the peregrine falcon might be partly impaired in its communication, while it might also be able to switch to higher frequencies when exposed to noise.

However, the calls of the two raptors, which encompass higher frequencies, also include lower frequencies, because the peregrine falcon as well as the eagle owl often communicated using broad frequency calls (Jurisevic and Sanderson 1994; Mollet 2019; Wrege and Cade 1977). Consequently, it is questionable whether masking at lower frequencies changes broad frequency calls in a way that communication is impaired although the raptors are able to use higher frequencies. However, Prommer et al. (2018) have shown that eagle owls are tolerant of human noise as long as it is regular and continuous and does not change suddenly. This suggests that eagle owls are not disturbed by road noise. Nevertheless, the extent to which road noise disturbs the eagle owl's hunting remains an open question.

Thus, it is not clear whether the avian predators of the rook, the eagle owl and peregrine falcon, are impaired by urban noise in their hunting behaviour, although they are able to communicate at higher frequencies. Observations and investigations on the rook's predators in Landau, which would go beyond the scope of this paper, are necessary in order to make overall statements about whether the rook's predators in Landau avoid noise. Nevertheless, it can be assumed that it is not only noise that determines whether rook nests are depredated by avian predators, but that traffic itself or the adjacent buildings might also influence the presence of predators.

Thus, the results of the study by Francis et al. (2009), which shows that predation pressure is affected by urban noise, may be transferable to the rook, but that would need to be investigated more extensively through further research into rook communication and predator abundance, i.e. comparing nest predation at quiet and noise-exposed sites.

However, as it has been observed that numerous other bird species avoid noise in experimental studies or when monitoring breeding pairs near roads compared to unaffected habitats (Bayne et al. 2008; Francis et al. 2009; Halfwerk et al. 2016; Hennigar et al. 2019; Liu et al. 2020), of even experience worse breeding success (McClure et al. 2017; Mulholland et al. 2018), it remains questionable whether the rook would not prefer quiet breeding habitats in an experimental study as well. If so, it could be assumed that factors other than noise, but which correlate with noise, are more important when choosing the breeding site, and that the rook accepts the additional costs caused by noise in order to benefit in other ways. It would then be interesting to determine which factors actually attract the rook to the city and to traffic routes.

Thus, although breeding trees are exposed to significantly more noise than random trees within Landau, it cannot be assumed with certainty that noise itself is the decisive factor in breeding tree selection, because the investigations of this thesis were not conducted experimentally but by observation in the rooks' natural habitat. Consequently, another factor that correlates with noise and thus with traffic routes might be decisive for the choice of breeding trees. Nevertheless, noise could be the reason by increasing nest survival due to reduced predation if the rook's predators itself are impaired by noise.

All in all, temperature has no influence on breeding tree selection of the rook in Landau. However, breeding trees are exposed to less ALAN and more noise than random trees. But neither ALAN nor noise show a significant difference between breeding trees and reference trees. Consequently, it remains questionable why reference trees are not used as breeding trees. The fact that breeding trees and reference trees often have similar values and show no significant difference may be due to the fact that they are often comparatively close to each other. It seems that the colonies are not yet saturated and that many of the reference trees could be used as breeding trees in subsequent years, but that would have to be investigated further for a validated statement.

Nevertheless, ALAN and noise can be initial indicators that explain the breeding tree selection of the rook on a medium-scale view within a city (breeding trees vs. random trees), whereas for a small-scale explanation within a few hundred metres (breeding trees vs. reference trees) other factors seem to be decisive.

10.4 Discussion of selected comparisons between breeding trees and reference trees

The trees of the breeding tree and reference tree categories were selected because a comparison between them would be interesting as - at first glance - it is unclear why reference trees are not used for breeding. Thus, breeding trees and reference trees are compared in detail in this chapter. In this context, the extent to which ALAN and noise in the individual comparisons are suitable as explanations for the breeding tree selection of the rook is evaluated. Although temperature between breeding trees and reference trees is compared, it is not considered to be an explanation for breeding tree selection, as this thesis did not show a statistically significant effect of temperature on breeding tree selection of rooks within Landau. Since a comparison of all breeding trees and reference trees would go beyond the scope of this chapter, breeding trees and reference trees in the Goethepark and Sovoyenpark group as well as Alter Meßplatz, Fort and the Bürgergraben group are discussed as examples.

Goethepark, Sovoyenpark

In Goethepark, Bm9, Bm10, Bm11, Nm8, Nm9, Nm10 and Nm11 are compared as examples. The question is why Nm8 is not used for breeding, although it is just as suitable as Bm9 in terms of tree genus, height and DBH. Bm10 and Bm11, on the other hand, seem less suitable in terms of tree genus, height and DBH, which is why they are compared with Nm8 to see whether ALAN and noise can explain why they are used for breeding.

Bm9 vs. Nm8 and Nm10:

Bm9, Nm8 and Nm10 are all large Platanus, thus the preferred tree genus for breeding of rooks. In contrast to Bm9, which is located at the edge of the park next to the road and the railway track, Nm8 is located 60 m further inside the park and Nm10 even further south in the centre of the park. Contrary to the assumption that trees within urban green spaces are located in colder areas, the temperature measured at Nm8 is 0.35 °C warmer than at Bm9. Although that temperature difference is only small, it remains questionable why the temperature measured at Nm8 is higher. The temperature measuring device of Nm10 failed, which is why no data is available there. Bm9 is exposed to 1.80 lx more and 10.97 dB more than Nm8 and Nm10. Thus, in contrast to the overall result of this thesis, Bm9 is exposed to more ALAN than Nm8 and Nm10. However, that matches the assumptions on which the hypothesis was based on, i.e. breeding trees are exposed to more ALAN and more noise. With respect to the noise level, Nm8 as well as Nm10 could be breeding trees, as they have an average noise level of 36.43 dB and 38.96 dB respectively, which is not far from the mean value of all breeding trees, which is 36.52 dB. In this context, of the 15 breeding trees seven and 5 respectively are exposed to less noise than Nm8 and Nm10 respectively. Consequently, Nm8 seems to be well suited for breeding with regard to ALAN as well as with regard to noise.

Bm12 vs. Nm8:

Bm12, a Platanus located in Sovoyenpark, is at a similar distance from a busy road and the railway tracks as Nm8. A comparison of the trees was conducted to see if ALAN or noise can explain why Bm12 is used as a breeding tree by rooks and Nm8 is not. Nm8 is 0.21 °C warmer than Bm12. ALAN cannot be the decisive factor for Nm8 not being used as a breeding tree either, as both Bm12 and Nm8 are exposed to 0.00 lx. Bm12 is exposed to 5.53 dB more than Nm8.

Thus, Bm9 as well as Bm12 are exposed to more noise than Nm8 and Nm10. Although overall there are several breeding trees exposed to less noise than Nm8 and Nm10 within Goethepark and Sovoyenpark, the trees that are exposed to more noise might be chosen, which could explain why Nm8 and Nm10 were not chosen.

Nm9 and Nm11 vs. Bm10 and Bm11:

However, in Goethepark many Acer are also used for breeding, and not only the tree genus Platanus, which is preferred by rooks as a breeding tree The Acer are located in a small forest strip on the eastern edge of the park along the railway tracks. Those were compared with an Acer close to the centre of the park, Nm9, and an Acer in the southwest part of the park, Nm11, which is located in a small forest strip as well. In contrast to the forest strip in the east of Goethepark, which is next to a railway track, the forest strip in the southwest is located at the edge of the park next to gardens. As none of the trees is located along a street, no sealed surfaces are close to the trees, so temperatures are not expected to differ much. That is confirmed by the measured values with a maximum difference of 0.64 °C. ALAN cannot be the explanatory factor either, as ALAN was not detected at any of the trees, as the level as always 0.00 lx. The values for noise do not show a clear result for all trees. While Nm11 is exposed to considerably less noise, Bm10 and Nm9 are exposed to similar noise levels, whereas Bm11 is exposed to the most noise of all four trees. Thus, noise cannot explain why Nm9 is not used as a breeding tree.

Consequently, in the case of the reference trees in Goethepark, ALAN cannot be an explanation of why those are not used for breeding in contrast to breeding trees. Noise, on the other hand, shows a tendency to frequently be greater for breeding trees than for reference trees in a direct comparison. Nevertheless, the noise level of breeding trees is not always higher than that of reference trees. Above all, the noise level of reference trees in Goethepark is often higher than the average noise level of all investigated breeding trees in Landau. Therefore, it is possible that the trees in one area that are exposed to more noise are selected, but that it is not the absolute noise level that is decisive. Furthermore, the question is whether the differences in noise levels are great enough to influence the breeding tree selection of the rook. That is difficult to assess as it can be assumed that the impact of noise is highly dependent on the rook's perception.

Alter Meßplatz, Fort, Bürgergraben

Within this group the aim of the comparisons is not only to determine why reference trees are not used for breeding in comparison to breeding trees, but also why the Fort and Bürgergraben are used as breeding sites instead of first using all Platanus around Alter Meßplatz that are not yet used for breeding. Therefore, the following trees are discussed below to check whether temperature, ALAN and noise can explain breeding site selection of rooks: Bm3, Bm4, Bm5, Bm6, Bm7, Nm2, Nm3, Nm4 and Nm5.

Bm6, Bm7 vs. Nm5:

Although all three trees are Platanus of the same height and DBH that are located around Alter Meßplatz, Bm6 and Bm7 are used for breeding in contrast to Nm5. As Nm5 is located in the southwest of Alter Meßplatz and not in the north, temperature, ALAN and noise might vary between the sites. Temperature differs only slightly, which was expected because all trees are surrounded by sealed surface. It is slightly darker at Bm6 and Bm7 in comparison to Nm5. That is consistent with the overall result of this thesis, which is that rooks seem to prefer sites for breeding that are exposed to less ALAN. Furthermore, the noise level at both breeding trees is significantly higher than at Nm5. The reason why the noise level is about 10 dB higher in the north of Alter Meßplatz might be because all cars pass by there on the way to the university and because the school Max-Slevogt-Gymnasium is closer to Bm6 and Bm7 than to Nm5. Consequently, ALAN as well as noise are consistent with the overall results of the thesis and can thus explain why Nm5 is not used for breeding. Nevertheless, whether or not there is a causal relationship remains questionable.

Bm5 vs. Nm5

Thus, the question arises if Bm5 located at Bürgergraben is better suited as a breeding tree than Nm5 at Alter Meßplatz. As expected, the temperature is colder, although only 0.47 °C, because Bm5 is located in a forest strip, while Nm5 is surrounded by sealed surfaces. Bm5 is not exposed to ALAN, whereas Nm5 is exposed to ALAN. However, the noise level is 3.83 dB lower at Bm5 than at Nm5. So Bm5 is exposed to less ALAN and less noise and, therefore, ALAN is consistent with the overall result of this thesis, while noise is not. However, breeding site selection is always a trade-off of different factors. Thus, it might be that rooks had to decide between trees exposed to more ALAN at Alter Meßplatz and trees exposed to less noise at Bürgergraben and based on other factors, which were not investigated in this thesis, Bürgergraben provides trees for rooks where greater breeding success can be expected.

Bm5 vs. Nm4

As the only trees along Bürgergraben are in the northeast and not in the southwest, a Fraxinus that is used for breeding (Bm5) was compared to a Fraxinus not used for breeding (Nm4). The fact that the temperature only differs by 0.12 °C and that both trees are not exposed to ALAN is in line with the expectations, as both trees are located along Bürgergraben in a small forest strip. However, Bm5 is exposed to 3.03 dB less noise than Nm4. Therefore, that is not consistent with the overall result of this thesis. As temperature and ALAN do not differ between the sites, it is not clear why rooks prefer to breed at a site that is exposed to less noise. Either the difference in noise is not big enough to be decisive in the rook's breeding site selection or other factors are more important than noise. However, the fact that there was a construction site about 50 m linear distance from Nm4 on the other side of the ditch during the measurements must be taken into account. Thus, the noise level measured at Nm4 might be higher than during breeding site selection of rooks in spring. However, it is not clear how great the impact on the noise measurement was.

Bm3, Bm4 vs. Nm5

The rooks also breed on trees in the Fort, which is a small urban forest. Selection of that breeding site, which is comparatively within a forest far from roads, is contrary to the hypotheses of this thesis. Thus, the question is how Bm3, Bm4 located within the Fort and Nm5 at Alter Meßplatz differ. By comparing those trees, conclusions can be drawn as to whether temperature, ALAN and noise can explain why the trees in the Fort are chosen by rooks for breeding instead of Nm5.

As expected, in contrast to Nm5, which is surrounded by sealed surfaces, Bm3 and Bm4 are located in about 0.84 °C colder areas. Moreover, in contrast to Nm5, Bm3 and Bm4 are not exposed to ALAN, which is an argument for Bm3 and Bm4 being used for breeding in contrast to Nm5. Since Bm3 is 90 m from the closest road, the noise level is comparatively low. Bm4 is located at the southern edge of the Fort and thus closer to a district road. However, the fact that the noise level is 4.53 dB, i.e. higher than at Nm5, is surprising as Nm5 is located close to the same road. Similarly to Nm4, Nm5 might be affected by a construction site which was about 50 m linear distance from Nm5 during the measurements. Thus, it remains questionable whether the noise level of Bm4 is representative. Nevertheless, ALAN might explain why Bm3 and Bm4 are used for breeding in contrast to Nm5. However, noise cannot explain why Bm3 is used for breeding and Nm5 is not. Thus, once again it might be a trade-off between less ALAN in the Fort and more noise at Alter Meßplatz or completely different factors were decisive for the decision.

Bm3, Bm4 vs. Nm2, Nm3

As breeding trees that are located in the middle of an urban green space far from roads contradict the hypothesis of this thesis, Bm3 and Bm4 within the Fort are compared to Nm2 and Nm3, which are located in the northeast and in the north of the Fort in a similar vegetation, to determine whether temperature, ALAN and noise can explain why rooks decided to breed in the west of the Fort.

The temperature at Nm3 is slightly higher than at the other trees. That may be because Bm3, Bm4 and Nm2 are located in the forest, while Nm3 is located on a lawn. However, as all trees are far from street lights they are not exposed to ALAN. As it is still questionable whether the noise level of Bm4 is higher due to construction noise, that tree is not considered in the comparison of noise. Bm3, Nm2 and Nm3 do not differ considerably. Consequently, there is neither a difference in ALAN nor in noise. Thus, none of the investigated variables can explain why Bm3 and Bm4 are used for breeding by the rook and Nm2 and Nm3 are not. Therefore, other factors have to be important in breeding site selection within the Fort.

All in all, ALAN and noise seem to be reasonable explanations for why reference trees are not used for breeding compared to breeding trees in some places, because breeding trees are often exposed to less ALAN and more noise in consistence with the overall result. However, frequently only one of the factors fits or none at all. Thus, it remains questionable which factors were decisive for the rook in its breeding tree selection there. Consequently, this descriptive analysis of the values of breeding trees and reference trees supports the result of the statistical analysis. Even though there seems to be a correlation between ALAN and noise and breeding tree selection, other factors seem to play a greater role in some places.

11 Limitations and future research

11.1 Mapping

For the mapping of the rookeries, it is necessary to take into account that not all colonies might be known, in the past as well as in 2020. The mapping of the rookeries is based on data from GNOR on former colony sites (GNOR 2015) and on the mapping of nests of the 2018 breeding season by students of the University of Koblenz-Landau (Mittelmeier and Marini 2018). It can be assumed that there are more locations and therefore more nests in the Anterior and South Palatinate sub-region than were considered in this thesis. When the list of repellent measures carried out was received at the end of June 2020, it already became apparent that measures had been approved by SGD Süd (Klöppel 2020) at locations that were not known as colony sites in spring and not considered in the mapping. Thus, an all-encompassing survey of the breeding population of rooks in the Anterior and South Palatinate sub-regions cannot be guaranteed within the scope of this work. It is also questionable how all-encompassing GNOR's mapping (GNOR 2015) of the recent years is. Therefore, statements on population development are often based on nest numbers for only a few years, e.g. only from 2013 and 2020. Therefore, all data has to be treated with caution. However, in the case of certain colonies, nest counting was carried out more frequently, especially at the hotspots presented by Bannas (2018). On the other hand, focusing on Landau, the nest numbers presented by Bannas (2018) for the years 2011 to 2018 only take into account the five hotspots of rookery colonies within Landau: (1) Pestalozzischule, (2) Otto-Hahn-Gymnasium, (3) Ostpark, (4) Goethepark and (5) Grundschule Godramstein. It is not known whether there were other colonies in the city area. However, there was a student project in 2018 counting nests of rooks in the whole city of Landau. The number of nests counted by the students (Mittelmeier and Marini 2018) is very close to the one given by Bannas (2018). Therefore, it can be assumed that the five hotspots present the number of all nests within Landau from 2011 to 2017 as well.

Nonetheless, only the breeding trees within Landau are relevant for the examination of the hypotheses, as the locations and characteristics of the breeding trees within Landau provide the basis for the manual and random selection of the investigated trees in Part II of this thesis. Within Landau it can be assumed that almost all breeding sites are known.

When discussing the development of colonies, breeding trees were assigned to a colony and those colonies were classified as either urban or rural. However, the definition of whether a colony is in an urban or rural area is not always clear, as many rooks breed on the outskirts of cities. For example, the colony in Edenkoben is located at a railway station, whereby part of the colony breeds in urban areas along roads and a petrol station, while the remaining part breeds on the other side of the railway tracks in a small forest. Such colonies were considered as urban colonies in this thesis.

11.2 Tree selection

The mapping of all breeding trees served as a base for the selection of the investigated breeding trees, reference trees and random trees. Tree genus, tree height and DBH of all breeding trees within Landau were used to identify potential breeding trees. However, sometimes only very few or even only one tree of a genus is used for breeding in Landau. Thus, the sample size for some tree genera is too small to develop thresholds that are genus specific. Therefore, in order to identify a potential breeding tree in Part II of this thesis the minimum values of tree height (10.00 m) and DBH (20.00 cm) of all tree genera, irrespectively of the tree genus, were taken as thresholds. However, the thresholds developed based on all genera are not necessarily representative for each genus. The lowest DBH value of a Platanus, which has a comparatively large sample size, is 30.00 cm. Consequently, due to the established minimum DBH value of 20.00 cm, a Platanus with 25.00 cm DBH could be selected as a potential breeding tree. Thus, it is questionable whether that Platanus would actually be a potential breeding tree due to the DBH, since the minimum value of the DBH of all tree genera is greater than the minimum value of Platanus. This issue could be tackled by using tree height and DBH of all urban breeding trees in the Anterior and South Palatinate sub-region as a basis to determine threshold values for tree height and DBH for each tree genus. Thus, the sample size for each genus would have been greater.

Moreover, there are other tree genera that are used for breeding in other cities in the Anterior and South Palatinate sub-region, but not in Landau, such as Aesculus, which is a breeding tree in Ludwigshafen. It might be advisable to integrate such tree genera into the potential breeding trees in Landau as well, because they could be used for breeding in Landau in the future.

Moreover, the random trees that were randomly selected using QGIS are not evenly distributed throughout the city. That is the case because clusters of the same tree genus in areas of the city of Landau lead to a high probability that several trees are randomly selected there, such as Platanus of which there is a high density on the parking lot next to the new exhibition grounds. Thus, random trees distributed over the entire city area could be more appropriate.

Beyond that, it is known that ramifications are important in nest site selection and thus also in breeding tree selection (Dietzen and Simon 2017). Consequently, the number of ramifications suitable for nests could be counted in future studies. Possibly, the crown diameter already recorded in the tree register could be used as a criterion for this purpose, as it can be assumed that the crown diameter correlates with the number of ramifications. In this context, it is necessary to take into account that the number of suitable ramifications for a certain crown diameter might vary between different tree genera. However, that would have to be investigated and verified. As the ramifications were not considered in this study, the breeding possibilities of the selected trees might not be optimal.

In addition, the number of trees with suitable characteristics in the vicinity of each other should be used as a further criterion. That could avoid a random selection of single suitable trees which are not surrounded by other potential breeding trees, which is important because rooks are colony breeders. It has to be assumed that trees with fewer suitable ramifications must have more trees of this kind nearby (e.g. wooded strip in Goethepark) than trees with many suitable ramifications in which more than 30 nests can be built (e.g. Schwanenweiher). Thus, the sum of ramifications of several suitable trees, according to tree genus, tree height and DBH, located close to each other could be meaningful. However, more detailed investigations are necessary to specify this criterion.

Consequently, the selection of potential breeding trees could be improved by integrating all tree genera of urban breeding trees within the entire area of the Anterior and South Palatinate, by using all those urban breeding trees as a larger sample for setting tree height and DBH thresholds and by adding the number of ramifications that are suitable for nesting as a criterion.

11.3 Measurement of temperature, ALAN, and noise

11.3.1 Temperature

At first glance, carrying out a temperature measurement to investigate the breeding behaviour of the rook in the summer instead of during the breeding season may seem rash. Indeed, a temperature measurement period in late summer might not necessarily be representative of the temperatures that are prevalent during the breeding season of the rook. However, the aim of this thesis is not to correctly reflect the temperature at the time of incubation, but to determine temperature differences between sites. In this respect, neither the season nor the weather is critical for that measurement. Nevertheless, it can be assumed that the temperature differences are more pronounced when solar radiation is stronger, due to the urban heat island effect (Kalnay and Cai 2003; Santamouris 2013). During strong solar radiation, it can be expected that temperature differences between substantially sealed and less sealed locations become clearer in the measurement results, because sealed surfaces heat up more (Kalnay and Cai 2003;

Santamouris 2013; Whitford 1985). During the measurement period, there were several days with temperatures just below 30 °C and clear skies, ensuring strong solar radiation. As a result, it can be assumed that temperature differences should have been more obvious during the measurement in summer than during the breeding season and would have been easier to recognise if they had been present.

Nevertheless, temperature has no influence on breeding tree selection of rooks in Landau. However, the extent to which the temperature at breast height and at crown height differs should be investigated in order to determine whether the temperature difference between the individual sites at crown height might be different. In addition, urban colonies should be compared with rural colonies to see whether temperature may be a reason for the rook to move to the city. But since it is difficult to determine whether temperature has an effect on breeding site selection based on field observations, for example temperatures in rural areas are usually colder than in urban areas, experimental studies are needed. The effects of different temperatures on the breeding success of rooks should be investigated.

However, whereas only nocturnal temperature values were taken in this thesis to avoid the influence of direct radiation, Gloutney and Clark (1997) measured the operative temperature, which takes insolation, wind and humidity into account. Insolation can be important in nest site orientation (Lloyd and Martin 2004) and thus possibly also in the rooks' selection of the ramifications for nest building within the crown. Measuring the temperature or the operative temperature close to or directly inside the nest, e.g. according to the methodology of Hovick et al. (2014) and Kulaszewicz and Jakubas (2018), and also perhaps after the nests have been abandoned, could reinforce the significance of the results.

In any case, the results of this thesis do not indicate that temperature is a decisive factor in the breeding tree selection of the rook. Nevertheless, further studies are needed to verify these results, as it cannot be assumed that - just because it is the case for rooks in Landau - temperature is not important in breeding tree selection for rooks in other regions. Under other environmental conditions and with greater temperature fluctuations, the results could be different.

11.3.2 ALAN

In case of ALAN, it is questionable whether the measurement at chest level is suitable for drawing conclusions for nests in the crown. Nevertheless, ALAN was measured at chest level for feasibility reasons. However, it can be assumed that street lights and possibly car headlights influence the light intensity at chest level. Therefore, during the measurement care was taken to take values that were measured at a time when no car was passing. Thus, the light measurement reflects the presence of street lamps in particular. However, the street lamps are mainly located lower than the crown and thus lower than nests. All street lamps installed by the city of Landau are shielded at the top so that scattering into the night sky is minimised (Heck 2020). Consequently, it can be assumed that the scattered light reaching the rooks at breeding height is considerably reduced compared to the value measured at ground level.

Hence, to obtain a comprehensive picture of ALAN, the measuring instruments would need to be mounted in the crown over a longer period of time and data collected from dusk until dawn. In case of breeding trees, it might be best to measure in empty nests directly after the breeding phase. However, a general problem with light measurement is that it is selective. A single leaf passing in front of the sensor can already distort the measurement. For that reason, it is difficult to measure a representative value for a tree that authentically reflects the light level to which that tree is exposed. Therefore, measuring ALAN in the nests might deliver better results. However, then it is necessary to develop a methodology to determine the light level that a breeding tree is exposed to, e.g. taking the mean value of the ALAN measurements conducted in several nests of a tree.

Alternatively to measuring ALAN, a method could be developed to calculate the light intensity in the nests based on distance to the nearest street lamp and nest height, similarly to what Russ et al. (2017) did to determine the light level in European blackbirds' nests. However, in that case, it may also be necessary to take into account that Populus, for example, sprout later and thus their leaves provide less protection from light than other trees, especially at the beginning of the breeding season.

Moreover, the question arises whether the luxmeter actually measures the light perceived by rooks. The wavelength measuring range of the luxmeter that was used is adapted to the human eye. However, as shown in the theoretical background, there is no reason to assume that this measuring range is not suitable for rooks. Nevertheless, in order to improve the credibility of the measurement, studies on the rook's perception of light would be necessary for the luxmeter to be optimally adjusted to perception by the rook.

Consequently, the results of this thesis are an initial approach which indicates that rooks avoid trees exposed to ALAN for breeding. However, this result must be treated with caution and further investigations are necessary. In that context, ALAN in particular should be measured at nest height in the future, if it is feasible to do so.

11.3.3 Noise

In contrast to ALAN, it can be assumed that the measurement of noise at a height of 3 m is almost representative of the situation in the crown, even though the noise might be slightly reduced there.

However, the noise measurement is based on the frequencies of the rooks' communication and on the frequencies that might be perceived by rooks. But as there are no studies known on the hearing range of rooks, the measurement range is based on frequency ranges known from rooks' communication and perceived by other bird species as presented in the theoretical background. Thus, all frequencies that might impair rooks should be covered in the recordings. Nevertheless, knowledge on the frequencies actually perceived by rooks and measurement methods adapted to it might improve the credibility of the results.

However, a general indication of frequency ranges and sound pressure levels might not be sufficient for a precise understanding of what type of noise affects rooks and in what way. Noise always consists of different frequencies with different intensities (Mahn 2011), as has already been described in the discussion. If, for example, 3 to 12 cars per minute pass by on a road, a volume of 60 dB is generated at a frequency of 1000 kHz (Mahn 2011). The calls of rooks are between 1 and 2.5 kHz (Fankhauser 1995; Røskaft and Espmark 1982) and on average they are 64.1 dBA (Fankhauser 1995) loud along roads. However, that is an absolute value which includes all frequencies of the call and moreover it is measured with an A weighting filter, thus not comparable to dB values. Consequently, the question arises as to the volume of the rook's call at 1000 kHz. If the rook's call at 1000 kHz is always above 60 dB naturally, it is not affected by masking at that frequency. However, if the call at 1000 kHz is 40 dB, it is affected by masking at that frequency. This means that for a detailed understanding of the influence of masking on rook communication, the individual frequencies of noise and of the different rook calls have to be compared. It could be that certain frequencies of certain calls are affected by masking and others are not. The extent to which that influences communication and thus breeding site selection would have to be investigated in a next step.

In any case, during the measuring period there were construction sites at some places close to the trees that were examined, which might influence the measurements due to construction noise. However, it was decided not to exclude those measurements since it is not clear how strong the influence of the construction sites actually is, because the investigated trees were all some distance away from the construction sites and because it is not clear whether the construction sites were already there at the breeding stage or not. Moreover, it affects breeding trees as well as reference trees and random trees and therefore the influence can be assumed to cancel each other out.

In addition, the question arises whether the pandemic situation caused by the COVID 19 virus, which led to a change in activities in public spaces, might also have had a minor influence; be it that there were fewer cars on the roads, less traffic at the swimming pool car park or at the car park behind the festival hall. However, it can be assumed that such an effect is small and that a comparison of the different measuring sites is representative to a large extent.

Regardless of possible improvements in noise measurement methodology, the question arises whether there is actually a causal relationship between rook breeding tree selection and noise or if other factors that were not investigated, which also occur along roads, are decisive for the selection of breeding trees. For example, roads form wide approach corridors that may also be important for breeding tree selection. Therefore, experimental studies that can minimise the impact of additional factors are needed to determine whether noise has an impact on the breeding success of rooks.

In that context, the question remains how noise directly affects the rook, i.e. to what extent communication is impaired due to masking. As mentioned previously, it can be assumed that - since rooks communicate with comparatively high volume - they may have to expend less energy to communicate despite the noise. However, in order to test that hypothesis, studies need to be conducted to test the volume of rooks' communication in the absence of noise and the volume of communication in the presence of noise. By comparing that to other bird species, it might be possible to draw conclusions on the energy expenditure of rooks' communication during noise.

In addition to the direct biological physiological influence of noise on the breeding tree selection of rooks, individual preferences might also play a role. For humans it has been proven that each individual perceives noise differently and thus feels disturbed by a certain noise level to a different extent (Pedersen and Marquardt 2009; Schreckenberg et al. 2010). That could also apply to rooks, which would mean that the choice of breeding trees depends on the noise, but some individuals prefer louder locations, while other individuals prefer quieter locations.

Consequently, in order to understand the influence of noise on rook breeding tree selection, conducting experimental studies is extremely important so as to determine whether there is a causal relationship between breeding tree selection and noise and to what extent communication and breeding success of rooks are affected by noise.

11.3.4 Correlation of temperature, ALAN and noise

An experimental study design is not only important in investigating the impact of noise on breeding tree selection of rooks effectively in the future. The correlation check of temperature, ALAN and noise showed a more or less medium correlation for all three variables. However, the correlation is not high and should therefore not affect the credibility of the results.

Nevertheless, temperature, ALAN and noise were selected for investigation because it was observed that rooks often breed along transport axes and high levels of those three variables were expected near transport axes. However, there are many more factors which differ between transport axes and urban green spaces and which might affect breeding tree selection and correlate with the investigated variables. Thus, examining certain variables in the field cannot ensure a causal relationship (Hennigar et al. 2019).

For that reason, the results of this study can provide initial evidence that rooks prefer breeding trees that are dark and exposed to noise. However, these initial results need to be investigated further and verified in subsequent experimental studies.

11.4 General methodological limitations

Beyond the different methodologies for measuring temperature, ALAN and noise and additional questions, there are limitations for all three variables that are generally valid.

Firstly, a larger sample would increase the significance of the results. The discussion of ALAN has shown how strongly the result depends on whether a tree under investigation happens to be next to a street light or not. A larger sample would minimise such biases. Excluding such trees as outliers from the statistical analysis would not be appropriate, since the values are correct, and the tree is indeed exposed to a high level of ALAN. In the case of noise as well, a larger sample would have improved the results significantly. Since 11 AudioMoths failed, a larger sample would have been better able to compensate for those failures. A larger sample could also have compensated for trees the values of which are higher due to construction noise. It is difficult to exclude those trees as outliers from the evaluation because the question that arises is at what distance from construction sites trees should be excluded. With a larger sample, the probability would be even greater that breeding trees, reference trees and random trees would all be influenced by construction site noise at some locations and thus the effects would cancel each other out.

Furthermore, the variables in this study were statistically evaluated individually and the correlation between the variables was also analysed. However, the extent to which rook breeding tree selection depends on the combination of the three variables temperature, ALAN and noise was not investigated. As shown in the discussion of breeding trees and reference trees, in some places rooks might have to weigh up whether to choose a breeding tree that is exposed to less ALAN or more noise. Thus, the statistical analysis of temperature, ALAN and noise in combination with each other could increase the significance of the results, as the choice of breeding site is a trade-off between different factors. Thus, a generalised linear mixed model and model selection based on AIC could help to determine which variables are the most appropriate for explaining breeding tree selection of rooks (Bolker et al. 2009).

11.5 Other factors to be considered

As has already become clear in the discussion so far, there are numerous other factors in addition to temperature, ALAN and noise which might possibly affect rook breeding tree selection and should be investigated further.

A frequently mentioned factor is reduced enemy pressure. Both ALAN and noise are generally known to affect the presence of predators in other bird species (Francis et al. 2009; Russ et al. 2017). However, the fact that it is often assumed that there are fewer predators in the city than in the countryside (Andris and Westermann 2011; L.U.P.O. 2016) may also have an impact on breeding tree selection and especially on the increasing breeding abundance of rooks within cities. Thus, research on the presence of predators at different breeding sites is necessary to also identify possible causes, such as ALAN or noise, for higher or lower abundance of predators. That could also reveal links between the presence of predators with ALAN and noise and thus identify possible major causes of breeding tree selection of rooks.

In addition, forage availability is a fundamental prerequisite for establishing rookeries (Olea 2009). The discussion on the influence of temperature has also shown that when temperature has an influence on rook breeding site selection, it is often due to changes in forage availability, e.g. in Northern Finland (Rytkönen et al. 1993). Thus, in Landau as well, the distance to food sources could have an impact on the area of the city where breeding trees are selected. For that reason, further research is needed to identify the main food sources of rooks in Landau.

Moreover, interspecific competition and intraspecific competition between different rookeries must be taken into account. Halfwerk et al. (2016) have shown interspecific competition for great tits, which prevailed over blue tits in the nest-box choice, so that blue tits only could breed in the nest-boxes exposed to noise. In Landau, for example, it is not clear why there are no rooks breeding in Nordpark. Since grey herons (*Ardea cinerea*) breed there, the question arises whether the latter might be a competitor for the rook in nest site selection, similar to the example of great and blue tits. In addition, Olea (2009) has shown for the Spanish study area that competition between rook colonies is a factor determining the colony size. Consequently, inter-colony competition could also be a reason why, for example, not all potential breeding trees at Alter Meßplatz are used for breeding, whereas other, apparently less suitable sites are used. Thus, a detailed investigation of the individual colonies within Landau is necessary to determine the effect of interspecific and intraspecific competition on the development and breeding site selection of rooks in Landau.

Furthermore, the question generally arises whether rooks have individual preferences in their choice of breeding site, i.e. whether some individuals prefer noise and breed at Alter Meßplatz, while others prefer silence and breed at the Fort.

11.6 Significance of the research findings for Landau and its limitations

In any case, the optimal overarching goal would be to manage the conflict between humans and rooks that prevails in Landau by means of regional planning concepts. That requires an all-encompassing knowledge of the criteria according to which rooks select breeding trees. It means that the knowledge gaps mentioned above must first be closed. Only when the behaviour of the rook in Landau is understood comprehensively will it be possible to discuss whether the situation in the city can be ameliorated by providing possible alternative habitats in the surrounding rural areas, how those alternative habitats can be made attractive for rooks and whether and how resettlement of the birds to those alternative habitats makes sense.

However, in this context the economic damage is of great importance. If it should indeed be the case that illegal repellent measures are carried out in agricultural areas around Landau, the provision of alternative habitats would be hopeless, because the enemy pressure in the surrounding area is then greater than in the city, since repellent measures can be counted as enemies. Thus, the economic damage caused by rooks would have to be quantified in order to assess whether compensation for damage caused by rooks might be necessary or, otherwise, to convince farmers that rooks do not constitute a threat to them and hence to convince farmers that repellent measures are not necessary. A study investigating economic damage by rooks for farmers has already been carried out by Feare (1974) in Scotland. However, such a study with an economic concept is not known for Germany and would therefore be helpful to address the conflict between farmers and rooks.

In the best case scenario, spatial planning interventions such as the removal and planting of certain tree genera in certain areas of the city could make locations within cities less attractive, and active preparation of potential alternative habitats in surrounding rural areas could make them particularly attractive for rooks. However, since rooks are highly adaptable intelligent birds (Seed et al. 2008; Tebbich et al. 2007), it remains questionable whether such measures would work at all or whether, as most previous attempts in other cities have shown (Andris and Westermann 2011; Gschweng 2016; Sepp and Dufner 2020; Stabsstelle Umwelt Lahr 2010), repellent measures might instead worsen the situation by dividing rookeries and increasing the overall number of rooks.

Based on the results of this thesis, rooks prefer noise, which is lower in rural areas than in cities. Consequently, if noise is indeed a decisive factor for rooks in breeding tree selection, the successful provision of alternative habitats may be limited by the lack of noise at provided sites. Therefore, busy bypasses with suitable tree genera, mainly Platanus, along the road, could be suitable as potential alternative habitats. On the other hand, noise reduction at sensitive sites, such as hospitals and schools, could make these sites less attractive for rooks. Thus, relieving congestion in urban areas and directing it to bypasses could not only reduce noise pollution from traffic noise, but may also encourage rooks to breed along bypasses instead of urban areas, thus reducing human-rook conflict. Nevertheless, there are still many questions that need to be clarified in order to better assess the effectiveness of such a measure. It is questionable whether the overall population might increase as a result because of the increase in suitable breeding habitats, i.e. rooks continue to breed within the city and establish a breeding colony at the new bypass in addition. In order to assess how much more the overall population in Landau can increase, the population in Landau would have to be observed over a longer period of time and the density dependency would have to be determined (Nentwig et al. 2017). In addition, factors such as food availability and interspecific competition, which determine colony sizes, would have to be investigated (Olea 2009). In that context, it should be taken into account that rooks often breed at the same sites for decades and are likely to return to the original site as soon as possible although repellent measures may be successful in the short term, making relocation to other sites more difficult (L.U.P.O. 2016; Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz 2015; Roth 2011).

Consequently, that investigation process is very lengthy and success is not guaranteed.

Therefore, there are only two measures to effectively address the conflict between humans and rooks in Landau in the short term, as was already mentioned by Bannas (2018). Firstly, negative effects must continue to be mitigated in locations where it is necessary such as hospitals and schools, as is already being done, for example by rook repellent measures, such as tree pruning. Secondly, acceptance of rooks by the residents of Landau has to be increased. There are many approaches, such as a rook nature trail (Gschweng 2016; Menzel 2020; Stichmann 2016), which were comprehensively presented in the theoretical background of Part I of this thesis.

Thus, this chapter shows that this thesis is only an initial step toward recording the entire rook population in the Anterior and South Palatinate sub-region and to a better understanding of breeding tree selection by rooks and thus toward addressing the conflict between humans and rooks. Many questions are still unresolved and there is room for much more research in the fields of ecology, economy and environmental education.

12 Conclusion

As more and more rooks breed within the urban area of Landau, the conflict between rooks and humans is increasing, especially due to noise and faeces. In order to develop long-term measures to reduce rook-human conflict, e.g. by establishing alternative habitats, it is crucial to understand the rooks' breeding tree selection.

Part I of this thesis with a mapping of rook nests in the overall Anterior and South Palatinate sub-region has shown 26 rookeries with 364 breeding trees and 1,600 nests. With 143 breeding trees and 682 nests within Landau, one third of all rooks breed in the municipality of Landau. In that context, the most frequently used trees are plane trees. The comparison of those results with data from previous years has shown that rooks breed in cities to an increasing extent. That is also shown for Landau with a 62% increase in rook nests within the last two years (2018: 419, 2020: 682). While many bird species are known to avoid roads, the mapping showed that within Landau many breeding trees of rooks are located along transport axes, i.e. roads and railway tracks. It was assumed that temperature, ALAN and noise differ at transport axes compared to other sites within the city. Moreover, an effect of temperature, ALAN and noise on habitat selection of rooks is already discussed in literature and studied in detail for other bird species. Thus, the influence of those three variables on breeding tree selection was investigated in Part II of this thesis. The hypotheses that manually selected breeding trees (Bm) are exposed to higher temperature, more ALAN and more noise than manually selected non-breeding reference trees (Nm) or randomly selected non-breeding trees (Nr) were tested.

It turned out that temperature in Landau has no effect on the breeding tree selection of the rook. Thus, the hypothesis that breeding trees are exposed to warmer temperatures than reference trees or random trees had to be rejected ($\mu_{Bm, temp}$ = 16.91 °C, $\mu_{Nm, temp}$ = 16.93 °C, $\mu_{Nr, temp}$ = 17.29 °C). It can be assumed that the temperature differences within Landau are too small to have an effect on breeding tree selection because the largest difference in the average nocturnal temperature measured during the investigations for this thesis is 2.31 °C.

The hypothesis that breeding trees are exposed to more ALAN than reference trees or random trees also had to be rejected ($\mu_{Bm, light}$ = 0.36 lx, $\mu_{Nm, light}$ = 0.41 lx, $\mu_{Nr, light}$ =2.00 lx). Contrary to expectations, breeding trees were exposed to significantly less ALAN at breast height around the tree trunk than reference trees. However, the measured differences in ALAN are small for the most part. Furthermore, it can be assumed that less light reaches the crown than measured at breast height on the trunk. Thus, the results that rooks prefer breeding trees exposed to less ALAN have to be verified by measuring at crown height.

It is only possible to accept the hypothesis that breeding trees are exposed to more noise than reference trees or random trees, as breeding trees were exposed to significantly more noise than random trees ($\mu_{Bm, noise}$ = 36.52 dB, $\mu_{Nm, noise}$ = 31.27 dB, $\mu_{Nr, noise}$ = 29.17 dB).
Thus, the variables ALAN and noise might explain why breeding trees are used for breeding in comparison to random trees but cannot explain why reference trees are not used for breeding. However, it remains questionable whether this is a causal relationship or whether other factors correlating with ALAN and noise are decisive in the breeding tree selection of rooks.
Nevertheless, this thesis can serve as a starting point and basis for further investigations of the rooks' breeding tree selection. For an all-encompassing understanding of the rooks' breeding tree selection other factors such as food availability, predator pressure and interspecific competition need to be investigated in addition. Furthermore, testing whether communication and breeding success of rooks are impaired by noise is needed in order to clarify whether there is a causal relationship between breeding tree selection and noise.
However, among other things, the idea behind this thesis was to gain a better understanding of the rooks' choice of breeding tree in order to be able to derive measures that could counteract the conflict between humans and rooks in Landau. One management approach could be to divert traffic from inner-city areas, especially schools and hospitals, to bypasses where tree genera suitable for breeding rooks are planted along the bypasses to establish suitable alternative habitats. However, the results of this thesis showing that rooks often breed along roads and seem to prefer locations with high noise levels are only a first step in the development of effective management approaches. Future studies need to address that issue in order to improve the understanding of breeding tree selection and to draw conclusions on the effective design of possible alternative habitats. An initial step would be to investigate whether the choice of breeding trees exposed to noise is associated with lower predator pressure. That should be followed by studies on enemy pressure in possible alternative habitats. Thus, further studies can lead to a better understanding of the breeding behaviour of rooks step by step and new insights and ideas can be gained as to what options for action in the conflict with rooks might be counterproductive or promising.
Nevertheless, it remains questionable whether future results will actually provide new approaches to solve the conflict between humans and rooks and how long it will take until beneficial findings are obtained. Therefore, the only efficient short-term approach is to mitigate the conflict by applying repellent measures at focal points, such as hospitals and schools, and to increase the acceptance of the rook among the residents of Landau.

13 Literature

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14 Appendix

Appendix I - Legal protection status of the rook

For approaches to conflict resolution, the protection status of the rook must be taken into account.
The European Birds Directive was adopted in 1979 and regulates the protection of birds in the European Union (EU) (BfN n.d.a). Article 5 of the Birds Directive provides that the intentional killing and capture of birds, the deliberate destruction and damage of nests and eggs, the collection of eggs, the deliberate disturbance of birds, in particular during the period of breeding and rearing, is in principle prohibited for all species covered by Article 1. Article 1 refers to all wild bird species that are native to the European countries that sign the directive. That includes not only the birds themselves, but also their eggs, nests and habitats (European Union 2009). Annex I of the Birds Directive lists bird species which are subject to special protection (European Union 2009). Annex II lists which bird species are permitted to be hunted in which country. (European Union 2009). The rook is neither listed in Annex I nor may Germany allow the rook to be hunted according to Annex II. Consequently, the rook is one of the EU's normally protected bird species.
In Germany, the Federal Nature Conservation Act (BNatSchG) regulates species protection and thus implements European law in national law (BfN n.d.b). However, German national law does not provide more strict protection than European law (Deutscher Bundestag 2009).
As a result, applications for repellent measures must therefore be submitted and can only be authorised under certain conditions, such as to avert economic damage in accordance with Article 45(7) of the BNatSchG (Deutscher Bundestag 2009).

Appendix II – Breeding trees of the Anterior and South Palatinate in 2020

Table 10: Colonies, tree and nest numbers and tree genera within the Anterior and South Palatinate in 2020

City	Location	Number of nests	Overall number of nests in colony	Overall number of trees in colony	Category	Colony	Tree genus	Date of mapping	Height	DBH
Duttweiler	Freibad	3	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	1	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	3	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	9	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	3	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	1	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	3	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	3	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	1	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		
Duttweiler	Freibad	1	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12		

Duttweiler	Freibad	2	30	11	Building edge	NW_Duttweiler_Freibad	Populus	2020-04-12
Edenkoben	Tankstelle	10	308	63	Building	SUEW_Edenkoben	Betula	2020-04-12
Edenkoben	Tankstelle	7	308	63	Building	SUEW_Edenkoben	Betula	2020-04-12
Edenkoben	Tankstelle	9	308	63	Building	SUEW_Edenkoben	Betula	2020-04-12
Edenkoben	Tankstelle	27	308	63	Building	SUEW_Edenkoben	Betula	2020-04-12
Edenkoben	Tankstelle	1	308	63	Building	SUEW_Edenkoben	Cedrus	2020-04-12
Edenkoben	Tankstelle	1	308	63	Building	SUEW_Edenkoben	Salix	2020-04-12
Edenkoben	Tankstelle	2	308	63	Building	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	6	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Betula	2020-04-12
Edenkoben	Waeldchen	3	323	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	5	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	6	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12

Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	9	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	9	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	8	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	2	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	8	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	5	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	6	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12

Edenkoben	Waeldchen	15	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	5	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	4	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	2	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	9	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	8	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	11	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	2	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	6	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12

Edenkoben	Waeldchen	2	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	9	308	63	Building edge	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Bahnhof	3	308	63	Building	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Bahnhof	7	308	63	Building	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Bahnhof	5	308	63	Building	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Bahnhof	2	308	63	Building	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Bahnhof	5	308	63	Building	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Bahnhof	16	308	63	Building	SUEW_Edenkoben	Robinia	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	2	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	1	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	7	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	2	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	2	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Edenkoben	Waeldchen	3	308	63	Building edge	SUEW_Edenkoben	Acer	2020-04-12
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10

Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	3	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	3	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	5	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	3	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	4	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	8	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10

Frankenthal	Parkfriedhof_ Frankenthal	7	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	13	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	3	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	3	119	40	Cemetery	FT_Parkfriedhof	Quercus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	6	119	40	Cemetery	FT_Parkfriedhof	Quercus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Quercus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	6	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	4	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10

Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	3	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	3	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	5	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	7	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	2	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	1	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10
Frankenthal	Parkfriedhof_ Frankenthal	4	119	40	Cemetery	FT_Parkfriedhof	Platanus	2020-04-10

Frankenthal	Neumayerring	1	21	4	Building	FT_Neumayerschule	Platanus	2020-04-10
Frankenthal	Schulstraße	1	21	4	Building	FT_Neumayerschule	Platanus	2020-04-10
Frankenthal	Schulstraße	1	21	4	Building	FT_Neumayerschule	Platanus	2020-04-10
Frankenthal	Schulstraße	6	21	4	Building	FT_Neumayerschule	Platanus	2020-04-10
Frankenthal	Flomersheimer_ Straße	2	13	5	Building	FT_Flomersheimer_Straß e	Platanus	2020-04-10
Frankenthal	Flomersheimer_ Straße	3	13	5	Building	FT_Flomersheimer_Str	Platanus	2020-04-10
Frankenthal	Flomersheimer Straße	5	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	2	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10

Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	2	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	2	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	6	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	4	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	2	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	4	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10

Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	1	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2021-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	12	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Frankenthal	Philipp-Rauch-Straße	3	78	31	Building	FT_Philipp-Rauch-Str	Platanus	2020-04-10
Gruenstadt	Industriestraße	6	72	14	Building	DUEW_Gruenstadt_Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Industriestraße	2	72	14	Building	DUEW_Gruenstadt_Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Industriestraße	11	72	14	Building	DUEW_Gruenstadt_Kirchheimer_Str	Platanus	2020-04-10

Gruenstadt	Industriestraße	7	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Industriestraße	6	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Industriestraße	6	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Kirchheimer_ Straße	6	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Kirchheimer_ Straße	2	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Kirchheimer_ Straße	1	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Kirchheimer_ Straße	1	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Kirchheimer_ Straße	1	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Industriestraße	3	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Industriestraße	5	72	14	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10
Gruenstadt	Auf_der_Wart	4	6	2	Building	DUEW_Gruenstadt_ Kirchheimer_Str	Platanus	2020-04-10

Grünstadt	Parkplatz_ VeniceBeach	5	72	14	Building	DUEW_Kirchheimer_ Str	Platanus	2020-04-10		
Grünstadt	Auf_der_Wart	2	6	2	Building	DUEW_Gruenstadt_Auf_ der_Wart	Platanus	2020-04-10		
Lambsheim	Friedhof_ Lambsheim	14	51	4	Cemetery	RP_Friedhof_ Lambsheim	Platanus	2020-04-10		
Lambsheim	Friedhof_ Lambsheim	5	51	4	Cemetery	RP_Friedhof_ Lambsheim	Platanus	2020-04-10		
Lambsheim	Friedhof_ Lambsheim	12	51	4	Cemetery	RP_Friedhof_ Lambsheim	Platanus	2020-04-10		
Lambsheim	Friedhof_ Lambsheim	10	51	4	Cemetery	RP_Friedhof_ Lambsheim	Platanus	2020-04-10		
Landau	Neustadter_ Straße	2	8	4	Building	LD_Neustadter_Straße	Platanus	2020-04-15	16	40
Landau	Neustadter_ Straße	3	8	4	Building	LD_Neustadter_Straße	Platanus	2020-04-14	16	40
Landau	Neustadter_ Straße	1	8	4	Building	LD_Neustadter_Straße	Platanus	2020-04-14	18	50
Landau	Neustadter_ Straße	2	8	4	Building	LD_Neustadter_Straße	Platanus	2020-04-14	18	40
Landau	Gillet	7	52	13	Park	LD_Gillet	Salix	2020-04-14	21	40
Landau	Neustadter_ Straße_Gillet	1	52	13	Building	LD_Gillet	Platanus	2020-04-14	16	50
Landau	Neustadter_ Straße_Gillet	4	52	13	Building	LD_Gillet	Platanus	2020-04-14	16	40
Landau	Neustadter_ Straße_Gillet	1	52	13	Building	LD_Gillet	Platanus	2020-04-14	16	50

Landau	Neustadter_ Straße_Gillet	1	52	13	Building	LD_Gillet	Platanus	2020-04-14	16	50
Landau	Neustadter_ Straße_Gillet	1	52	13	Building	LD_Gillet	Platanus	2020-04-14	18	40
Landau	Neustadter_ Straße_Gillet	13	52	13	Building	LD_Gillet	Tilia	2020-04-14	18	60
Landau	Neustadter_ Straße_Gillet	1	52	13	Building	LD_Gillet	Tilia	2020-04-14	20	50
Landau	Neustadter_ Straße_Gillet	4	52	13	Building	LD_Gillet	Alnus	2020-04-14	18	50
Landau	Neustadter_ Straße_Gillet	1	52	13	Building	LD_Gillet	Platanus	2020-04-14	16	40
Landau	Neustadter_ Straße_Gillet	2	52	13	Building	LD_Gillet	Platanus	2020-04-14	18	50
Landau	Neustadter_ Straße_Gillet	6	52	13	Building	LD_Gillet	Platanus	2020-04-14	18	50
Landau	Neustadter_ Straße_Gillet	10	52	13	Building	LD_Gillet	Fraxinus ornus	2020-04-14	20	60
Landau	Reduitstraße	4	21	3	Building	LD_Reduistr	Platanus	2020-04-14	24	110
Landau	Reduitstraße	5	20	3	Building	LD_Reduitstr	Platanus	2020-04-14	16	80
Landau	Reduitstraße	11	20	3	Building	LD_Reduitstr	Platanus	2020-04-14	20	100
Landau	Schwanenweihe r	12	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	16	140
Landau	Schwanenweihe r	12	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	20	80
Landau	Schwanenweihe r	2	179	16	Park	LD_Schwanenweiher	Acer	2020-04-14	22	70

Landau	Schwanenweiher	1	179	16	Park	LD_Schwanenweiher	Juglans nigra	2020-04-14	18	50
Landau	Schwanenweiher	5	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	24	150
Landau	Schwanenweiher	14	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	26	140
Landau	Schwanenweiher	12	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	26	150
Landau	Schwanenweiher	13	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	22	150
Landau	Schwanenweiher	10	179	16	Park	LD_Schwanenweiher	Platanus	2018-04-14	22	100
Landau	Rheinstraße	35	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	24	130
Landau	Rheinstraße	3	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	24	95
Landau	Rheinstraße	39	179	16	Park	LD_Schwanenweiher	Platanus	2020-04-14	24	130
Landau	Jugendstil_ Festhalle	10	179	16	Park	LD_Schwanenweiher	Platane	2020-04-14	26	120
Landau	Hauptbahnhof	3	179	16	Building	LD_Schwanenweiher	Platanus	2020-04-14	14	50
Landau	Hauptbahnhof	5	179	16	Building	LD_Schwanenweiher	Platanus	2020-04-14	16	60
Landau	Hauptbahnhof	3	179	16	Building	LD_Schwanenweiher	Platanus	2020-04-14	14	50
Landau	Landau_ Amtsgericht	11	55	6	Building	LD_Marienring	Platanus	2020-04-14	18	60

Landau	Landau_ Amtsgericht	4	55	6	Building	LD_Marienring	Platanus	2020-04-14	18	60
Landau	Friedrich-Ebert-Straße	25	55	6	Building	LD_Marienring	Platanus	2020-04-14	18	70
Landau	Marienkirche	2	55	6	Building	LD_Marienring	Platanus	2020-04-14	14	40
Landau	Marienkirche	5	55	6	Building	LD_Marienring	Platanus	2020-04-14	16	50
Landau	Marienkirche	8	55	6	Building	LD_Marienring	Platanus	2020-04-14	10	30
Landau	Sovoyenpark	8	211	45	Park	LD_Goethepark	Ginkgo biloba	2020-04-14	22	90
Landau	Sovoyenpark	11	211	45	Park	LD_Goethepark	Quercus petraea	2020-04-14	24	130
Landau	Sovoyenpark	5	211	45	Park	LD_Goethepark	Platanus	2020-04-14	26	100
Landau	Sovoyenpark	3	211	45	Park	LD_Goethepark	Tilia	2020-04-14	24	80
Landau	Sovoyenpark	4	211	45	Park	LD_Goethepark	Platanus	2020-04-14	24	110
Landau	Sovoyenpark	1	211	45	Park	LD_Goethepark	Acer	2020-04-14	18	55
Landau	Sovoyenpark	3	211	45	Park	LD_Goethepark	Acer pseudoplatanus	2020-04-14	16	30
Landau	Sovoyenpark	2	211	45	Park	LD_Goethepark	Tilia	2020-04-14	16	30
Landau	Sovoyenpark	1	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	16	30
Landau	Sovoyenpark	1	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	14	30

Landau	Sovoyenpark	3	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	14	30
Landau	Sovoyenpark	1	211	45	Park	LD_Goethepark	Gleditsia triacanthos inermis	2020-04-14	22	70
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Acer pseudoplatanus	2020-04-14	14	22
Landau	Goethepark	3	211	45	Park	LD_Goethepark	Fraxinus	2020-04-14	14	24
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Tilia cordata	2020-04-14	18	40
Landau	Goethepark	41	211	45	Park	LD_Goethepark	Platanus	2020-04-14	28	120
Landau	Goethepark	6	211	45	Park	LD_Goethepark	Fraxinus	2020-04-14	22	70
Landau	Goethepark	31	211	45	Park	LD_Goethepark	Quercus robur	2020-04-14	28	130
Landau	Goethepark	30	211	45	Park	LD_Goethepark	Platanus	2020-04-14	22	120
Landau	Goethepark	2	211	45	Park	LD_Goethepark	Tilia cordata	2020-04-14	24	80
Landau	Goethepark	3	211	45	Park	LD_Goethepark	Tilia cordata	2020-04-14	26	110
Landau	Parkstraße	4	211	45	Park	LD_Goethepark	Fraxinus	2020-04-14	14	40
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	18	36
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Fraxinus	2020-04-14	16	35
Landau	Goethepark	2	211	45	Park	LD_Goethepark	Acer	2020-04-14	16	80
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Robinia	2020-04-14	18	40

Landau	Goethepark	1	211	45	Park	LD_Goethepark	Robinia	2020-04-14	18	40
Landau	Suedring	1	211	45	Building	LD_Goethepark	Platanus hispanica	2020-04-14	50	18
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Acer	2020-04-14	14	25
Landau	Goethepark	2	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	18	50
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	18	50
Landau	Goethepark	6	211	45	Park	LD_Goethepark	Fraxinus	2020-04-14	20	33
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	12	20
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Quercus cerris L.	2020-04-14	24	110
Landau	Goethepark	1	211	45	Park	LD_Goethepark	Acer pseudoplatanus	2020-04-14	20	60
Landau	Goethepark	2	211	45	Park	LD_Goethepark	Acer	2020-04-14	20	45
Landau	Goethepark	6	211	45	Park	LD_Goethepark	Platanus	2020-04-14	26	130
Landau	Jahnstraße	8	211	45	Park	LD_Goethepark	Fagus sylvatica Atropunicea	2020-04-14	18	130
Landau	Jahnstraße	3	211	45	Park	LD_Goethepark	Acer platanoides	2020-04-14	10	30
Landau	Otto-Hahn-Gymnasium	2	211	45	Building	LD_Goethepark	Platanus	2020-04-14	24	180
Landau	Meßplatz	13	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	50

Landau	Meßplatz	3	113	27	Building	LD_Meßplatz		2020-04-14	18	50
Landau	Meßplatz	5	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	60
Landau	Meßplatz	3	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	16	40
Landau	Meßplatz	1	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	14	30
Landau	Meßplatz	5	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	60
Landau	Meßplatz	3	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	16	50
Landau	Meßplatz	4	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	60
Landau	Meßplatz	4	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	70
Landau	Meßplatz	16	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	60
Landau	Meßplatz	6	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	50
Landau	Meßplatz	5	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	16	50
Landau	Meßplatz	4	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	60
Landau	Am Kronwerk	1	113	27	Building	LD_Meßplatz	Tilia	2020-04-14	18	50
Landau	Am Kronwerk	1	113	27	Building	LD_Meßplatz	Acer	2020-04-14	16	25
Landau	Am Kronwerk	1	113	27	Building	LD_Meßplatz		2020-04-14	18	40
Landau	Meßplatz	17	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	60
Landau	Meßplatz	14	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	70
Landau	Meßplatz	6	113	27	Building	LD_Meßplatz	Platanus	2020-04-14	18	60
Landau	Am_ Buergergraben	2	113	27	Building	LD_Meßplatz	Fraxinus	2020-04-14	16	30
Landau	Am_ Buergergraben	2	113	27	Building	LD_Meßplatz	Fraxinus	2020-04-14	18	30
Landau	Am_ Buergergraben	1	113	27	Building	LD_Meßplatz	Fraxinus	2020-04-14	16	20
Landau	Am_	1	113	27	Building	LD_Meßplatz	Fraxinus	2020-04-14	16	40

	Buergergraben									
Landau	Am_ Buergergraben	1	113	27	Building	LD_Meßplatz	Fraxinus	2020-04-14	21	43
Landau	Am_ Buergergraben	2	113	27	Building	LD_Meßplatz	Alnus	2020-04-14	22	21
Landau	Am_ Buergergraben	1	113	27	Building	LD_Meßplatz	Acer pseudoplata nus	2020-04-14	10	20
Landau	Am_ Buergergraben	1	113	27	Building	LD_Meßplatz	Acer pseudoplata nus	2020-04-14	16	30
Landau	Fortanlage	1	20	10	Park	LD_Fortanlage	Acer platanoides	2020-04-14	12	30
Landau	Fortanlage	2	20	10	Park	LD_Fortanlage	Acer campestre	2020-04-07	23	41
Landau	Fortanlage	1	20	10	Park	LD_Fortanlage	Fraxinus	2020-04-14	20	30
Landau	Fortanlage	2	20	10	Park	LD_Fortanlage	Acer campestre	2020-04-14	18	40
Landau	Fortanlage	2	20	10	Park	LD_Fortanlage	Acer platanoides	2020-04-14	23	43
Landau	Fortanlage	3	20	10	Park	LD_Fortanlage	Acer platanoides	2020-04-14	25	52
Landau	Fortanlage	2	20	10	Park	LD_Fortanlage	Acer platanoides	2020-04-14	22	46
Landau	Fortanlage	2	20	10	Park	LD_Fortanlage	Acer platanoides	2020-04-14	25	53

Landau	Fortanlage	1	20	10	Park	LD_Fortanlage	Acer platanoides	2020-04-14	26	41
Landau	Fortanlage	4	20	10	Park	LD_Fortanlage	Acer platanoides	2020-04-14	28	57
Landau	Lazarettstraße	1	11	5	Building	LD_Lazarettstr	Tilia	2020-04-15	20	62
Landau	Robert-Koch-Straße	1	11	5	Building	LD_Lazarettstr	Acer rotblättriger Bergahorn	2020-04-15	20	38
Landau	Lazarettstraße	3	11	5	Building	LD_Lazarettstr	Tilia	2020-04-15	22	90
Landau	Robert-Koch-Straße	4	11	5	Building	LD_Lazarettstr	Tilia	2020-04-15	22	56
Landau	Robert-Koch-Straße	2	11	5	Building	LD_Lazarettstr	Acer	2020-04-15	21	75
Landau	An_den_Lerchenwiesen	1	3	2	Building	LD_An_den_Lerchenwiesen	Betula	2019-04-15	18	30
Landau	An_den_Lerchenwiesen	2	3	2	Building	LD_An_den_Lerchenwiesen	Platanus	2020-04-15	14	30
Landau	Goethepark	5	211	45	Park	LD_Goethepark	Fraxinus	2020-04-23	16	40
Landau	Schillerpark	1	211	45	Park	LD_Goethepark	Pinus	2020-05-18	24	60
Landau	Schillerpark	1	211	45	Park	LD_Goethepark	Pinus		22	60
Landau	Schillerpark	1	211	45	Park	LD_Goethepark	Pinus	2020-05-18	22	60
Landau	Schillerpark	2	211	45	Park	LD_Goethepark	Quercus	2020-05-18	28	70
Landau		1					Acer platanoides	2020-06-22	25	41
Ludwigshafen	Ebertpark	8	43	11	Building	LU_Ebertpark	Platanus	2020-04-12		

Ludwigshafen	Ebertpark	8	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Ebertpark	2	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Ebertpark	5	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Ebertpark	4	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Ebertpark	1	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Ebertpark	1	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Buergermeister-Gruenzweig_ Straße	7	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Buergermeister-Gruenzweig_ Straße	9	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Buergermeister-Gruenzweig_ Straße	1	43	11	Building	LU_Ebertstraße	Platanus	2020-04-12
Ludwigshafen	Buergermeister-Gruenzweig_ Straße	7	43	11	Building	LU_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Realschule_ am_Ebertpark	1	2	2	Building	LU_Realschule_am_ Ebertpark	Platanus	2020-04-12

Ludwigshafen	Realschule_am_Ebertpark	1	2	2	Building	LU_Realschule_am_Ebertpark	Platanus	2020-04-12
Ludwigshafen	Bliesstraße	2	18	2	Building	LU_Bliesstraße	Platanus	2020-04-12
Ludwigshafen	Bliesstraße	16	18	2	Building	LU_Bliesstraße	Platanus	2020-04-12
Neustadt	Ostschule	2	15	7	Building	NW_Grundschule_Ostschule	Platanus	2020-04-13
Neustadt	Ostschule	2	15	7	Building	NW_Grundschule_Ostschule	Platanus	2020-04-13
Neustadt	Ostschule	3	15	7	Building	NW_Grundschule_Ostschule	Platanus	2020-04-13
Neustadt	Ostschule	2	15	7	Building	NW_Grundschule_Ostschule	Platanus	2020-04-13
Neustadt	Ostschule	3	15	7	Building	NW_Grundschule_Ostschule	Platanus	2020-04-13
Neustadt	Ostschule	2	15	7	Building	NW_Grundschule_Ostschule	Platanus	2020-04-13
Neustadt	Ostschule	1	15	7	Building	NW_Grundschule_Ostschule	Platanus	2020-04-13
Obrigheim	Eisbach	1	24	7	Rural landscape	DUEW_Obrigheim_Eisbach	Populus	2020-04-10
Obrigheim	Eisbach	1	24	7	Rural landscape	DUEW_Obrigheim_Eisbach	Populus	2020-04-10
Obrigheim	Eisbach	3	24	7	Rural landscape	DUEW_Obrigheim_Eisbach	Populus	2020-04-10
Obrigheim	Eisbach	3	24	7	Rural landscape	DUEW_Obrigheim_	Populus	2020-04-10

						Eisbach		
Obrigheim	Eisbach	1	24	7	Rural landscape	DUEW_Obrigheim_ Eisbach	Populus	2020-04-10
Obrigheim	Eisbach	6	24	7	Rural landscape	DUEW_Obrigheim_ Eisbach	Populus	2020-04-10
Obrigheim	Eisbach	8	24	7	Rural landscape	DUEW_Obrigheim_ Eisbach	Populus	2020-04-10
Offenbach	Bruehlgraben	2	5	3	Building edge	SUEW_Bruehlgraben	Populus	2020-04-13
Offenbach	Bruehlgraben	2	5	3	Building edge	SUEW_Bruehlgraben	Populus	2020-04-13
Offenbach	Bruehlgraben	1	5	3	Building edge	SUEW_Bruehlgraben	Populus	2020-04-13
Rheingoenheim	Bhf_Rheingoen heim	5	5	1	Building	LU_Bhf_Rheingoenheim	Platanus	2020-04-12
Rheingoenheim	Hoher_Weg	1	3	3	Building	LU_Hoher_Weg	Platanus	2020-04-12
Rheingoenheim	Hoher_Weg	1	3	3	Building	LU_Hoher_Weg	Platanus	2020-04-12
Rheingoenheim	Hoher_Weg	1	3	3	Building	LU_Hoher_Weg	Platanus	2020-04-12
Roedersheim-Gronau	Hauptstraße	23	33	4	Building	RP_Roedersheim-Gronau_Hauptstr	Platanus	2020-04-11
Roedersheim-Gronau	Hauptstraße	16	33	4	Building	RP_Roedersheim-Gronau_Hauptstr	Platanus	2020-04-11
Roedersheim-Gronau	sGaessl	2	33	4	Building	RP_Roedersheim-Gronau_Hauptstr	Betula	2020-04-11

Roedersheim-Gronau	sGaessl	2	33	4	Building	RP_Roedersheim-Gronau_Hauptstr	Betula	2020-04-11
Speyer	Deutsches_Forschungsinstitut	1	82	23	Building	SP_Deutsches_Forschungsinstitut	Platanus	2020-04-12
Speyer	Deutsches_Forschungsinstitut	2	82	23	Building	SP_Deutsches_Forschungsinstitut	Quercus rubra	2020-04-12
Speyer	Deutsches_Forschungsinstitut	1	82	23	Building	SP_Deutsches_Forschungsinstitut	Juglans	2020-04-17
Speyer	Deutsches_Forschungsinstitut	4	82	23	Building	SP_Deutsches_Forschungsinstitut	Acer pseudoplatanus	2020-04-12
Speyer	Deutsches_Forschungsinstitut	6	82	23	Building	SP_Deutsches_Forschungsinstitut	Acer pseudoplatanus	2020-04-12
Speyer	Hans-Sachs-Straße	5	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	1	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	1	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	5	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	9	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12

Speyer	Hans-Sachs-Straße	3	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	2	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	2	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	1	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	1	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	2	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Emanuel-Geibel-Weg	6	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	2	82	23	Building	SP_Deutsches_Forschungsinstitut	Acer pseudoplatanus	2020-04-12
Speyer	Hans-Sachs-Straße	14	82	23	Building	SP_Deutsches_Forschungsinstitut	Acer platanoides	2020-04-12
Speyer	Hans-Sachs-Straße	4	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Hans-Sachs-Straße	9	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Emanuel-Geibel-Weg	2	82	23	Building	SP_Deutsches_Forschungsinstitut	Aesculus	2020-04-12
Speyer	Emanuel-Geibel-Weg	1	82	23	Building	SP_Deutsches_Forschungsinstitut	Robinia	2020-04-12

Appendix III -Tree height and DBH of breeding trees within Landau

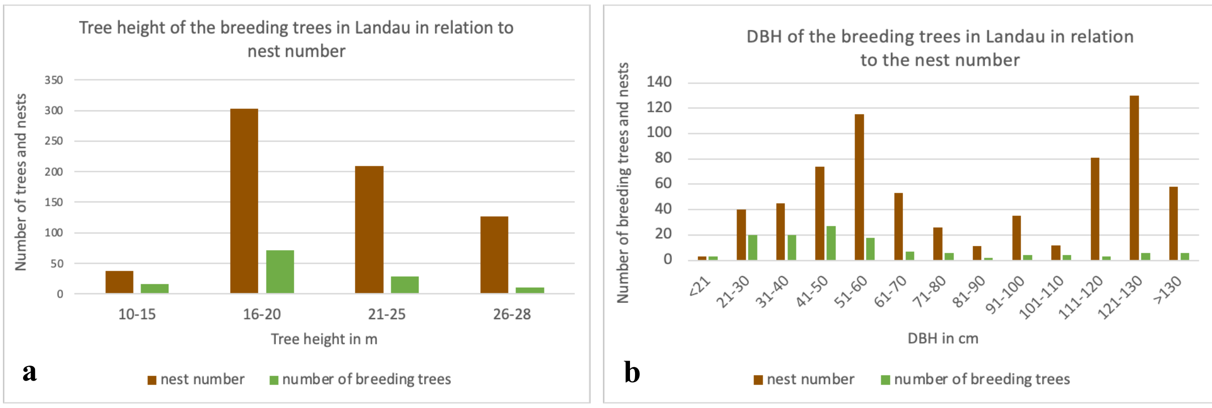

Figure 32: (a) DBH of breeding trees in Landau in relation to the number of nests and (b) tree height of the breeding trees in Landau based on the mapping in 2020

Appendix IV - Development of the urban colony in Grünstadt and the rural colony at the Eisbach

The colony in Grünstadt is the only colony in the study area where several years of data are available from an urban and a nearby rural colony, which is the rural colony at the Eisbach close to Obrigheim only 3 km away from Grünstadt. Therefore, it is possible to determine whether the number of nests increased in the city of Grünstadt while it decreased in the colony at the Eisbach. Figure 33a shows the absolute nest numbers for both urban and rural areas, while Figure 33b shows the percentage of urban and rural nests in relation to each other. While the total number of nests in Grünstadt and at the Eisbach together increased strongly from 2011 (70) to 2013 (266), the number of urban nests increased much more (2011: 16, 2013: 187) compared to the number of rural nests (2011: 54, 2013: 79; Figure 33a). That is also reflected in Figure 33b, which shows that the proportion of urban nests has risen strongly (2011: 23%, 2013: 70%).

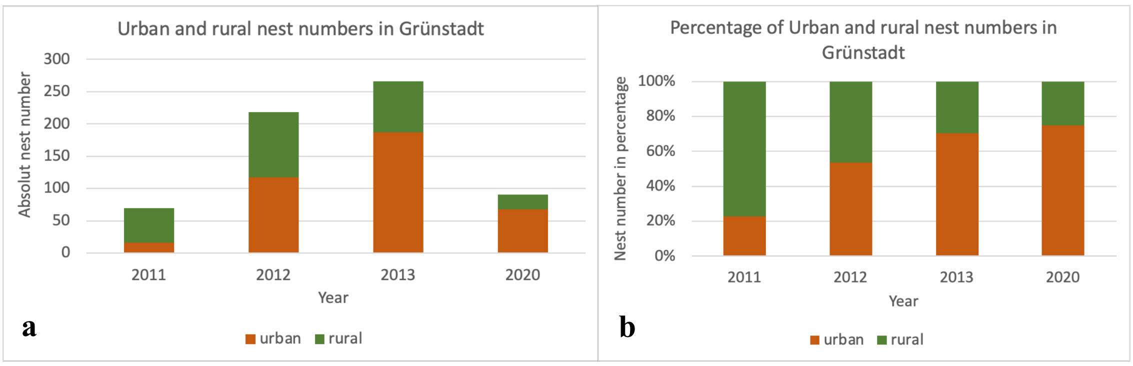

Figure 33: Development of (a) urban and rural nest numbers in Grünstadt and (b) the percentage of urban and rural nests from 2011 to 2020 based on data from GNOR (GNOR 2015) and the own mapping in 2020

Consequently, it is possible that the rooks that used to breed at the Eisbach have moved to Grünstadt. However, there was a much greater increase in the number of urban nests than can be explained by a decrease in the number of rural nests. This means that in addition to the rooks that used to breed at the Eisbach, either other rooks must have joined the urban population in Grünstadt as well or there must have been a strong natural increase in the population
However, the total number of nests fell very sharply from 2013 to 2020 (2013: 266, 2020: 91). Maybe some of the rooks that used to nest at those locations now breed in the new colony in Edenkoben, whereby the reasons for the establishment of the new colony in Edenkoben remain unclear.

Appendix V – Repellent measures in the study area

Table 11: Rook nests removed between 2010 and 2020 in the counties and cities of Südliche Weinstraße, Landau in der Pfalz, Germersheim, Neustadt an der Weinstraße, Dürkheim an der Weinstraße, Ludwigshafen, Speyer, Frankenthal (Klöppel 2020)

Datum	Ort	Straße	Grund	Maßnahme	Art der Zustimmung
13.12.11	Grün-stadt	Leininger Gymnasium Grünstadt	Beeinträchtigung Schulhof + Schulbetrieb	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
06.01.12	LD-Queich-heim	Queichheimer Hauptstraße	Baumfällung wg Kanalschäden	Baumfällung	Ausnahme nach § 45 (7) BNatSchG
06.02.12	LD-Damm-heim		Baumfällung wg mangelnder Standsicherheit	Baumfällung	Ausnahme nach § 45 (7) BNatSchG
25.04.13	Landau	Langstr. 9	Beeinträchtigung Kindergarten Freigelände	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
28.01.13	Grün-stadt	Rathaus	Kronenpflege, Einkürzungen	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
19.12.13	LD-Damm-heim	Flurstück Nr. 3947	Baumfällung wg mangelnder Standsicherheit	Baumfällung	Ausnahme nach § 45 (7) BNatSchG

18.12.14	Grün-stadt	Bahnhof	Baumfällung wg mangelnder Standsicherheit	Baumfällung	Ausnahme nach § 45 (7) BNatSchG
17.01.14	Landau	Pestalozzi-schule	Beeinträchtigung Schulhof + Schulbetrieb	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
13.10.14	SP-Duden-hofen	Radweg Dudenhofener Straße	Baumfällung wg mangelnder Standsicherheit	Baumfällung	Ausnahme nach § 45 (7) BNatSchG
30.11.15	Landau	Goethepark	Kroneneinkürzung wg mangelnder Bruchsicherheit	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
29.04.15	Neu-stadt/ Wstr.	VHS	Baumfällung wg mangelnder Standsicherheit	Baumfällung	Ausnahme nach § 45 (7) BNatSchG
05.04.16	Freins-heim	Marktplatz	Etablierung einer Kolonie	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
15.04.16	Grün-stadt	Südring 5	Beeinträchtigung Kindergarten Freigelände	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
27.10.17	Deides-heim	Bahnübergang Bahnhof	Kronenpflege, Einkürzungen	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
24.11.17	Landau	Ostbahnstraße	Baumfällung, wg, Straßenausbau	Baumfällung	Ausnahme nach § 45 (7) BNatSchG
24.12.17	Röders-heim-Gronau	David-Möllinger-Straße	Beeinträchtigung Spielplatz	Nestentnahme, Astvereinze-lung	Ausnahme nach § 45 (7) BNatSchG
10.10.18	Eden-koben	Bahnhof	Baumpflegemaß-nahmen	Nestentnahme, Einkürzungen	Ausnahme nach § 45 (7) BNatSchG
11.12.18	Groß-karl-bach	Radweg, Flurstück-Nr. 1902	Kroneneinkürzung wg mangelnder Bruchsicherheit	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG

27.02.18	Grün-stadt	Südring 5	Beeinträchtigung Kindergarten Freigelände	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
13.04.18	Landau	Kita Villa Mahla	Beeinträchtigung Kindergarten Freigelände	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
16.07.18	Landau	Ostpark	Massaria, Kroneneinkürzung	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
22.02.18	NW-Dutt-weiler	Freibad	Baumfällung wg mangelnder Standsicherheit	Baumfällung	Ausnahme nach § 45 (7) BNatSchG
23.03.18	Freinsh eim	Grundschule	Beeinträchtigung Schulhof + Schulbetrieb	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
09.03.18	Schau-ern-heim	Grundschule	Beeinträchtigung Schulhof + Schulbetrieb	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
10.12.18	SP-Duden-hofen	Dudenhofer Straße	Baumpflegemaß-nahmen	Nestentnahme, Einkürzungen	Ausnahme nach § 45 (7) BNatSchG
22.01.19	Fran-kenthal	Fontanesien-straße	Beeinträchtigung Spielplatz	Nestentnahme, Astvereinze-lung	Ausnahme nach § 45 (7) BNatSchG
19.12.19	Fran-kenthal	Fontanesien-straße	Beeinträchtigung Spielplatz	Nestentnahme, Astvereinze-lung	Ausnahme nach § 45 (7) BNatSchG
14.03.19	LD-Queich-heim	Grundschule	Beeinträchtigung Schulhof + Schulbetrieb	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
02.04.19	Fran-kenthal	Kita Kirchgraben-straße	Beeinträchtigung Kindergarten Freigelände	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
28.03.19	Landau	Kita Langstraße	Beeinträchtigung Kindergarten Freigelände	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG

12.03.19	Landau	Maria-Ward.Schule	Beeinträchtigung Schulhof + Schulbetrieb	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
10.01.19	Rödersheim-Gronau	David-Möllinger-Straße	Beeinträchtigung Spielplatz	Nestentnahme, Astverein-zelung	Ausnahme nach § 45 (7) BNatSchG
22.01.19	Landau	Pestalozzi-schule, Otto-Hahn-Gymnasiums, Max-Slevogt-Gymnasiums Grundschule Godramstein	Beeinträchtigung Schulhof + Schulbetrieb	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
24.03.20	Dann-stadt	Seebachring Spielplatz	Beeinträchtigung Spielplatz	Nestentnahme, Astverein-zelung	Ausnahme nach § 45 (7) BNatSchG
03.03.20	Fran-kenthal	Kita Kirchgraben-straße	Beeinträchtigung Kindergarten Freigelände	Nestentnahme	Ausnahme nach § 45 (7) BNatSchG
23.01.20	Landau	Goethepark	Kroneneinkürzung wg mangelnder Bruchsicherheit	Kronenein-kürzung	Ausnahme nach § 45 (7) BNatSchG
16.03.18	Landau	Langstraße	Unzumutbarkeit Terrasse Gastätte	Nestentnahme	Befreiung nach § 67 (2) BNatSchG
22.01.19	Bad Dürk-heim	Dresdener Str. 16-32	Baumfällung wg Kanalschäden	Baumfällung	Einvernehmen § 9 (1) LNatSchG
14.03.19	Landau	Langstraße	Unzumutbarkeit Terrasse Gastätte	Nestentnahme, Astverein-zelung	Befreiung nach § 67 (2) BNatSchG
28.01.20	Bad Dürk-heim	Dr.-Hugo-Bischoff-Straße 1a	Kroneneinkürzung Herstellung Verkehssicherheit	Kronenein-kürzung	Befreiung nach § 67 (2) BNatSchG

Appendix VI - Temperature preferences of various bird species for breeding site

Table 12: Nest site preferences in temperature in comparison to the ambient temperature and/or temperature at randomly selected sites for comparison in different bird species

Bird species				Ambient temperature in °C			Temperature at breeding sites		Breeding success		
Latin	**English**	**Breeding behaviour**	**Study area**	**Min**	**Max**	**Mean**	**Breeding preferred at sites which are**	**Temperature differences at preferred breeding sites**	**Highest breeding success at sites which are**	**Tempe-rature with highest breeding success**	**Literature**
Alle alle	Little auk	colony breeder, rocky coast	Spitsbergen (Norway)	-	-	4.02	-	in the mean 0.43°C warmer in nests than ambient temperature	warmer	-	Kulaszewicz and Jakubas 2018
Calcarius ornatus	Chestnut-collared longspurs	ground-nesting bird	Montana (USA)	-	38.00	-	warmer	-	cooler	8.7 °C colder than the	Lloyd and Martin 2004

										prefered nest	
Callipepla squamata	Scaled quail	ground-nesting bird	Southern Great Plains (USA)	5.00	40.60	-	Cooler	8.2°C cooler than random sites during afternoon	warmer	-	Carroll et al. 2018
Colinus virginianus	Northern bobwhite	ground-nesting bird	Southern Great Plains (USA)	5.00	40.60	-	Cooler	5.7°C cooler than random sites during afternoon	cooler	-	Carroll et al. 2018
Corvus frugilegus	Rook	colony breeder, tree	Oulu (Finland)	-	-	5.5 to 9	warmer	-	Warmer	9°C	Rytkönen et al. 1993
Hirundo rustica	Barn swallow	walls, beams of anthropo-genic structures	Cardiff, Wales, (UK)	6.80	23.82	15.41	-	-	cooler	-	Facey et al. 2020

Melanerpes lewis	Lewis's woodpecker	cavity breeders	Idaho (North America)	-3.00	38.00	-	-	-	warmer	-	Newlon and Saab 2011
Petrochelidon pyrrhonota	Cliff swallow	eaves	New Brunswick (Canada)	-	28.60	-	-	-	cooler	6.4°C colder than the prefered breeding site	Imlay et al. 2019
Tympanuchus cupido	Greater Prairie-chicken	ground-nesting bird	Oklahoma (USA)				cooler		-		Hovick et al. 2014

Appendix VII - Hearing range of various bird species

Table 13: Hearing range of bird species

Species	Hearing range at a cutoff at 60 dB SPL	Best hearing	Reference
Anas platyrhynchos	66 Hz to 7.6 kHz	2 kHz	(Hill 2017)
Columba livia	ca. 40 Hz to 6.5 kHz	1 to 2 kHz	(Heffner et al. 2013)
Corvus corone cornix	up to ca. 8 kHz	1 kHz	(Jensen and Klokker 2006)
Coturnix japonica	59.5 Hz to 7 kHz	2 kHz	(Strawn and Hill 2020)
Cyanocitta cristata	up to ca. 8 kHz	2 kHz	(Cohen et al. 1978)
Melospiza georgiana	up to ca. 10 kHz	3 kHz	(Okanoya and Dooling 1987)
Melospiza melodia	up to ca. 11 kHz	2 kHz	(Okanoya and Dooling 1987)
Melopsittacus undulatus	77 Hz to 7.6 kHz	3 kHz	(Heffner et al. 2016)
Molothrus ater	up to ca. 5.5 to 9.5 kHz (depending on the methodology)	2 to 4 kHz	(Gall et al. 2011)
Nymphicus hollandicus	up to ca. 6 kHz	3 kHz	(Okanoya and Dooling 1987)
Serinus canarius	up to ca. 8 kHz	3 kHz	(Okanoya and Dooling 1987)
Sturnus vulgaris	up to ca. 8 kHz	3 kHz	(Okanoya and Dooling 1987)
Taeniopygia guttata	up to ca. 6 kHz	4 kHz	(Okanoya and Dooling 1987)
Human	up to ca. 18 kHz	3 kHz	(Jackson 2012)

Appendix VIII – Histograms

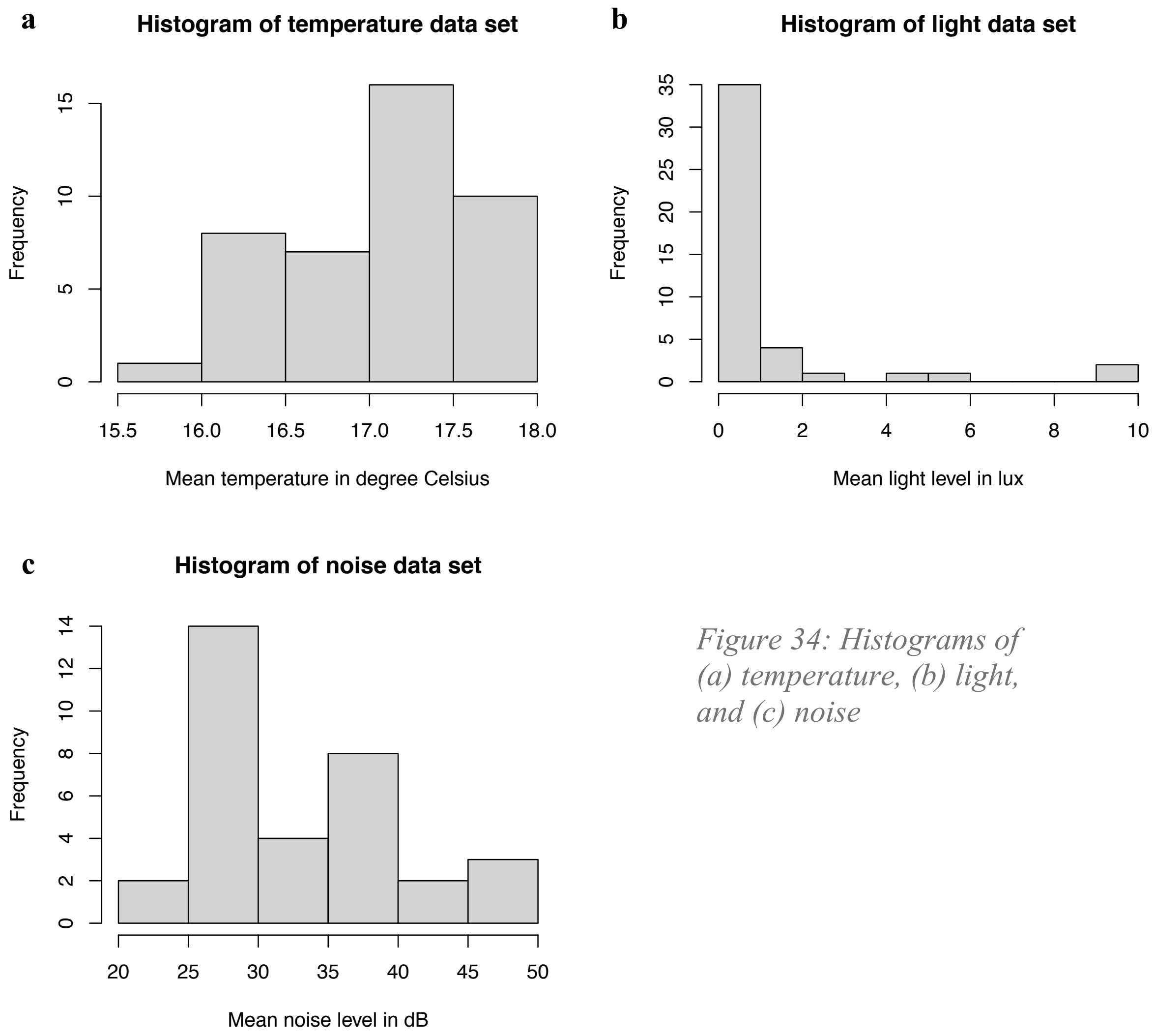

Figure 34: Histograms of (a) temperature, (b) light, and (c) noise

Appendix IX – Residuals vs. fitted values

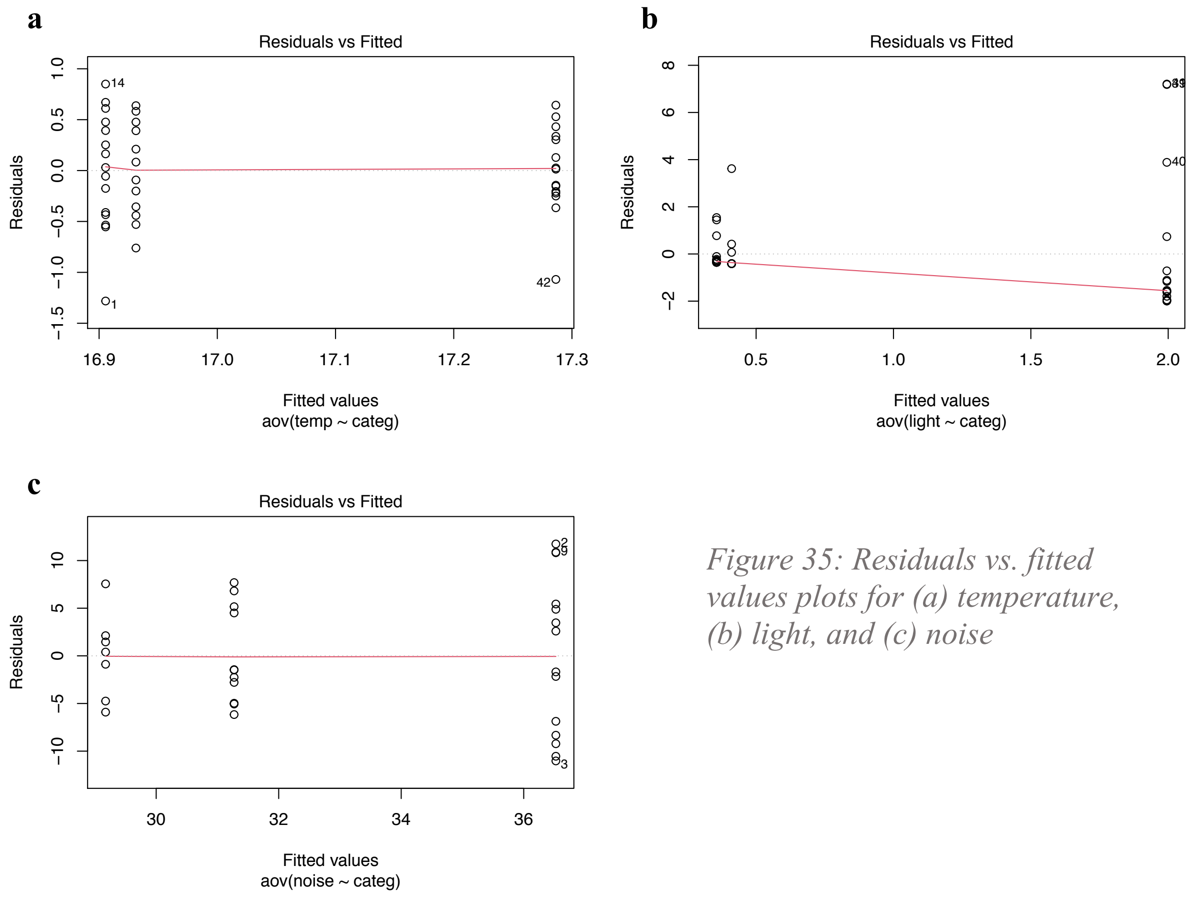

Figure 35: Residuals vs. fitted values plots for (a) temperature, (b) light, and (c) noise

Appendix X – Cook's Distance

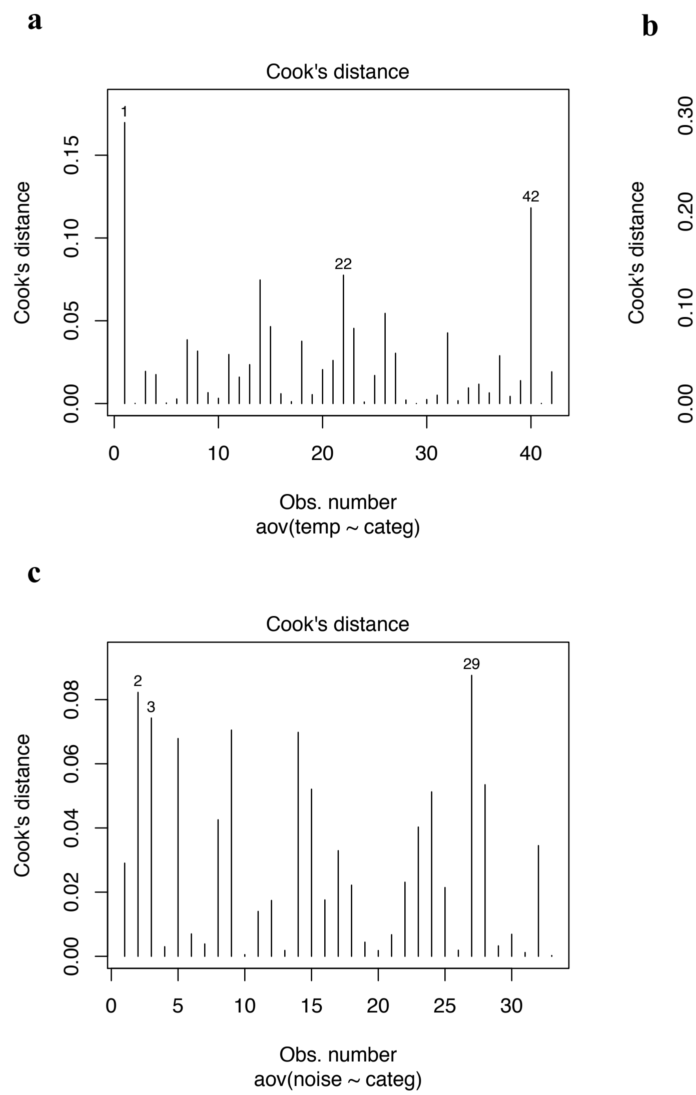

Figure 36:Cook's Distance of (a) temperature, (b) light, and (c) noise

Appendix XI – R script

```
#### Preparation ####
# set working directory
# import data set Daten_Alle
# check data
str(Daten_Alle)

# change temperature to numeric
Daten_Alle$temp <- as.numeric(Daten_Alle$temp)
# create boxplot temperature
boxplot(temp~categ, data = Daten_Alle, main = "Mean temperature of the investigated trees",
        xlab = "Tree category", ylab = "Temperature in degree Celsius")

# create boxplot light
boxplot(Lux~categ, data = Daten_Alle, main = "Mean light level of the investigated trees",
        xlab = "Tree category", ylab = "Light level in lux")

# change noise to numeric
Daten_Alle$noise <- as.numeric(Daten_Alle$noise)
# create boxplot noise
boxplot(noise~categ, data = Daten_Alle, main = "Mean noise level of the investigated trees",
        xlab = "Tree category", ylab = "Noise level in dB")

################
#### ANOVA ####
################

#### Check for Assumptions ####
############################

#### normal distribution ####
# (1) check for normal distribution visually with histogram
# (2) check for normal distribution with Shapiro-Wilk Test
```

```
#    for data and residuals
#    H0 assumes normal distribution
#    if p-value is below 0.05 data is not normally distributed

# create histogram temperature
hist.temp <- hist(Daten_Alle$temp, main="Histogram of temperature data set",
        xlab = "Mean temperature in degree Celsius", ylab = "Frequency")
# Shapiro-Wilk Test temperature
shapiro.test(Daten_Alle$temp)
# W = 0.96876, p-value = 0.2998
# normally distributed
# normal distribution of residuals temperature
# calculate residuals
res.temp = residuals(lm(temp ~ categ))
temp.aov <- aov(temp ~ categ)
res.temp = temp.aov$residuals
# Shapiro-Wilk Test residuals temperature
shapiro.test(res.temp)
# W = 0.97129, p-value = 0.3646
# normally distributed

# create histogram light
hist(Daten_Alle$Lux, main="Histogram of light data set", xlab = "Mean light level in lux",
          ylab = "Frequency")
# Shapiro-Wilk Test light
shapiro.test(Daten_Alle$Lux)
# W = 0.50668, p-value = 5.857e-11
# not normally distributed
# normal distribution of residuals light
# calculate residuals
res.light = residuals(lm(light ~ categ))
light.aov <- aov(light ~ categ)
res.light = light.aov$residuals
# Shapiro-Wilk Test residuals temperature
```

```
shapiro.test(res.light)
# W = 0.69117, p-value = 2.495e-08
# not normally distributed

# create histogram noise
hist(Daten_Alle$noise, main="Histogram of noise data set", xlab = "Mean noise level in dB",
        ylab = "Frequency")
# Shapiro-Wilk Test noise
shapiro.test(Daten_Alle$noise)
# W = 0.92088, p-value = 0.02196
# not normally distributed
# normal distribution of residuals noise
# calculate residuals
res.noise = residuals(lm(noise ~ categ))
noise.aov <- aov(noise ~ categ)
res.noise = noise.aov$residuals
# Shapiro-Wilk Test residuals temperature
shapiro.test(res.noise)
# W = 0.97116, p-value = 0.532
# normally distributed

#### variance homogeneity ####
# (1) check with Levene's test
#     H0: variances of the groups are the same
#     if p-value is above 0.05 there is variance homogeneity
# (2) check visually with residual vs fitted plot

install.packages("carData")
library(carData)
library(car)

# Levene's Test temperature
leveneTest(Daten_Alle$temp, Daten_Alle$categ)
# Levene's Test for Homogeneity of Variance (center = median)
```

```
# p-value = 0.4145
# variance homogeneity

# visual check: residuals vs fitted plot temperature
plot(temp.aov)

# Levene's Test light
leveneTest(Daten_Alle$Lux, Daten_Alle$categ)
# Levene's Test for Homogeneity of Variance (center = median)
# p-value = 0.08043
# variance homogeneity

# visual check: residuals vs fitted plot light
plot(light.aov)

# Levene's Test noise
leveneTest(Daten_Alle$noise, Daten_Alle$categ)
# Levene's Test for Homogeneity of Variance (center = median)
# p-value = 0.02782
# no variance homogeneity

# visual check: residuals vs fitted plot noise
plot(noise.aov)


#### outliers ####
# detect outliers with Cook's distance and Residuals vs Leverage temperature
# plots
# Cook's distance plot shows the three most extreme values

# Cook's distance light
plot(light.aov, 4)
# Residuals vs Leverage temperature
plot(light.aov, 5)
```

```
# Cook's distance temperature
plot(temp.aov, 4)
# Residuals vs Leverage temperature
plot(temp.aov, 5)

# Cook's distance noise
plot(noise.aov, 4)
# Residuals vs Leverage noise
plot(noise.aov, 5)
# Export as PDF with size 5x4.5

# outliers are plausible and are therefore not extracted



#### conduct ANOVA ####
########################

# since ANOVA is robust against violation of normal distribution and variance
# homogeneity it is anyhow conducted
# moreover, a permutation test is conducted based on the ANOVA

temp <- Daten_Alle$temp
light <- Daten_Alle$Lux
noise <- Daten_Alle$noise
categ <- Daten_Alle$categ

### temperature ###
# ANOVA temperature
temp.aov <- aov(temp ~ categ)
summary(temp.aov)
# p-value = 0.0815
plot(temp.aov)
# PermTest with 1000 replicates
```

```
library(pgirmess)
PermTest(temp.aov, B = 10000)
# p-value = 0.082
# not significant

### light ###
# ANOVA light
light.aov <- aov(light ~ categ)
summary(light.aov)
# p-value = 0.0531
plot(light.aov)
# PermTest with 1000 replicates
light.perm <- PermTest(light.aov, B = 10000)
# p-value = 0.046
# significant
# Tukey-HSD (Post-Hoc-Test)
tukey.light <- TukeyHSD(light.aov)
tukey.light
# N-B: p=0.05
# Z-B: p=1.64
# Z-N: p=1.58

### noise ###
# ANOVA noise
noise.aov <- aov(noise ~ categ)
summary(noise.aov)
# p-value = 0.043
plot(noise.aov)
# Export as PDF with size 6x4.5
# PermTest with 1000 replicates
PermTest(noise.aov, B = 10000)
# p-value = 0.038
# Tukey-HSD (Post-Hoc-Test)
tukey.noise <- TukeyHSD(noise.aov)
```

```
tukey.noise
# N-B: p=0.14
# Z-B: p=0.06
# Z-N: p=0.79


#### Plot noise as a logistic regression model ####
###########################################

# Bm, Nm and Nr are divided into breeding and non-breeding trees according to
# the column breeding

breeding <- Daten_Alle$breeding
noise.2 <- Daten_Alle$noise

# plot the graph
plot(noise.2, jitter(breeding, 0.15, amount = NULL), pch = 19, col = "white",
     xlab = "Noise level in dB",
     ylab = "Probability of a tree being used for breeding",
     main = "Breeding or non-breeding tree based on the noise level")

# fit a glm
glm.breeding.noise.2 <- glm(breeding ~ noise.2, binomial)
summary(glm.breeding.noise.2)
# p-value = 0.0251

# noise level
min(noise.2, na.rm = TRUE)
# 23.2684028
max(noise.2, na.rm = TRUE)
# 48.267153
xv <- seq(23.268403, 48.267153, 0.01)

# Confidence intervals
```

```
yv <- predict(glm.breeding.noise.2, list(noise=xv), type = "response", se.fit=TRUE)
# 1.96: due to 97,5%-quantile
CI=yv$se.fit*1.96

# draw the line
yv <- predict(glm.breeding.noise.2, list(noise.2=xv), type = "response") lines(xv, yv, col =
"black")

# plot polygon
polygon(c(xv, rev(xv)), c(yv-CI, rev(yv+CI)), col = "grey", border = NA)

# add points
points(jitter(breeding,factor = 0.2, amount = NULL)~noise.2, pch = 19, color = "black")
```

Appendix XII - Temperature, ALAN and noise of all investigated trees

Table 14: Mean value and variance of the three variables temperature, artificial light and noise on all examined trees in Landau

Tree ID	Temperature in °C		ALAN in lx		Noise in dB	
	Mean	Variance	Mean	Variance	Mean	Variance
Bm1	15.62	12.50	0.00	0.00	29.65	10.71
Bm2	16.94	15.50	1.13	0.20	48.27	39.71
Bm3	16.47	13.08	0.00	0.00	25.50	1.13
Bm4	16.49	13.54	0.00	0.00	34.36	17.25
Bm5	16.85	12.49	0.00	0.00	25.99	1.43
Bm6	17.07	14.17	0.05	0.00	40.00	57.85
Bm7	17.52	18.80	0.08	0.00	39.12	39.83
Bm8	16.35	17.77	0.00	0.00	28.19	8.88
Bm9	17.16	15.78	1.80	0.35	47.40	13.22
Bm10	16.73	14.56	0.00	0.00	37.53	18.40
Bm11	16.37	13.04	0.00	0.00	41.41	51.13
Bm12	17.30	10.91	0.00	0.00	41.96	33.07
Bm13	17.38	16.64	0.13	0.00	34.84	2.14
Bm14	17.76	15.44	1.90	8.69	47.35	25.26
Bm15	17.58	14.31	0.25	0.03	27.30	5.62
Nm1	17.14	21.68	0.00	0.00	35.77	20.16
Nm2	16.40	13.18	0.00	0.00	26.22	3.18
Nm3	16.84	13.43	0.00	0.00	25.11	1.61
Nm4	16.73	11.82	0.00	0.00	29.02	9.63
Nm5	17.32	16.96	0.83	0.27	29.83	23.51
Nm6	16.49	14.34	0.48	0.14	28.49	14.82

Nm7	16.17	16.83	0.00	0.00	NA	NA
Nm8	17.51	11.28	0.00	0.00	36.43	40.12
Nm9	17.01	12.90	0.00	0.00	38.09	16.76
Nm10	NA	NA	0.00	0.00	38.96	9.69
Nm11	16.58	13.45	0.00	0.00	26.30	15.01
Nm12	17.57	13.84	4.03	7.31	29.79	9.74
Nm13	17.41	15.41	0.00	0.00	NA	NA
Nr1	17.14	14.41	2.73	2.98	36.73	30.34
Nr2	17.30	14.29	0.83	0.15	NA	NA
Nr3	17.13	11.18	0.38	0.19	23.27	1.05
Nr4	17.07	14.34	0.03	0.00	30.63	8.46
Nr5	17.93	13.27	1.28	0.78	NA	NA
Nr6	17.41	11.88	0.20	0.00	NA	NA
Nr7	17.59	15.08	0.40	0.05	NA	NA
Nr8	17.62	13.46	0.88	0.21	31.29	15.72
Nr9	17.04	14.35	0.43	0.00	NA	NA
Nr10	17.82	23.13	0.05	0.00	NA	NA
Nr11	17.08	22.49	9.18	36.52	NA	NA
Nr12	16.92	15.25	5.88	14.30	NA	NA
Nr13	NA	NA	9.20	37.55	NA	NA
Nr14	16.22	31.68	0.00	0.00	28.29	8.65
Nr15	17.31	9.36	0.00	0.00	24.43	0.85
Nr16	17.72	17.00	0.45	0.17	29.57	17.31

Appendix XIII - Properties of the street lamps closest to the investigated trees

Table 15: Luminous colour and type of the street lamps closest to the tree under investigation and the results of the light measurement

Tree ID	Street lighting ID	Luminous colour in K	Distance to the tree in m	Type of street light	Light in lx	
					Mean	Variance
Bm1	4158	3000	49	roadside street light	0.00	0.00
Bm2	1836	4000	10	roadside street light	1.13	0.20
Bm3	3189	3000	90	roadside street light	0.00	0.00
Bm4	3192	3000	24	roadside street light	0.00	0.00
Bm5	8666	3000	20	roadside street light	0.00	0.00
Bm6	1583	3000	13	roadside street light	0.05	0.00
Bm7	1592	3000	17	roadside street light	0.08	0.00
Bm8	2853	3000	32	roadside street light	0.00	0.00
Bm9	7665	3000	5	roadside street light	1.80	0.35
Bm10	8303	3000	74	middle street light	0.00	0.00
Bm11	2306	3000	15	roadside street light	0.00	0.00
Bm12	8589	3000	13	roadside street light	0.00	0.00
Bm13	7411	NA	6	roadside street light	0.13	0.00
Bm14	7684	3000	16	roadside street light	1.90	8.69
Bm15	1151	3000	2	roadside street light	0.25	0.03
Nm1	1813	4000	19	roadside street light	0.00	0.00
Nm2	7004	3000	101	roadside street light	0.00	0.00
Nm3	7004	3000	76	roadside street light	0.00	0.00
Nm4	8658	3000	16	roadside street light	0.00	0.00
Nm5	1573	3000	10	roadside street light	0.83	0.27
Nm6	1571	4000	17	roadside street light	0.48	0.14

Nm7	2878	3000	29	roadside street light	0.00	0.00
Nm8	8303	3000	32	roadside street light	0.00	0.00
Nm9	8303	3000	69	roadside street light	0.00	0.00
Nm10	1565	3000	61	roadside street light	0.00	0.00
Nm11	1553	3000	11	roadside street light	0.00	0.00
Nm12	7675	3000	10	roadside street light	4.03	7.31
Nm13	5372	NA	6	roadside street light	0.00	0.00
Nr1	7058	2000	9	middle street light	2.73	2.98
Nr2	1575	3000	13	roadside street light	0.83	0.15
	6433	4000	12	middle street light		
Nr3	8668	3000	6	roadside street light	0.38	0.19
Nr4	7084	2000	18	roadside street light	0.03	0.00
Nr5	6405	4000	4	middle street light	1.28	0.78
Nr6	6651	3000	10	roadside street light	0.20	0.00
Nr7	6277	4000	7	middle street light	0.40	0.05
Nr8	1891	3000	8	roadside street light	0.88	0.21
Nr9	5306	2000	3	roadside street light	0.43	0.00
Nr10	8282	3000	20	roadside street light	0.05	0.00
Nr11	1628	4000	15	roadside street light	9.18	36.52
Nr12	1521	4000	4	roadside street light	5.88	14.30
Nr13	8052	2000	2	roadside street light	9.20	37.55
Nr14	1996	3000	131	roadside street light	0.00	0.00
Nr15	8516	3000	35	roadside street light	0.00	0.00
Nr16	1231	NA	12	roadside street light	0.45	0.17