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Ecology

Diploma Thesis

Does Artificial Light at Night (ALAN) impact feeding activity in Common Starlings (*Sturnus vulgaris*)?

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Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

Chiara Sopart

Engineering Ecology
Nature Conservation

Thesis title

Does Artificial Light at Night (ALAN) impacts feeding activity and breeding success of Common starlings (Sturnus vulgaris)?

Objectives of thesis

The main aim is to evaluate the effects of disturbance/light inducing activity at night on birds. Specifically, to study the effects of artificial light at night on the activity at daytime of breeding individuals of Starlings Sturnus vulgaris, considering differences in breeding and feeding behavior. To do that will be compared the responses of two groups of birds breeding in 2 x 12 nest boxes mounted on lamp posts in two different sites: One site lit while the other one not.

Methodology

The species focused in the study (Sturnus vulgaris) is native in Europe and western Asia, being well adapted to a large variety of habitats. The data were collected through the use of nest-boxes with light and temperature loggers. Data were recorded automatically every 10 sec. In total 5.844.206 light and temperature values were collected. The age determination of individuals will be performed by using Heinroth (1966): Die Vögel Mitteleuropas & http://www.starlingtalk.com/inthenest.htm.

Raw data will be cleaned and organized using Text Editor and Open Office. Then, statistical analyses will be performed by using R software.

The proposed extent of the thesis

50

Keywords

bird; breeding; disturbance; feeding activities; light pollution;

Recommended information sources

Adams, C.A., Blumenthal, A., Fernández-Juricic, E., Bayne, E., St Clair, C.C., 2019. Effect of anthropogenic light on bird movement, habitat selection, and distribution: A systematic map protocol. Environ. Evid. 8, 1–16. doi:10.1186/s13750-019-0155-5

Hölker, F., Moss, T., Griefahn, B., Kloas, W., Voigt, C.C., Henckel, D., Hänel, A., Kappeler, P.M., Völker, S., Schwope, A., Franke, S., Uhrlandt, D., Fischer, J., Klenke, R., Wolter, C., Tockner, K., 2010. The dark side of light: A transdisciplinary research agenda for light pollution policy. Ecol. Soc. 15, 13. doi:10.5751/ES-03685-150413

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Declaration

I declare that I have worked on my diploma thesis titled "Does Artificial Light at Night (ALAN) impact feeding activity in Common Starlings (*Sturnus vulgaris*)?" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break copyrights of any their person.

In Prague on 30.03.2021 C. Sopart

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I would like to thank Federico Morelli Ph.D., Reinhard Klenke Ph.D. and all other persons involved in this thesis, for their advice, their help and support during my work on this thesis and for all the time they spend working with me.

Data sources:

Data from light loggers was collected and pre-processed by Dr. Reinhard Klenke, Charlotte Groß, Sally Haddad and Teresa Nitz. All photographs were taken by Dr. Reinhard Klenke.

Does Artificial Light at Night (ALAN) impact feeding activity in Common Starlings (*Sturnus vulgaris*)?

Abstract

Artificial Light at Night (ALAN) is illuminating our environment with many consequences for humans, flora, and fauna. This thesis takes a closer look at the consequences of nightly illumination on breeding Common Starlings (*Sturnus vulgaris*). Data was collected on two experimental sites, one illuminated and one dark with twelve nesting boxes at each site. Loggers inside the boxes measured the number of foraging flights undertaken by the adult starlings in the morning and the evening hours. The data was evaluated to answer the questions if ALAN influences the feeding frequencies of adult starlings, and if birds that are exposed to ALAN start and stop their foraging earlier than the birds breeding on the dark site. Even though no effect of ALAN on the feeding frequencies of starlings could have be found, this thesis gives an overview on why ALAN can still significantly influence breeding behaviour in starlings. In the end I take a look at some potential measures to decrease the negative influence of ALAN on the environment.

Keywords: Artificial Light at Night, bird, breeding, disturbance, feeding activities, illumination, light pollution, Sturnus vulgaris

Ovlivňuje umělé světlo v noci (ALAN) krmení u špačků obecných (*Sturnus vulgaris*)?

Abstrakt

Umělé světlo v noci (USVN) osvětluje naše prostředí s mnoha důsledky pro člověka, flóru a faunu. Tato práce se blíže zabývá důsledky nočního osvětlení na chov špačků obecných (*Sturnus vulgaris*). Data byla sbírána na dvou experimentálních stanovištích, v jednom osvětleném a v jednom tmavém s dvanácti hnízdy v budkách na každém stanovišti. Uvnitř boxů se měřilo, jak často dochází ke krmení od dospělých špačků v ranních a večerních hodinách. Data byla hodnocena za účelem odpovědi na otázky, zda USVN ovlivňuje frekvenci krmení dospělých špačků a zda ptáci, kteří jsou vystaveni USVN, zahájí a zastaví své shánění potravy dříve, než ptáci rozmnožující se na tmavém místě. Přestože nebyl nalezen žádný účinek USVN na frekvenci krmení špačků, tato práce poskytuje přehled o tom, proč může USVN stále významně ovlivnit chování chovu špačků. Nakonec se zaměřím na některá potenciální opatření ke snížení negativního vlivu USVN na životní prostředí.

Klíčová slova: umělé světlo v noci, pták, chov, rušení, krmení, osvětlení, světelné znečištění, Špaček obecný

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ALAN: Artificial Light at Night

LAN: Light at Night

PLP: Polarized Light Pollution

NABU: Nature Conservation Union Germany (Naturschutzbund Deutschland)

GHG : Greenhouse Gas

Introduction

Artificial Light at Night (ALAN) influences our environment progressively. While bringing some advantages to our daily life, it also bears threats for humans, plants, and animals, constituting potentially a biodiversity threat. Especially birds are often affected by nightly illuminations. Artificial light sources might confuse their navigation during migration periods (Rebka et al., 2019), change their hormonal composition (Jiang et al. 2020) and change their reproduction cycle by altering their song complexity, egg laying date or perception of mating cues (Russ et al., 2017; Dominoni et al., 2015; Maddocks et al., 2002; Kempenaers et al., 2010). Furthermore, ALAN can significantly change food webs, due to insects being attracted to it. This can further influence the foraging behaviour of species like birds or bats predating the insects and might be one of the factors leading to the current insect decline (Grubisic et al., 2018). A further change in predation cycles might be achieved due to several predators avoiding areas with a high nightly illumination (Russ et al., 2017). Bird species might therefore benefit from breeding in artificially illuminated areas, due to the avoidance of predators. ALAN can thereby increase the breeding success in birds.

1 Objectives and Methodology

1.1 Objectives

The main goal of this thesis is to evaluate the effect Artificial Light at Night (ALAN) has on breeding Common Starlings (*Sturnus vulgaris*). Primarily it will be evaluated if ALAN influences the feeding frequencies of parental Starlings. The questions if ALAN influences the amount of feeding activity and the foraging time in Starlings will be evaluated.

1.2 Methodology

Data was collected on two experimental sites, one illuminated and one dark (Holzhauer et al., 2015). Twelve nesting boxes were attached on each site and loggers inside the boxes measured light and temperature each second. This resulted in 5.844.206 measurements from a time span of roughly 5 weeks. The measurements were taken over eight hours each in the morning and in the evening hours. The combined data was cleaned and organized with the GNU Sed Editor and read into R Studio. It was then split again into the different days, sites, and boxes. The feeding frequencies per box and per day were calculated and summarized for each site on each day. An ANOVA was carried out to see if the amount of activity on each site dependes on the light conditions at night. A Kolmogorov-Smirnov-Test showed whether the activities on each site come from the same distribution or if there is a significant difference in times of activity. Finally, the average feeding frequencies per day from both sites were calculated (minimum, maximum, mean and mode) to check for any development in feeding frequencies over time.

2 Literature Review

2.1 Urbanization

Since the mid-19th century, fast-developing urbanization took place (Häussermann. 2012). Mumford (1956) divides different stages of natural urbanization, whereas the first stage is dependent on the available agricultural land and its productivity. The second stage contained the development of river and sea transport and the introduction of roads for carts. The next important aspect is the production of grains and oils that can be stored over a long time and made a specialization in agriculture possible. The third stage is, according to Mumford, defined by population growth and technical improvement. Liu et al. (2010), on the other hand, are talking about an internal and external rural hollowing, leading to rapid urbanization. They state the driving forces of income, investment, and non-agricultural employment in urban areas as internal factors, and industrialization, and external exacerbated institutional barriers as external factors. However, this rapid urbanization bears several alterations for the environment, which are discussed in the following chapters.

2.1.1 Fragmentation and Biodiversity loss

Didham (2010) defines habitat fragmentation as the process of dividing large, continuous habitats into smaller, more isolated habitat fragments, resulting in habitat loss, population decline, biodiversity loss, and the alteration of ecosystem functions and community structure. Lords & Norton (1990) define it as the disruption of continuity and emphasize that it can be applied to any domain, where continuity is important for the ecosystem. The reasons for fragmentation in the present large scale are mostly human disturbances, like land clearing (Franklin et al., 2002). Jaeger et al. (2017) specify further that, especially in cities, man-made, intricate linear structures, mostly from streets, railway lines, and main roads, cause these barriers, emission, or collision effects as well as aesthetic effects. The effects of this fragmentation include damages for soil and vegetation, changes in the microclimate, emissions like pollutants and noise, changes in the water balance, fragmentation of habitats of animals and plants, changes in the landscape, and disadvantages for land use (Jaeger et al., 2017). To understand the main problems that habitat fragmentation causes for biodiversity, we need to look at the theory of island biogeography (MacArthur and Wilson, 1967). The theory suggests that the species richness on an island depends on its size and isolation from the mainland. Furthermore, fewer species are supported by smaller and more isolated areas. If we transfer this to fragmented areas, we can assume that smaller and more isolated fragments support fewer species, leading to a decreased biodiversity in each fragment. Another theory is based on the model of metapopulations (Levins, 1970). A metapopulation is defined as a group of subpopulations that interact with each other through the exchange of genes (Lexikon der Biologie, 1999). If we look at population extinction, studies suggest that connected populations persist longer than isolated populations, except for populations living in a connected area with hostile conditions (Molofsky and Ferdy, 2005; Levin, 1995; Harrison and Quinn, 1989). If we consider a disruption of gene flow, due to the fragmentation of a population's habitat, we can assume a higher extinction risk for populations in fragmented areas.

2.1.2 Light Pollution

Within the last years, the artificial light at night (ALAN) increased to such an extent that it pollutes the environment, representing a serious biodiversity threat (Hölker, Wolter, et al., 2010). The reasons for this are the alleged benefits that light brings us in our daily life. Peña-García et al. (2015) found out that especially yellow-sodium light with optimal lightning uniformity, makes people feel significantly safer when walking through streets at night. Kuechly et al. (2012) name more reasons for the increasing light demand, like shift work, advertising, making navigation easier, or reducing the fear connected to darkness itself. Studies found that the most frequent sources of artificial light are street lights, lighted buildings and towers, such as kindergartens, schools, and hospitals or commercial, industrial, or service areas, security lights, lights on vehicles, flares on offshore oil platforms, block buildings and Airfields (Longcore & Rich, 2004; Kuechly et al., 2012). ALAN is further increased by the light reflected from the sky and known as Skyglow (Longcore and Rich., 2004). Luginbuhl et al. (2009) used a ground-up method to link this Sky glow to land use on the ground. Their results suggest that sports lighting is the largest emittent, followed by c-stores and restaurants, hotels and shopping-centers and last schools. This evidence shows that the level of light emission differs in different areas, considering how well the emitted light is shielded or blocked by other buildings or environmental elements. So how does this light emission pollute our environment? Hollan (2009) defines pollution as an impairment of the purity of the environment. More specifically, light pollution is an alteration of light levels in the outdoor environment, from those naturally present, due to man-made sources of light. He then adds that for indoor areas it can only be talked about light pollution if the altered light level compromises human health. Stone (2017) simply defines light pollution as too much light at night, highlighting that artificial light becomes pollution when natural light is mostly absent.

Longcore and Rich (2004) distinguish between astronomical light pollution, where celestial bodies become invisible due to light that is directed or reflected upwards, and ecological light pollution, consisting of direct glare, chronically increased illumination, and temporary, unexpected fluctuations in lighting. One more definition comes from Gallaway et al. (2010) who distinguish between positive light, which improves visibility for humans, and light pollution, which causes glare, deepens shadows, and washes out the stars, and thereby reduces visibility. Furthermore, population, as measured by the percent of the population living in urban areas, as well as economic factors, like real per capita GDP, foreign investment, and land-use patterns, are significant variables to explain the existence of light pollution (Gallaway et al., 2010).

2.2 Problems of light use for the environment

Like all kinds of pollutions, light pollution bears various risks for the environment. Examples of this are implications for wildlife, especially a thread for biodiversity given for many insects, fish, birds, bats, amphibians, other animals, and plants, due to changed night cycles that influence reproduction and migration, human health, energy consumption, global warming, and the observation the night sky (Gallaway et al., 2010; Hölker, Wolter, et al., 2010). The following chapter will give a brief overview of the main effects of light pollution in different areas.

2.2.1 **Energy and Economy**

Lighting up the environment every night brings along a lot of energy demand. This activity is costly, as well as burning many resources, which is causing further emissions. Already in 1991, the US light pollution accounted for ca. 58 billion kWh of electricity, 8.7 billion kWh of that thrown directly at the sky (Hunter and Crawford, 1991). These result in the burning of coal, oil, nuclear fuels, and further pollution, as well as the spending of money, that could be invested differently (Hunter and Crawford, 1991). In 2009 it was already 72.9 million MWh of electricity generated as light pollution at a cost of $6.9 billion a year, only in the US (Gallaway et al., 2010). With 250,8 TWH, lightning made up 2,8% of the whole final energy consumption in Germany in 2019 (AGEB, 2020). This total final energy consumption includes all final energy carriers such as mineral oil, gases, electricity, district heating, coal, and renewable energies. According to en.lighten (http://www.enlighten-initiative.org/) „Electricity for lighting accounts for approximately 15% of global power consumption and 5% of worldwide greenhouse gas (GHG) emissions. A switch to efficient on-grid and off-grid lighting globally would save more than $140 billion and reduce CO2 emissions by 580 million tonnes every year“.

2.2.2 Light and humans

The human biorhythm is determined by the so-called „zeitgebers“, which regulate different functions like sleeping and waking, core body temperature, a variety of hormones, and different relationships such as performance and well-being (Knab, 2013). The most important zeitgeber is the sunlight, and it can be replaced by electrical light with an intensity of at least 2000 Lux and more (Knab, 2013). Stevens and Rae (2001) point out that our circadian rhythm evolved over millions of years with the day-night pattern of solar radiation as the primary circadian cue. This ensured that the pattern maintained a 24-hour rhythm of hormonal melatonin release, as well as other physiological rhythms like the sleep-wake cycle. Already the emission of 100 Lux blue light prevents our brains from releasing melatonin (Knab, 2013). Several studies are implying that exposure to light at night (LAN) increases the risk of prostate cancer in men (Kim et al., 2017; Kloog et al., 2009) and breast cancer in women (James et al., 2017; Kloog et al., 2008, 2009), respectively that blind women, who do not perceive LAN, have a smaller risk of breast cancer (Feychting et al., 1998). This might be explained by the so-called LAN-Hypothesis, which Kantermann & Roenneberg (2009) explain as suppression of melatonin, a hormone produced under the control of the circadian clock at night, and its synthesis, by light. Melatonin is a kind of neurotransmitter, which potentially acts as an eliminator of oxygen radicals, atoms, or molecules that can damage DNA, which in turn can cause cancer. However, there are studies as well that did not find any link between exposure to LAN and breast cancer (Johns et al., 2018).

2.2.3 Light on Flora

Just like humans adapted to a day-night cycle over millions of years, so did plants and animals. In plants, ALAN can cause early leaf out, late leaf loss, and extended growing periods (Hölker, Wolter, et al., 2010). One explanation is the photoperiodism of the plant, which is either long-day or short-day related and defines the importance of the relative length of the day, especially for sexual reproduction (Garner and Allard. 1920). For example, the floral initiation in the Cocklebur (*Xanthium pennsylvanicum*) is prevented when the dark period it is subjected to is shorter than 8 hours (Hamner & Bonner, 1938). So, if the plant is subjected to photoperiods longer than 16 hours, it stays completely vegetative. According to Prue (1994), plants keep track of the day-night rhythm with the help of photoreceptors and endogenous oscillators with characteristic properties in relation to light-dark cycles. Prue explicates further that this also helps them to locate certain events during the year, like shorter days in autumn leading up to a cold winter. If ALAN prevents plants from following their needed photoperiods, they are at risk to adapt to seasonal changes as well as reproduction patterns. For trees, Chaney (2002) found, that while the light intensity does not affect a trees photosynthesis, ALAN, especially the red to infrared range of the spectrum, can change flowering patterns by extending the day length and thereby promote continued growth, preventing trees from developing dormancy that is crucial to surviving over cold winters. By looking at the light-sensitive tree species, Škvareninová et al. (2017) examined the extend of biorhythm change due to light pollution in sycamores (*Acer pseudoplatanus L.*) and *Rhus typhina*. Light pollution caused the delay of the onset of autumn vegetative phenological phases at crown parts by 13 to 22 days on average, the duration of leaf coloring was prolonged by 6 to 9 days, and the duration of leaf fall by 6 to 7 days.

2.2.4 Light on Fauna

As for the fauna, circa 30% of all vertebrates and more than 60% of the invertebrates are nocturnal (Hölker, Wolter, et al., 2010). There are many examples of animals from different habitats feeling the effects of ALAN. Under normal conditions, the moonlight is the primary light source during the night. Many nocturnal mammals adapted to a higher intensity of the moonlight by reducing their movements in open areas, limited foraging activity in open areas, restricting movement, reducing the total duration of the activity, or concentrating on foraging and longer movements during the darkest periods of the night (Beier, 2006). Studies found these adaptations mostly in prey animals, such as snowshoe hares (Gilbert & Boutin, 1991), kangaroo rats (Lockhard & Owings, 1974a; Daly et al., 1992), old-field mice (Wolfe & Tan Summerlin, 1989), or Woolly Opossums (Julien-Laferrière, 1997), but as well in mainly foraging species like Greater short-nosed fruit bats (*Cynopterus sphinx*) (Elangovan & Marimuthu, 2001). Lockhard and Owings (1974b) theorize that this behavior might be a trade-off between the profit of maintaining the metabolism and therefore the reproduction of the species, and the cost of getting caught by a predator. This was validated by a study conducted by Clarke (1983), who found the activity of deer-mice to be much lower in an artificially illuminated chamber compared to dark ones. Furthermore, Short-eared owls in this experiment were significantly more successful in hunting those deer-mice in an illuminated environment. Similar results were already found in 1945 by Dice. Here he was able to conclude that the chance of an owl successfully securing dead mice was significantly higher in illuminated rooms.

Furthermore, just like humans, animals have a circadian rhythm that is stimulated by zeitgebers (Beier, 2006) and can therefore be shifted due to ALAN. Dauchy et al. 1997) found that ALAN strongly suppresses Melatonin and abets tumour forming in rats, even with only low-intensity light. The circannual rhythm furthermore regulates annual changes in body mass, like gaining weight before hibernation, hormones, the circadian activity pattern over the course of the year, reproductive status, and reproduction seasons, causing parturition of most mammals to occur during specific seasons of the year (Beier, 2006).

Some further problems are described by Beier (2006) as the possible influence of street lights in increasing the chance of roadkills and the disruption of dispersal movements and corridor use. He explains the higher possibility of animals dying from roadkill due to the rapid shift in illumination, which leaves them blinded for some time. After the animal got used to the street light, all less illuminated areas seem black, and the animal might become disoriented and unwilling to flee into the dark areas. However, if they return into the dark area, Beier sees them at a disadvantage regarding their ability to see in the dark for about 10 to 40 minutes. The influence of ALAN on Corridors used by animals could be shown by (Beier, 1995) while investigating the dispersal of young cougars in urban areas. The cougars tried to avoid corridors with light when travelling at night, preferring dark areas or following the direction of the darkest horizon. Furthermore, the cougars would travel in one direction, stopping when seeing lights and returning to their starting point or using long detours to avoid the illuminated areas. Zollner and Lima (1999) found that white-footed mice, a prey animal, were moving towards nearby woodland faster and more often when the moon was shining brighter. This might be explained with better perceptual abilities during full moonlight and the trial to escape possible predators faster. The moonlight, however, might have a completely different effect than ALAN, since the eyes of most mammals perceive ALAN differently, setting most of the landscape in darkness and thereby cause animals to move away from corridors with night lightning (Beier, 2006). A different effect of ALAN was found on the dispersal of turtle hatchlings. The procedure of hatching is described by Salmon (2006) as follows: after hatching from their eggs, the turtles dig their way up towards the surface. They wait until the surface sand is cooled down and, therefore, mostly emerge at night. Then the process of seafinding begins, where the turtles crawl away from large dark objects like dunes and vegetation behind the beach and towards the flatter and lower beach facing horizon, that typically reflects and emits light from the stars or moon. McFarlane found in 1965 that 95% of hatchlings of a nest oriented themselves wrongly towards bright lights and skyglow, costing many of them their lives. They might be run over by cars or they never reached the ocean. Other marine animals like fishes underlie changes due to ALAN as well. During the larval recruitment of coral-reef fish, ALAN can cause habitat avoidance, endocrine disruption, faster and heavier growth, and increased mortality rates, which all may have negative implications for the fitness and post-settlement survival of the fish (O'Connor et al., 2019). Interdial fish, that live at the seashore are proven to increase their activity when exposed to ALAN, thereby having a higher oxygen consumption and a disrupted circadian rhythm (Pulgar et al., 2019). Furthermore, while Brüning et al. (2018) could not find any changes in Melatonin concentration in European Perch and Roach, they could, however, find significantly lower concentrations of sex hormones, such as 11-Ketotestosterone, 17ß-Estradiol and in the mRNA expression of gonadotropins, when the fish were exposed to ALAN. Those changes can strongly influence the reproduction of these fish, thereby changing the whole population structure.

2.2.5 Light Pollution and insects

Since insects are a special case when it comes to ALAN, they will be looked at in more detail in this chapter. Insects are critically important as pollinators and for the whole food web in terrestrial ecosystems, making problems with ALAN a problem with serious ecological consequences (Eisenbeis, 2006). Eisenbeis (2006) goes on to picture three possible outcomes of insects interacting with light sources. Number one sees the insect flying directly towards the illumination source and dying on the hot surface. In scenario number two, the insect circles the light source for a long time, either dying from exhaustion, being caught by a predator, or falling to the ground, where they are at great risk of predation. Scenario number three sees the insects able to get back to the shelter of the darkness, where they either rest and fly back to the lamp or stay inactive and being exposed to predators. The first possibility on how the insects are drawn towards the light sees the insects being disturbed from their normal activity by one or more artificial illumination sources. Eisenbeis theorizes that the illumination has a dazzling effect on the insects, that attracts them towards it and keeps the insects within the light zone due to a „fixation" or „captivity" effect. The second possibility is explained as the light source preventing the insects from navigating their way with the help of special landmarks, like the moon, stars, trees, or the profile of the horizon to orient. The insects are following their flyway when they encounter a light source. This light source makes it impossible for the insects to see the landmarks important for their navigation and thereby to follow their original flyway, keeping them within the illuminated area. Eisenbeis calls this the „crash barrier" effect. The third possibility is called the „vacuum cleaner" effect because it sees the insect being „sucked out" of their habitat by the light source. Owens et al. (2018) also found that the firefly aquatica ficta visually responds to short-wavelength ambient light. This might make it hard for this species to distinguish fellow individuals from artificial light, decreasing its´ reproduction success. Only between 1990 and 2017, Hallmann et al. (2017) found an extremely strong decline in average airborne insect biomass by 76%. Grubisic et al. (2018) see light pollution as one factor responsible for this decline, among factors like land-use changes, use of pesticides, habitat fragmentation, and climate change. This is underpinned by Owens et al. (2020), who see the main danger for insects in ALAN impacting nocturnal and diurnal insects through effects on movement, foraging, reproduction, predation risk, and development, contributing to their sharp decline. Horváth et al, (2009) point out the effect of Polarized Light Pollution (PLP), consisting of „light that has undergone linear polarization by reflecting off smooth, dark buildings, or other human-made objects, or by scattering in the atmosphere or hydrosphere at unnatural times or locations“. According to them, PLP can function as an ecological trap for polarization-sensitive species. Furthermore it can influence the navigation, foraging and predatory risk of those species. Considering the huge role insects play as pollinators and prey for many species like fish, bats, or birds, and as polluters, a decline is problematic for the entire ecosystem.

2.3 Light on birds

Birds, perhaps, are one of the species most strongly affected by ALAN. This chapter is reviewing different effects on various kinds of birds. Jiang et al. (2020) found out that exposure to ALAN can cause changes in the hormonal and bacterial processes in Eurasian tree sparrows, which may explain alterations in their behavior. ALAN suppressed the bird’s melatonin secretion and birds that were under constant dim light, had Melatonin concentrations 2-4 times lower, than birds that were kept in dark-light cycles. These low melatonin concentrations in birds exposed to ALAN are kept low in both daytime and night. A low melatonin level may explain locomotor activity abnormality and sleeping disruption, due to exposure to ALAN. Further, Jiang et al. explain that this affects taxonomic compositions, species diversity, and community structure of intestinal microbiota in the birds. Jiang et al. saw in the changes of gut microbiota community possible explanations for weight loss, digestive dysfunction, and foraging disturbances. All those malfunctions could become problematic for the vegetation as well since they could disturb the seed distribution provided by birds. Furthermore, it bears problems for the gut health and immune system of sparrows. One more factor that Jiang et al. found is, that ALAN leads to the earlier beginning of the locomotive activity and later rest at night.

Dominoni et al. (2020) proved that the effect ALAN has on a bird’s daytime and nighttime activity depends on a three-way interaction of ALAN, noise pollution, and whether the birds originate from rural or urban areas. Urban birds exposed to the noise experienced a high decrease in their activity over the day, while light exposure did not affect their daytime activity. The combination of light and noise however caused an antagonistic effect, decreasing the effects of noise pollution on daytime activity. Forest birds on the other hand showed a decrease in daytime activity if they were exposed to noise and as well when exposed to light. At the same time, the combination of them both showed an additive effect, meaning that both factors combined, neither had a strengthen nor a weakened effect. The nighttime activity of urban birds was decreased by the exposure to noise and increased by the exposure to ALAN. The light increased the nighttime activity by 26 minutes. Birds from urban areas that were exposed to both, light and noise at night, had increased nighttime activity of 30 minutes, showing a synergistic effect when light and noise are combined. Forest birds increased their nighttime activity by 35 minutes when exposed to ALAN while neither noise nor the combination of noise and light had a significant effect on the nighttime activity. Nordt and Klenke (2013) found that noise, as well as ALAN advances the song onset in urban European Blackbirds. Their findings showed that the louder the noise, the earlier the birds started their singing and that cloud coverance increased the effects of ALAN, leading to earlier singing as well.

Great tits were shown to have a decreased daily energy expenditure when feeding their offspring under white or green ALAN (Welbers et al., 2017). However, it was also proven that there was a higher caterpillar abundance in areas with green and white ALAN, making the food supply for the birds' offspring easier to obtain while spending less energy.

For migratory birds, ALAN bears a special threat. 70% of the birds are considered migratory, and of these more than 80% are considered to be migratory during the night (Horton et al., 2019). If birds are attracted to the light depends on numerous factors such as the wavelength of the light or the weather conditions during the night. Horton et al. (2019) found that migratory birds in the U.S. have a 13.1% higher exposure to light radiation when migrating in the fall. This exposes especially juveniles to danger as their first-ever migration takes place in the fall. One more thread, especially for migratory birds, are wind turbines. The birds collide with the wind turbines, partly after being attracted to the light emitted by them. Rebka et al. (2019) found that in general birds are more attracted to the light, respectively more collisions with wind turbines occur when the sky is covered by clouds and the stars aren't visible. This is probably due to the orientation system of the birds. The only light not attracting the birds in that study, was red continuous or red blinking light, with blinking light attracting fewer birds in general. This is probably due to the fact, that birds belong to the group of Tetrachromats, a group that uses four different color receptors for seeing, and that they react sensitively towards yellowish-orange, green, and blue hues (Klenke et al., 2014).

In a study by Dominoni et al. (2020), the authors also found stronger effects on egg-laying dates, when the birds were exposed to white or green light. They found that ALAN can alter egg-laying dates in great tits, but only in late and cold springs, suggesting that temperatures are a factor playing into this alteration. More alterations in the reproduction and breeding processes of bird species, due to ALAN, were found, inter alia, by Dominoni et al. (2015). They found that city birds, in March, subjectively perceive a day 49 minutes longer, than birds with less ALAN concentrations. They explain that this corresponds to a 19 day longer photoperiod and that these urban birds reach reproductive maturity 19 days earlier than rural birds. Similarly to that, Russ et al. (2017) found that already one Lux per night advances the date of clutch initiation in European Blackbirds by 6 days, compared to birds in conditions without ALAN. Furthermore, the authors found that the blackbirds not only preferred illuminated nesting sites but also that they indeed have a higher breeding success in those areas. This can probably be explained by the fact that urban predators are rather diurnal, while their main nocturnal predators try to avoid artificial lighting. However, there are probably climatic conditions playing into this as well. Kempenaers et al. (2010) also found that some songbird species start singing significantly earlier when living near street lights. If those males were occupying edge territories near streetlights, they were twice as successful in getting extra- pair mates than their close neighbours or the males occupying central forest territories. The last thing they found was that females started laying their eggs on average 1,5 days earlier when exposed to street lights. It should be clear that ALAN can affect the breeding behavior of many species strongly, mainly by advancing their reproduction maturity, singing, and egg-laying dates. Besides that, ALAN seems to prolong the nighttime activity of most birds, while shortening the daytime activity. It should be noted, however, that there are many covariates to the way that birds react to light. The reaction may differ due to light characteristics (e.g. wavelength, intensity, direction, and flashing pattern), environmental variables (e.g. weather variables, temporal variables, moon phase, land/freshwater/ocean), and population characteristics (e.g. species, bird activity during an intervention, domestication status, migratory status)(Adams et al., 2019).

2.3.1 Behavior, habitat, breeding of Starlings

The NaBu (Nature Conservation Union Germany, a) defines the Starling (*Sturnus vulgaris*) as a widespread bird in Central Europe, breeding in gardens, in various forests and parks, and often near meadows. Residential buildings, stables, or even lanterns with sufficiently large cavities are as well popular breeding grounds for Starlings (NaBu b). Also, they seem to prefer nesting places, close to the places where they have already nested before (Kessel, 1957). Starlings can be identified by their black feathers, with a violet-green metallic shine, or white dotted plain feathers, their yellow beak, and a longer tail, that distinguishes them from blackbirds. (NaBu a). They are diurnal and ground feeding (Martin, 1986). Tinbergen (1981) was able to evaluate and describe the Starlings mating and foraging behavior in detail. He explains that the foraging of Starling takes place in open postures. This foraging happens in small groups of Starlings. Around April the Starlings start building their nests. The male is looking for a fitting nesting place, and as soon as he has found one, begins to fill it with coarse nesting material such as dry leaves, stalks, or root remains (NaBu b). After he attracted a female with his calls, she begins to fill the nest with finer plant material and herbs or essential oils, to reduce bacterial and mite infestation and to improve the condition of the young. (NaBu b). The females increase in weight and the pair start feeding together more often and closer to the colony (Tinbergen, 1981). Starlings like to breed where other couples have already settled and may defend their breeding ground, but the wider surroundings are used together to forage (NaBu b). Normally, the female lays 4-6 whitish to light blue-green eggs and the young hatch after 12 to 13 days (NaBu b). After the laying of the first egg, Starlings continue to lay one egg each day until the clutch is complete with a similar clutch size each year (Kessel, 1957). After the first breeding, some males might look for another female to pair with and breed for a second time, while others stay monogamous (NaBu b). During the breeding process, Tinbergen (1980) witnessed that incubation starts immediately after the last egg has been laid, and the females do most of the incubation.. If the female deserts the nest due to predation or other disturbances or is killed, during either egg-laying or incubation, the male will toss out the eggs within thirty-six hours or less and try to find a new female for mating (Kessel. 1957). After the young hatch, the feeding starts and increases sharply, reaching the maximum, when the hatchlings are 6-10 days, with roughly 300 daily feeding trips done by their parents. Kluyver (1933) found similar numbers for nests with 6 young ones, accounting for 6895 and 7668 feedings over one fledging period in two nests. Tinbergen (1980) observed that the parent’s diet roughly consisted of „peck“ prey. This Tinbergen defines as small prey, that can be taken in within one peck. Often the Starlings pecked several times, collecting small flies and swallowing them. For the nestlings, Tinbergen observed, that the Starlings collected rather bigger prey, such as leatherjackets, Crane flies, Antler Moths, Crambus species, and in some years *Hadena monoglypha* caterpillars. Heinroth (1966) describes the Starlings search for food as circling. Here the Starling sticks its closed beak into the earth and then opens the two halves of the beak. This opens cracks in the earth and enables it to get into the burrows of larvae and worms. The diet seems to be very important for the survival of the nestlings. Kluyver (1930) found that too many larvae of the Crane fly made the nestlings' feces too liquid for the parents to remove it from the nest. This removal normally happens daily, and if not performed, the nestlings can die. According to Kluyver the feeding began at sunrise and for the first days, ended at sunset. When the hatchlings were a little older, the feeding would often stop already one hour before sunset. Furthermore, most feedings per hour were brought in the morning hours. In the afternoon, this number was much smaller.

2.3.2 **Chick Development**

The website www.starlingtalk.com (Starlingtalk 2021) photo-documented the development of young Starlings from the hatching to the fully grown bird. On the first day after hatching the chicks are still naked with their eyes closed. A light fluff might be present on their backs and top of the head. Until day four, the chicks are only increasing in size. They then start growing some more fluff around their neck area. From day five on the plumage starts growing, as well as the wing feathers. The wing feathers are visibly growing each day now. Around day six they start to open their eyes, and around day seven they begin to be very noisy, screaming for food. Around day nine, the growing feathers cover nearly all of the hatchlings' body and the wing feathers start to unfurl. Their eyes are fully opened on day ten and there are barely any naked spots left on their body. Around day twelve, the wing feathers seem to be developed and the Starlings are described as quite energized. After two weeks the chicks start hanging around the box entrance more and more, peeking their heads out occasionally. 15 days after hatching the Starlings can fly and prepare to leave the nest. After 19 days all but one chick had left the nest after being fed the last time by their mother. After three weeks especially the male Starlings start practicing their singing (Heinroth & Heinroth, 1966). Furthermore, Heinroth & Heinroth (1966) describe the chicks as not frightened but rather curious about new things. Furthermore, they describe the development of their plumage. After six weeks the first plumage change takes place. When the Starlings are about two month old white dots are starting to show on their chest. Two weeks later wide rows of dots have formed. When the birds are a little older than four months their feathers are completly keratinized. Until the spring the bird rubs off the white dots and the purple and green shimmer of the plumage becomes visible.

2.3.3 Light on Starlings

Many birds use ultraviolet wavelength to perceive colour, but ALAN is usually UV deficient (Lewis & Morris, 1998). Maddocks et al. (2002) found that female Starlings highly preferred males they perceived under UV-present light. They conclude that UV is important for the correct perception of plumage hues. Therefore, ALAN can significantly influence mating processes in Starlings, because female Starlings use UV cues for their mate assessment and preferred males with an intact UV reflection in their plumage. Maddocks et al. (2001) found significantly higher basal plasma corticosterone concentrations in Starling juveniles that were kept in UV-deficient conditions. Corticosterone is the dominant stress hormon in many birds that might decrease the investement in the immune system during stressful times, potentially change the complexity of song produced by songbirds and initiate the typical fight of flight reaction (Buchanan, 2000). It should therefore come as no surprise that Starlings kept in UV-deficient light showed significantly more escape behaviour and less perching, suggesting that commonly used UV-deficient light sources may have behavioural and physiological effects in Maddocks et al. (2001) experiment. Burger (1953) sees photic changes as the primary agents in the external environment influencing reproductive periodicity in Starlings. He claims that a Starlings reproduction cycle depends greatly on the length of days and if a male is exposed to as little as 8.5 hours of light per day over a long time „both rate and amplitude of spermatogenesis are greatly retarded.“ This implies that ALAN might heavily influence reproduction cycles in Starlings and trigger spermatogenesis in male Starlings long before the actual reproduction season. Kessel (1957) also observed a uniformity in egg laying times in Starlings and claims that wide-spread environmental factors such as light or local climatic conditions must largely influence the time of egg laying. Dawson and Goldsmith (1983) found evidence that exposure to light over 13 or 18 hours per day induced marked increases in plasma gonadotropin levels and rapid gonadal maturation in Starlings and caused them to switch off their reproduction system.This state is then called photorefractory condition (G. E. Bentley et al., 1998). This change in reproductive state signicantly influences the ability of the Starling immune system to respond to a mitogenic challenge (G. E. Bentley et al., 1998). Bentley et al. (1998) claim that increasing day length causes full reproductive maturation in Starlings during the spring, followed by photorefractoriness in the form of gonadal regression, feather molt, and reproductive unresponsiveness to long day lengths in the summer and subsequent acquisition of photosensitivity in the autumn. The cycle allows the reproductive system of Starlings to respond to long day lengths at the appropriate time of year and thereby breeding occurs only when the conditions allow optimized chances of raising the young. There is also evidence that the hypothalamo-pituitary-gonadal axis in Starlings perceives and responds to day length, regardless of light intensity (Bentley et al., 1998). ALAN might thereby prevent the acquisition of photosensitivity in the autumn and cause Starlings to breed during unfavorable times in the year or to remain in the photorefractory condition. However, the experimental study plots from that study were situated in an rural area with very low human density. The free ranging starlings might not have been impacted, since they migrate to milder areas of Central Europe during the darker time of the year (Nabu a).

Practical Part

2.4 Data Collection

The Data was kindly provided to me by Reinhard Klenke Ph.D. from the Helmholtz Centre for Environmental Research Leipzig and collected by him, Charlotte Groß, Sally Haddad, and Teresa Nitz in 2017 as described in Holzhauer et al. (2015) as part of the interdisciplinary research project Verlust der Nacht (Loss of the Night). The Data was collected in the Westhavelland Nature Park in the federal State of Brandenburg, northern Germany. 750 km² of the 1315 km^2 area of the Westhavelland Nature Park are distinguished as an „International Dark-Sky Reserve” by the International Dark-Sky Association (2014). According to Holzhauer et al. (2015) two experimental sites were distinguished, both consisting of managed permanent grassland habitats, that are mown twice a year between October and June. Adjoining this grassland, there is an agricultural drainage ditch, with little to no water flow on both experimental sides. The two sides were differentiated in „western“ and „eastern“ site and separated by an Euclidean distance of 600 m. On each of those sites, 12 street lights were put up, arranged in three rows parallel to the drainage ditch, the first line in a distance of 3 meters to the ditch. The lights had a 20 m spacing between them and were arranged on a 60 m x 40 m grid. The western site with the lights L1-L12 was illuminated at night, beginning and ending with the civil twilight. The lights L13-L24 were placed on the eastern site, however since this was the dark control site I will refer to those lights as D01-D12 for this thesis. The illumination timing was controlled by an electrical astronomical time switch, containing information about the location on the globe and the corresponding times for civil dusk and dawn. The lamps were mounted 4.75 m above the ground and equipped with 70 W high-pressure sodium lamps. This resulted in a total luminous flux of 6750 lm, with 0.5% of this being an upward light ratio emitted above the horizontal. In April 2013, one artificial nestbox was mounted at each street lamp post. The Nestboxes were equipped with light and temperature Loggers inside each box, that took measurements every second, resulting in 5.844.206 light and temperature values. The 10 seconds measurements would have not caught all feeding acitivity and were therefore excluded. Every time a Starling would enter or leave the nesting box the entrance hole was blocked for a moment, resulting in a light peak before and after the Starling blocked the entrance, and thereby the incoming light. The data was collected on 8 different dates, over 8 hours each, in the morning and the evening. In that time the most frequenct feeding is done (Kessel, 1957). Furthermore, the number of nestlings in each box was photo-documented.

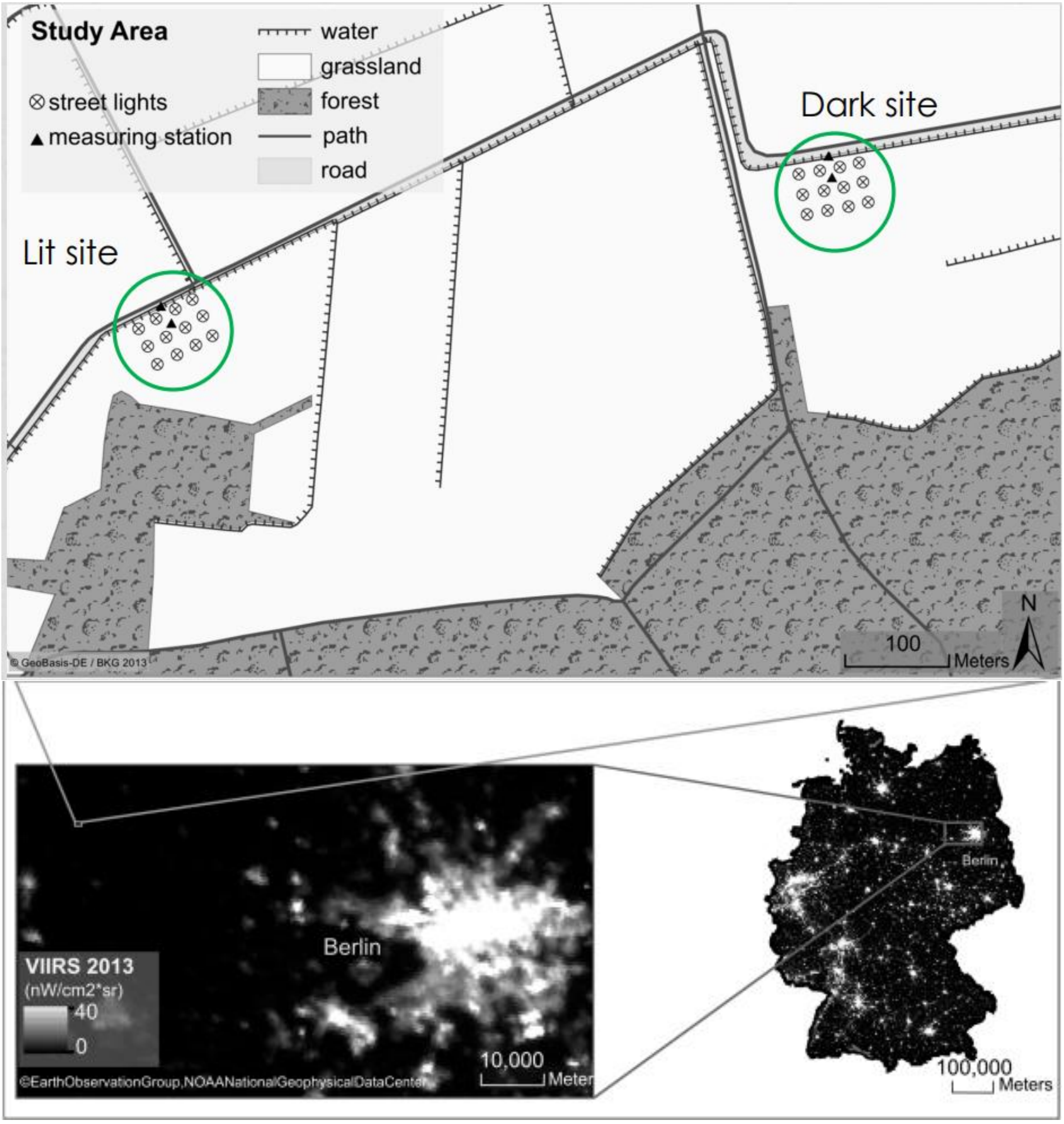

Figure 1: Map of the Data collection area, light map of the area and map of loctaion (Holzhauer et al., 2015).

2.4.1 Handling of the Data

The raw data sets from each box provided to me were combined into one big data file. It was organized using the Text Editor Gnu SED, to prepare it for the analysis with the software environment for statistical computing and graphics R (https://www.rstudio.com/) using the RStudio IDE (Integrated Development Environment). The data held information about the Logger taking measurements and in which box the measurements were taken, the date and the time of each measurement and the temperature in °C and light intensity in Lux.

R Studio was used to split the data again into the different boxes and days and to determine the outlier values for each box, using boxplots. Extreme outlier values, that indicated a failed measurement were eliminated and the Mean, Median, Mode, the Quantiles, minimum and maximum light, and temperature values for each nesting box distinguished. Furthermore, plots were created, using the plot function in R to distinguish light trends over time, high and low light peaks, light frequencies, and light differences over time (Figures 2 and 3). The bird activity was evaluated by looking at the light peaks. A bird flying off or returning to the box blocked the entrance hole in the box for a moment. This leads to a temporary decrease in light intensity inside the box, which would be measured by the logger. Conversely, a light peak occurred before the bird blocked the entrance hole and after the entrance hole was opened again due to the light falling into the nesting box. Thereby, it could be distinguished how early the birds started their activity, how active they were, and at what time their activity stopped.

The Frequencies per hour were summarized for each box for further testing. To evaluate the development over time the analysis started with the 6th of May 2017, the first day of the measuring in the experiment. This was followed by the 18th of May, the 23rd of May and, finally, the 14th of June as the last days of measurements. This way there were three data sets on the activity in the morning hours, and 2 sets on the activity on the evening.

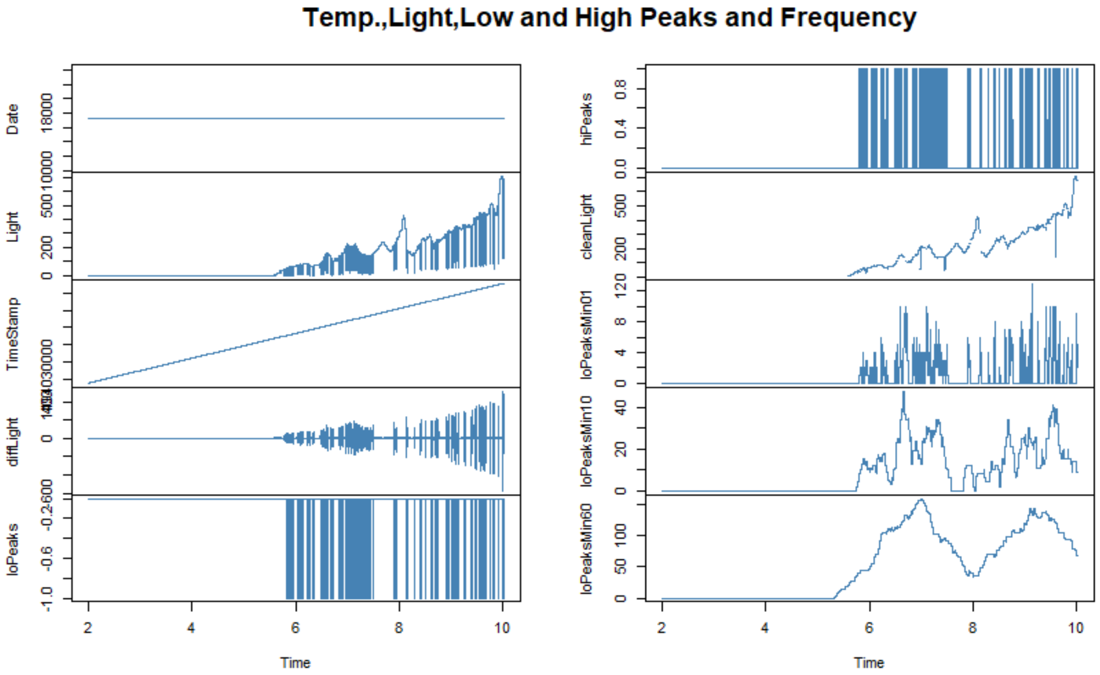

Figure 2: Light Differences measured on the 6th of May 2017 in Box D06. The fields loPeaksMin01, loPeaksMin10 and loPeaksMin60 show the Feeding Frequencies per minute, per ten minutes and per hour.

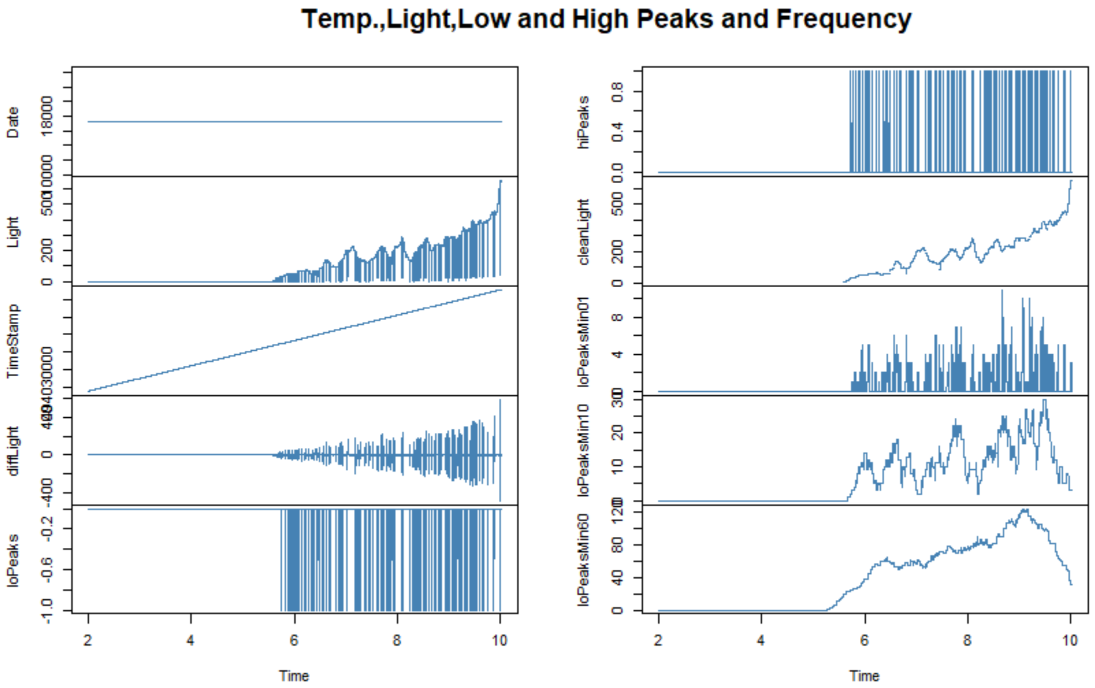

Figure 3: Light Differences measured on the 6th of May 2017 in Box L06. The fields loPeaksMin01, loPeaksMin10 and loPeaksMin60 show the Feeding Frequencies per minute, per ten minutes and per hour.

2.4.2 Testing

Different statistical tests were performed to test the following hypotheses:

H1a: ALAN influences the amount of feeding activity shown by Starlings.
H0a: The amount of feeding activity of the Starlings does not depend on ALAN.

H1b: Starlings start and stop their feeding activity over the day earlier when they are exposed to ALAN.
H0b: The time during which the Starlings show feeding activity over the day is not influenced by ALAN.

After checking if the data about the feeding frequencies per hour in all boxes from both sites had a normal distribution (Shapiro test), an ANOVA was carried out to examine whether the amount of feeding activity is influenced by the light conditions on each site (peaks ~ site). A Spearman's correlation test was performed to check for any possible relation between the boxes on the two sites. Then, a Kolmogorov-Smirnov-Test was performed to evaluate if the distribution of activity differs between the dark and the lit site. For this, all hours with no activity (zero peaks) were excluded, to avoid ties and to get an exact p-value. Furthermore, hours with incomplete measures were excluded for each box on each day as well. This way it could be evaluated whether the activity on the lit and the dark site comes from the same distribution. Finally, the average feeding frequencies per day from both sites were calculated (minimum, maximum, mean and mode) to check for any development in feeding frequencies over time.
The question, whether ALAN influences breeding success in Starling could unfortunately not be tested, due to problems with a Corona infection at the beginning of March 2021.

2.4.3 Photodocumentation of the Breeding Course

Pictures from one day before the start of the measurements show the different stages of the breeding process in the different nesting boxes.

Figure 5: 05.05.2017 - D06 (Klenke, 2017)

Figure 4: 05.05.2017 - D01 (Klenke, 2017)

Figure 7: 05.05.2017 - L12 (Klenke, 2017)

Figure 6: 05.05. 2017 - D09 (Klenke, 2017)

Figure 8: 05.05.2017 - L11 (Klenke, 2017)

Figure 9: 05.05.2017 – D02 (Klenke, 2017)

The pictures show how different the stages of breeding are one day before the start of the measuring. While the nest seems to still be in the making in nesting box D06, the female in box D01 is already done laying her eggs. In the box L12 the first chick has hatched while the hatching process in the box D09 is already finished. The young in Box D09 seem to be around three to four days old (Heinroth, 1966; Starlingtalk, 2021). Since the chicks in box L11 still do not have wing feathers they should not be older than six days old on the 5th of May 2017 (Starlingtalk, 2021). The young in the box D02 already have rather grown-out wing feathers while other feathers are still not quite as developed. This indicates that the young might have been already around eight days old at the beginning of the measurements. Also, the development over time is a variable to explain the Starlings' feeding frequencies. Pictures from nesting box D01 show the development of the hatchlings during the time of measurement.

Figure 10: D01, 05.05.2017 (Klenke, 2017)

Figure 11: D01, 11.05.2017 (Klenke, 2017)

Figure 12: D01, 12.05.2017 (Klenke, 2017)

Figure 13: D01, 18.05.2017 (Klenke, 2017)

Figure 14: D01, 23.05.2017 (Klenke, 2017)

Figure 15: D01, 14.06.2017 (Klenke, 2017)

The pictures show the beginning of the hatching process to be around the 10th of May in box D01. One day later nearly all chicks have hatched. Around the 23rd of May, the chicks already have fully developed plumage and nearly fully grown wing feathers. Three weeks later on the 14th of June the chicks are strong enough and have already left the nesting box.

3 Results and Discussion

3.1 Results

3.1.1 ANOVA

The ANOVA was carried out to test for a dependence of the amount of the Starlings activity on the light conditions at night (Peaks ~ Plot). The created plots (Figures 2 and 3) indicated a very different amount of activity in each nesting box. The ANOVA tested whether those differences were caused by the different light conditions at night or not. However, the ANOVA did not indicate a significant difference in the number of peaks on both sites. A dependence of the amount of feeding activity on light conditions at the site could not be significantly determined (all P values > 0.05, Table 1).

Table 1: Results of the ANOVA for each day

06.05.2017 **2 a.m. – 9 a.m.**	**18.05.2017** **4 a.m. – 11 a.m.**	**18.05.2017** **3 p.m. – 10 p.m.**	**23.05.2017** **5 p.m. – 10 p.m.**	**14.06.2017** **3 a.m. – 10 a.m.**
F = 0.993 P = 0.32	F = 0.257 P = 0.613	F = 0.048 P = 0.827	F = 1.248 P = 0.266	F = 0.664 P = 0.416

3.1.2 Kolmogorov-Smirnov-Test

The Plots showing the activity of the Starlings on both measurement sites, indicate that ALAN leads to an earlier decrease in the Starlings activity in the morning hours (Figures 16 to 20). However, the Kolmogorov-Smirnov-Test showed, that these results are not statistically significant (Table 2). The feeding activity comes from the same distribution on all days (all P values > 0.05, Table 2). In the evening, no effect of ALAN on the time of activity could be found either. This did not change after the Starlings were exposed to ALAN for more than one month.

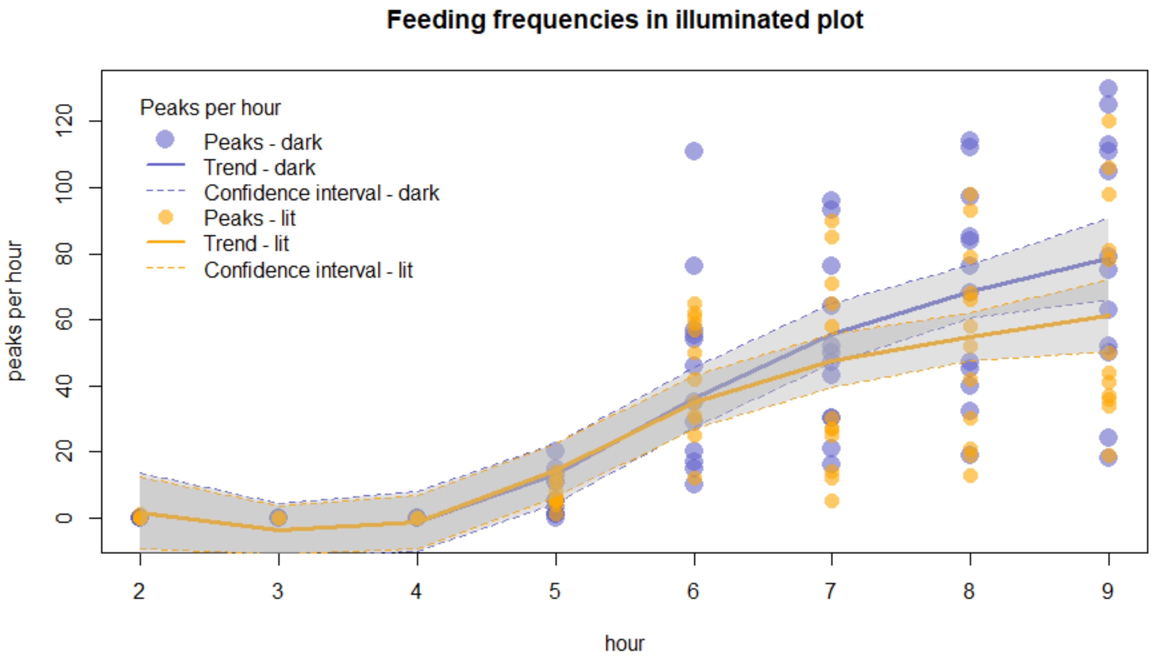

Figure 16: Activity of the Starling, indicated by the peaks per hour on both sites 06.05.2017, 2 a.m. - 9 a.m.

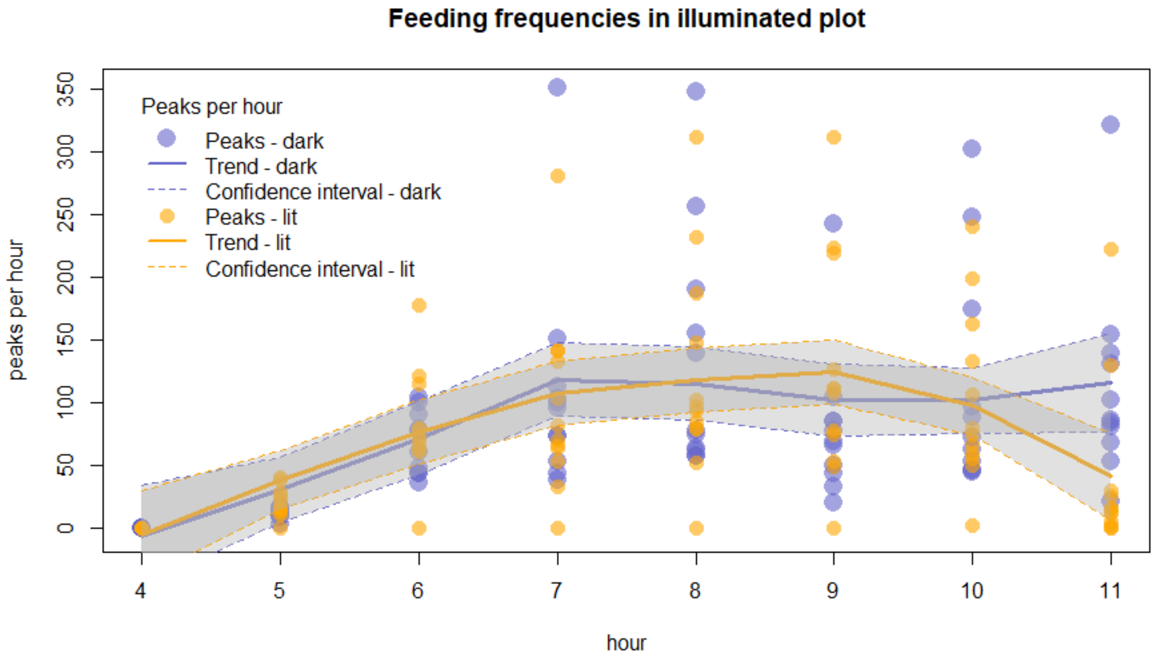

Figure 17: Activity of Starlings, indicated by the peaks per hour on both sites 18.05.2017, 4 a.m. - 11 a.m.

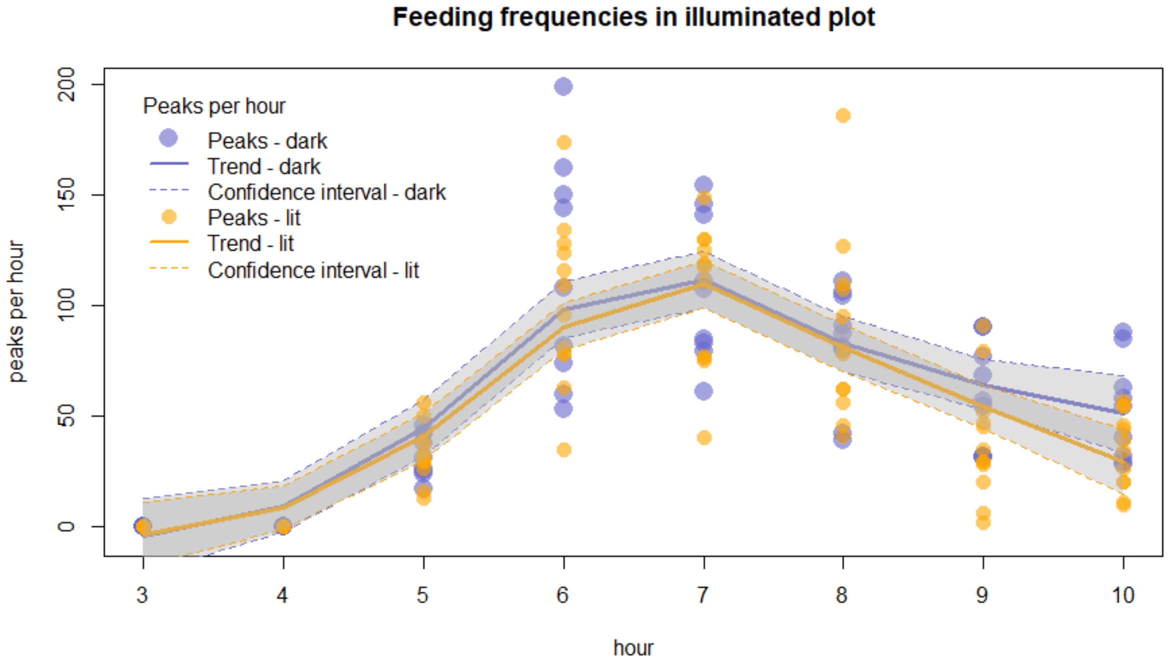

Figure 18: Activity of the Starlings, indicated by the peaks per hour on both sites 14.06.2017, 3 a.m. - 10 a.m.

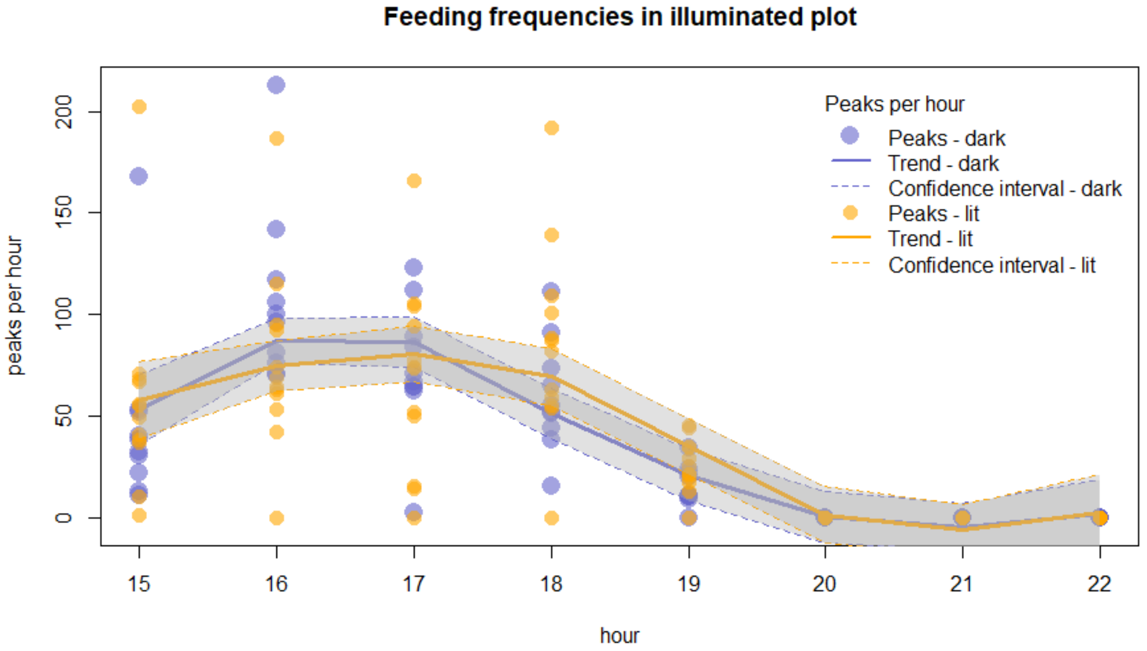

Figure 19: Activity of the Starlings, indicated by the peaks per hour on both sites 18.05.2017, 3 p.m. - 10 p.m.

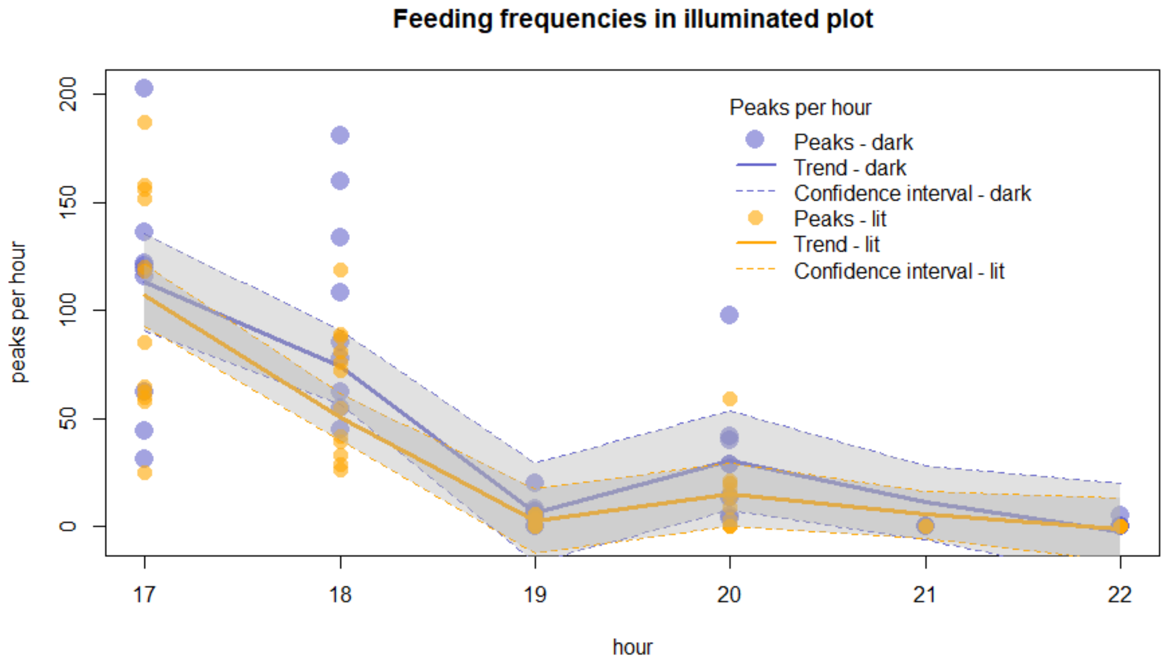

Figure 20: Activity of the Starlings, indicated by the peaks per hour on both sites 23.05.2017, 5 p.m. - 10 p.m.

Table 2: Kolmogorov-Smirnov-Test for each day to compare the figures 16 to 20 for each day

06.05.2017 **2 a.m. – 9 a.m.**	**18.05.2017** **4 a.m. – 11 a.m.**	**18.05.2017** **3 p.m. – 10 p.m.**	**23.05.2017** **5 p.m. – 10 p.m.**	**14.06.2017** **3 a.m. – 10 a.m.**
D = 0.4 *P* = 0.873	*D* = 0.2 *P* = 1	*D* = 0.4 *P* = 0.873	*D* = 0.25 *P* = 1	*D* = 0.5 *P* = 0.474

3.1.3 Feeding Frequencies per day

Table 3:Average Feedings (peaks) in all boxes per day lit site

	06.05.2017 **2 a.m. – 9 a.m.**	**18.05.2017** **4 a.m. – 11 a.m.**	**18.05.2017** **3 p.m. – 10 p.m.**	**23.05.2017** **5 p.m. – 10 p.m.**	**14.06.2017** **3 a.m. – 10 a.m.**
Minimum	0	0	0	0	0
Maximum	120	312	202	187	186
Mean	26	74.34	39.24	30.6	50.03

Table 4: Average Feedings (peaks) in all boxes per day dark site

	06.05.2017 **2 a.m. – 9 a.m.**	**18.05.2017** **4 a.m. – 11 a.m.**	**18.05.2017** **3 p.m. – 10 p.m.**	**23.05.2017** **5 p.m. – 10 p.m.**	**14.06.2017** **3 a.m. – 10 a.m.**
Minimum	0	0	0	0	0
Maximum	130	352	213	203	199
Mean	31.18	80.22	37	40.7	56.10

3.1.4 Differences in the boxes

Box- and Pirate Plots (Figures 21 to 24, Appendix) indicated a high variance in the Starlings activity at different times of the day and between different boxes on each site.

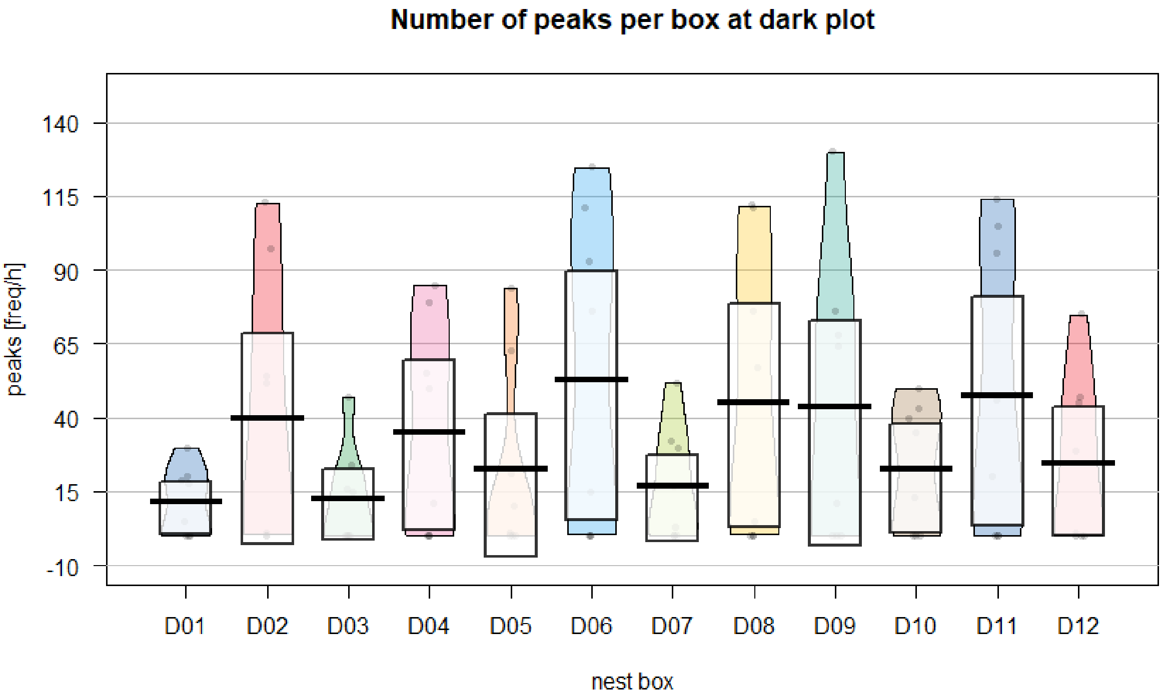

Figure 21: Number of Peaks in each box at the beginning of measurement 06.05.2017, dark site

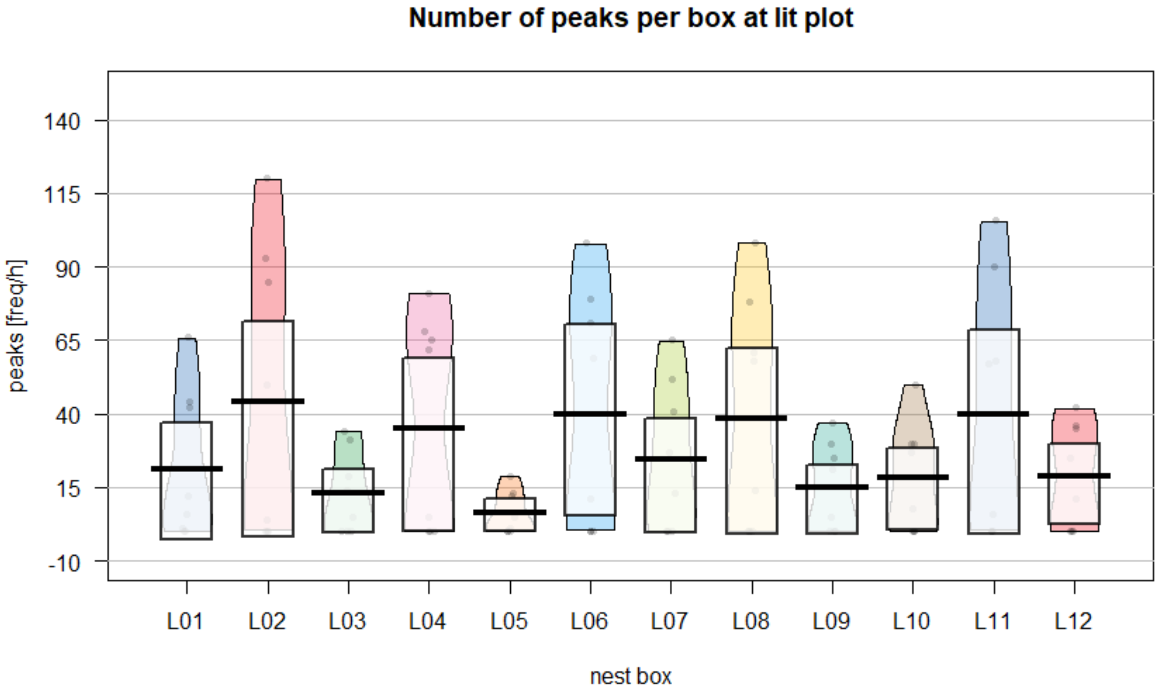

Figure 22: Number of Peaks in each box at the beginning of measurement 06.05.2017, lit site

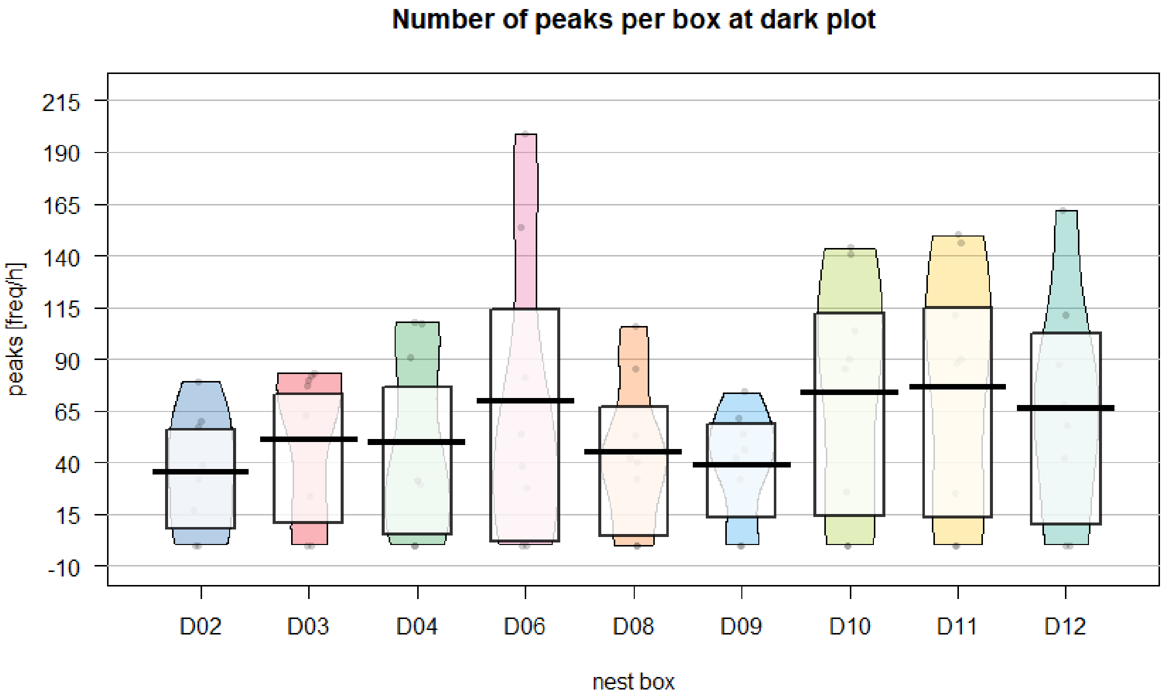

Figure 23: Number of peaks per box at the end of measuring 14.06.2017, dark site. The boxes D01, D05 and D07 already did not produce anymore data.

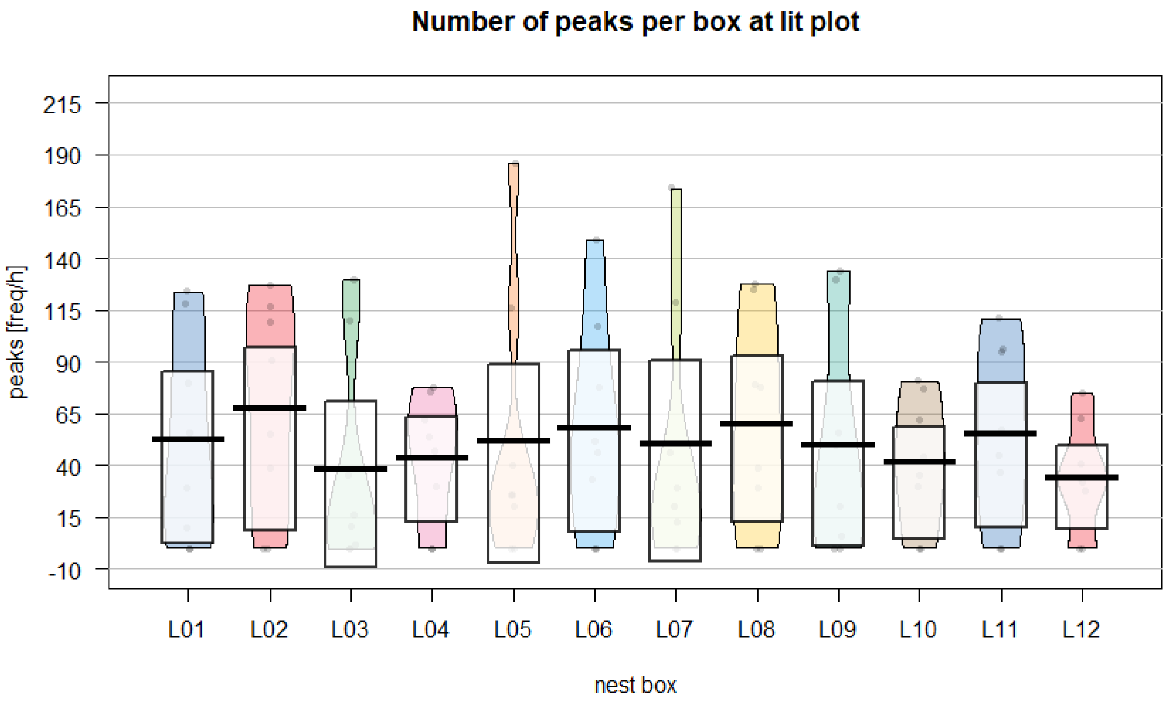

Figure 24: Number of peaks per box at the end of measuring 14.06.2017, lit site

3.2 Discussion

The ANOVA did not indicate any significant difference in the activity on both sites. The amount of activity does therefore not depend on the light conditions that prevail at night on each site. The H0a that the amount of feeding activity of the Starlings does not depend on ALAN must therefore be accepted. Furthermore, there was no evidence, that ALAN influences the time of feeding activity in Starlings. There seems to be an earlier decrease in the Starlings activity in the morning hours when the Starlings were exposed to ALAN. However, this difference is not significant. Therefore, the H0b that the time during which Starlings are active does not depend on ALAN, cannot be ruled out. It should be noted however, that the Loggers measuring the light inside the boxes had limited sensitivity. They could not detect the light differences at night between both sites. This might mean that we did not detect effects of earlier onset of activity during the night. The loggers only show differences between an open hole or a hole covered by a Starling above a certain threshold of light. This threshold is only reached in the morning, but not before sunrise. The pirate plots showed differences between the boxes during the measurement. This might be explained by the amount and the size of the hatchlings in each nesting box. Kessel (1957) claims that large broods are fed more frequently than small ones, but that the difference in the number of feedings is not proportional to the number of young in the nest. Differences in brood size might therefore account for differences in feeding activities. It was visible that the development of hatchlings in each box differed during the time of measurement.While some chicks were already several days old, others were not even hatched. This leads to different feeding frequencies in each box, depending on the development state of the young. As described on the website Starlingtalk (2021) the hatchlings leave the nest approximately after 19 days. This means that some chicks probably left the nest during the time of measuring, while others were still being fed by their parents. This would fit with the absence of data on the last day of measurements on the dark site in the boxes D01, D05 and D07. Also, the time of maximum feedings differed in each box due to this.

In general, the Starlings seem to feed more often in the morning hours (18.05.2017, lit site, morning: on average 74.34 feedings per box; evening: on average 39.24 feedings per box; 18.05.2017, dark site, morning: on average 80.22 feedings per box; evening: on average 37 feedings per box). Furthermore, the feeding frequencies in the boxes increased between the 6th of May and the 18th of May, with a maximum of 312 feedings per day on the lit site, and 352 feedings on the dark site. After this, the number of feedings decreased again till the last day of measures on the 14th of June. This matches with findings by Kluijver (1933), Wallraff (1951), and Tinbergen (1980), who all found the maximum amount of feedings between 250 and 350 feedings per day with the most frequent feedings around the time the hatchlings are between one and two weeks old. This course of feeding frequencies indicates that, even though the chicks in each box are several days apart in age, most of them hatched at a similar time. When the young are small, feeding starts at sunrise and ends at sunset but often stops one hour before sunset when the young are a little older (Kessel 1957). Furthermore, Kessel (1957) explains that with the increasing age of the hatchlings the size of the particles fed and the manner of feeding changes. During the first few days, the young are fed with small insects like small caterpillars grubs that are carefully placed in the youngs throat by their parents. With ongoing time the insects fed are getting larger and might even consist of hard-shelled beetles. Also the feedings get more hurried and the insects are quickly jabbed into the youngs throat. This behavior can be problematic for late-hatched that might not get enough food and can also suffer injuries from their parents fast feeding. Also playing into the feeding behavior is the number of insects available on each site. Insects seem to be drawn towards illumination and stay in illuminated areas, because of the “fixation effect”, the “crash barrier effect” or the “vacuum cleaner” effect (Eisenbeis. 2006). Holzhauer et al. (2015) set up insect traps in 2012, to test the abundance of insects at each experimental site. Before the illumination of the western site, no significant difference in insect abundance between the sites was detected. After the illumination, the catch per hour performance of the lit site was up to 120 times higher than at the dark site. This could explain why the Starlings activity on the lit site only decreases earlier in the morning hours, but not in the evening hours. The insects are only drawn towards the illumination during the night. This means that the insect’s abundance is probably still similar on both sites. After the start of the illumination around dawn, more insects are drawn towards the light and therefore, a higher insect abundance can be measured at the illuminated site. When the Starlings begin their activity in the morning hours the ones on the illuminated site can catch more prey faster, due to a higher insect density. They can therefore stop their activity earlier, while the birds on the dark site need to continue foraging to get a similar amount of insect biomass. However, the Starlings might have foraged rather outside of the experimental plots and would therefore not be affected by the insect density inside the study area. This will still need further testing. Some more research can be done to determine if ALAN influences the insect composition in an area, since Kluyver (1930) found that the nestlings’ diet can have a great impact on their survival.

Even though my results did not indicate an effect of light pollution on the number of feeding frequencies or on the time of feedings, ALAN was proven to influence many species and strongly influences birds and, as such also Starlings. ALAN causes hormonal and behavioural changes like foraging disturbances (Jiang et al. 2020), activity shifts (Dominoni et al., 2020), an earlier start of singing in songbirds (Kempenaers et al., 2010), or altered reproducing and breeding processes (Dominoni et al., 2015). Starlings seem to use day length as a cue for their reproduction cycle and the length of a day greatly influences the spermatogenesis in male Starlings (Burger, 1953). A change in the reproductive state of a Starling can furthermore influence the immune response to a mitogenic challenge (G. E. Bentley et al., 1998). Also, the UV deficient nature of ALAN influences the correct perception of plumage hues in Starlings and thereby further influence their reproduction (Maddocks et al., 2002). The UV deficit of ALAN can also cause higher basal plasma corticosterone concentrations in Starlings (Maddocks et al., 2001) and thereby alter their fight or flight reaction and their song complexity (Buchanan, 2000). It should therefore be clear that ALAN bears risk for many (bird-) species, including Starlings and should if possible, be prevented.

3.3 Potential measures to improve Light Conditions at Night

However, there are ways to minimize the amount of light and the main negative effects related to the alteration of the environment. One way to minimize the need for light, is to consider the reflection potential of surfaces (Huggins et al., 2019). The reflection potential influences how good we can see objects on a certain background. To make those objects more visible while using less light, we need a tonal difference of the object compared the background (Huggins et al., 2019). A more obvious step is to avoid over lighting, by shutting off light in areas that are not used (Falchi et al., 2011). Especially Light sources that locally emit more illuminance than prevailing street lighting, constantly distract our eyes and cause a so-called "psychological blinding", the constant adaptation of our eyes to the light conditions (Huggins et al., 2019). Certain light management systems allow the adaption of light emission on local, timely, seasonal, and weather-related conditions to decrease the luminance of prevailing objects (Huggins et al., 2019). Huggins et al. (2019) recommend a maximum candela per m² (cd/m²) of 50-100 cd/m² on areas smaller than 10 m², and maximal 2-5 cd/m² for larger areas. More cd/m² should only be applied in special cases, when the visualization of details is necessary. Furthermore, downward light flux outside the area to be lit, should not be wasted (Falchi et al., 2011). This can be achieved by shielding the lamp and using efficient reflector materials, so the light flux is directed downwards (Posch, 2013). Another measure would be to set down the speed limit in ecologic sensitive areas to 30 km/h, to avoid traffic and decrease illumination need (Huggins et al., 2019). Lights near roads should furthermore be dimmed, when it is known that the street is not used frequently during certain times of the day (European Commission. 2019; Huggins et al., 2019). New bulbs like Metal halide high-pressure lamps or ceramic lamps provide a much better optic quality while reducing psychological blinding and being energy efficient (Lang, 2013). However, those kinds of bulbs have a high percentage of short waved blue light emission, which should be avoided (Lang, 2013; Falchi et al., 2011). Since normally lamps with yellow-red spectral components are preferable when it comes to ALAN, bulbs with a blue light spectrum need to be of especially high quality (Lang, 2013). For conservation areas low-pressure sodium vapor lights or PC Amber LED with highly reduced blue light emission are to be preferred (Huggins et al., 2019). Light emission like UV-lights or IR-radiations may be outside the human visible spectrum and therefore not visible but can be perceived by insects or birds and should therefore, if possible, be filtered out (Huggins et al., 2019). To find the right amount of light and fitting bulb source requirement systems should be created (Huggins et al., 2019). Summarized, this means lamps that direct their light more accurately toward where it is needed, lamps that emit light with a spectral distribution causing minimal harm, timers and sensors to turn lights on only when needed, and the consideration for lightsensitive areas, especially the periphery of residential areas, forests, parks, and shores of water bodies (Hölker, Moss, et al., 2010). Finally, it is important to raise awareness within the society, to educate people about the problems of ALAN and to raise the will to find solutions (Brinkmeier 2013).

4 Conclusion

The data allows me to conclude that, in this experiment, ALAN does not influence the feeding activity of breeding Starlings in the study area. Neither the amount of feeding activity was influenced by ALAN, nor the time of the activity was altered. This fact did not change after one month of exposure to ALAN either. Differences in the Starlings feeding activity are more likely to be explained by differences in the breeding state or maybe the insect abundance that is influenced by ALAN. To test this however, further studies will be necessary.

Nevertheless, ALAN was shown to influence the environment in several studies. Not only does a constant nightly illumination cost a lot of money and electricity (Gallaway et al., 2010; AGEB, 2020), but it also strongly influences circadian rhythms, behavior and health in humans, plants, and animals (e.g., Knab, 2013; Kloog et al., 2009; Hölker, Wolter at al., 2010; Eisenbeis, 2006). It might even be one of the drivers causing the current insect decline, among other factors (Grubisic et al., 2018). Birds are one of the most strongly affected species with ALAN influencing hormone concentrations (Jiang et al., 2020), migration (Rebka et al., 2019) and reproduction processes (Russ et al., 2017; Dominoni et al., 2015; Maddocks et al., 2002). Starlings use light clues in their reproduction cycle to find the optimal breeding time (Kessel, 1957). ALAN might therefore confuse their reproduction cycle and lead to a decrease in the breeding success. To prove this, however, further studies are needed. ALAN should be minimized, and if that is not possible, the light sources should be switched to more sustainable options. By making important objects more visible during the night time and decreasing the overall light intensity in areas (Huggins et al., 2019), directing the light flux of illumination sources downward (Posch, 2013), and switching to better bulbs (Huggins te al., 2019) a lot of light pollution can be avoided. This would bring benefits to the human circadian cycle and health, as well as to many other species that are exposed to ALAN.

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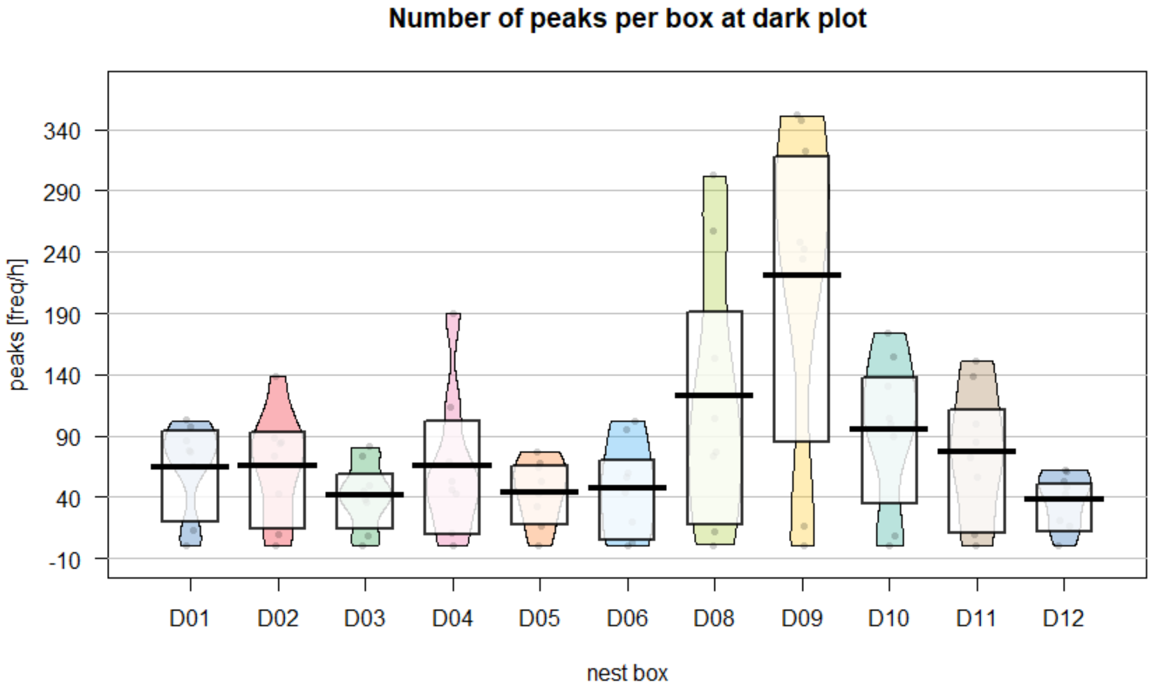
6 References Figures

Figure 1: Holzhauer, S. I. J., Franke, S., Kyba, C. C. M., Manfrin, A., Klenke, R., Voigt, C. C., Lewanzik, D., Oehlert, M., Monaghan, M. T., Schneider, S., Heller, S., Kuechly, H., Brüning, A., Honnen, A. C., & Hölker, F. (2015). Out of the dark: Establishing a large-scale field experiment to assess the effects of artificial light at night on species and food webs. *Sustainability (Switzerland)*, *7*(11), 15593–15616. https://doi.org/10.3390/su71115593

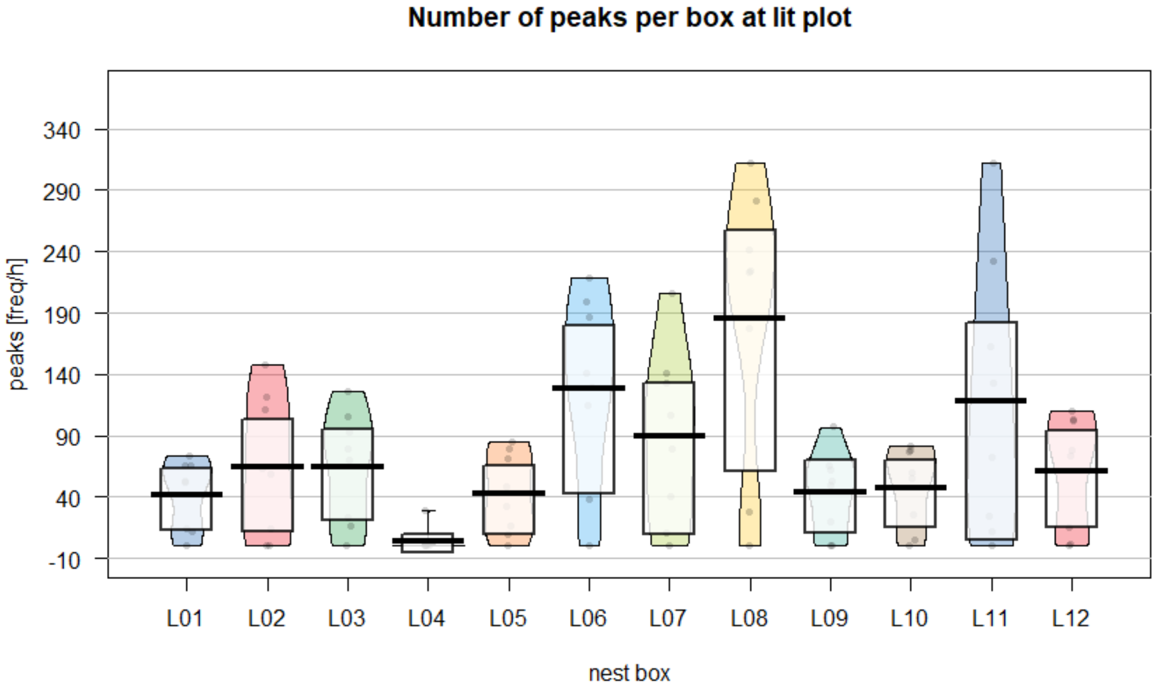
Figure 4 – Figure 15: Klenke, R. (2017). Birds in illuminated landscapes. Verlust der Nacht, Fieldwork & First Results.

7 Appendix

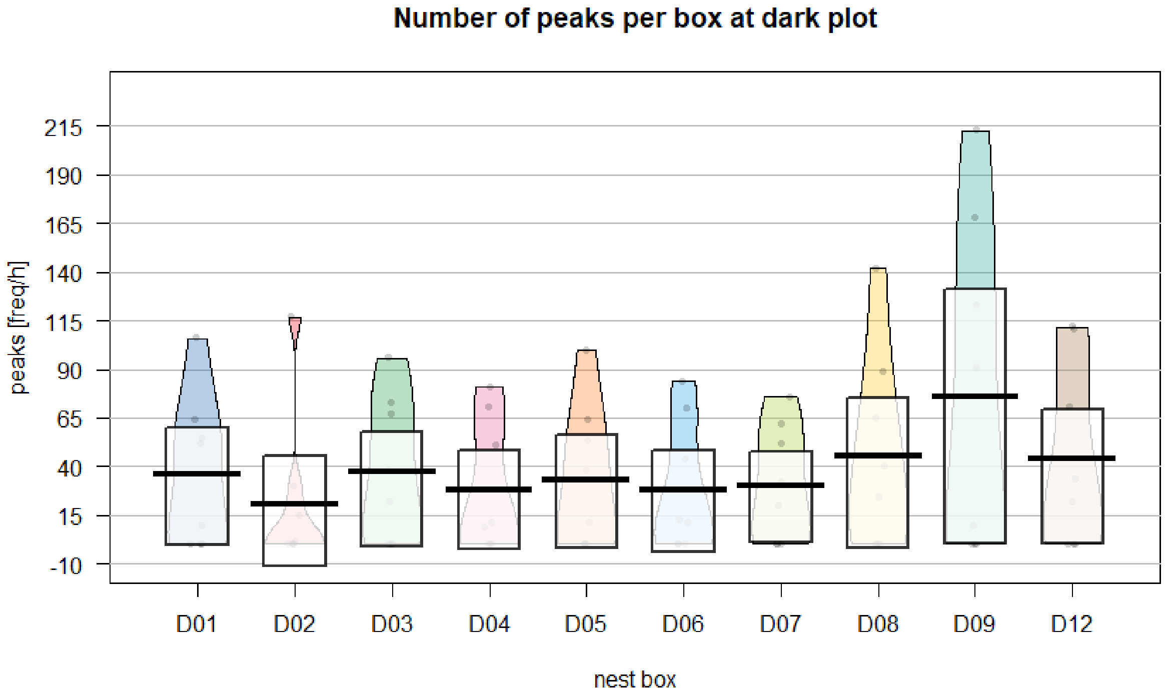
7.1.1 Pirate Plots



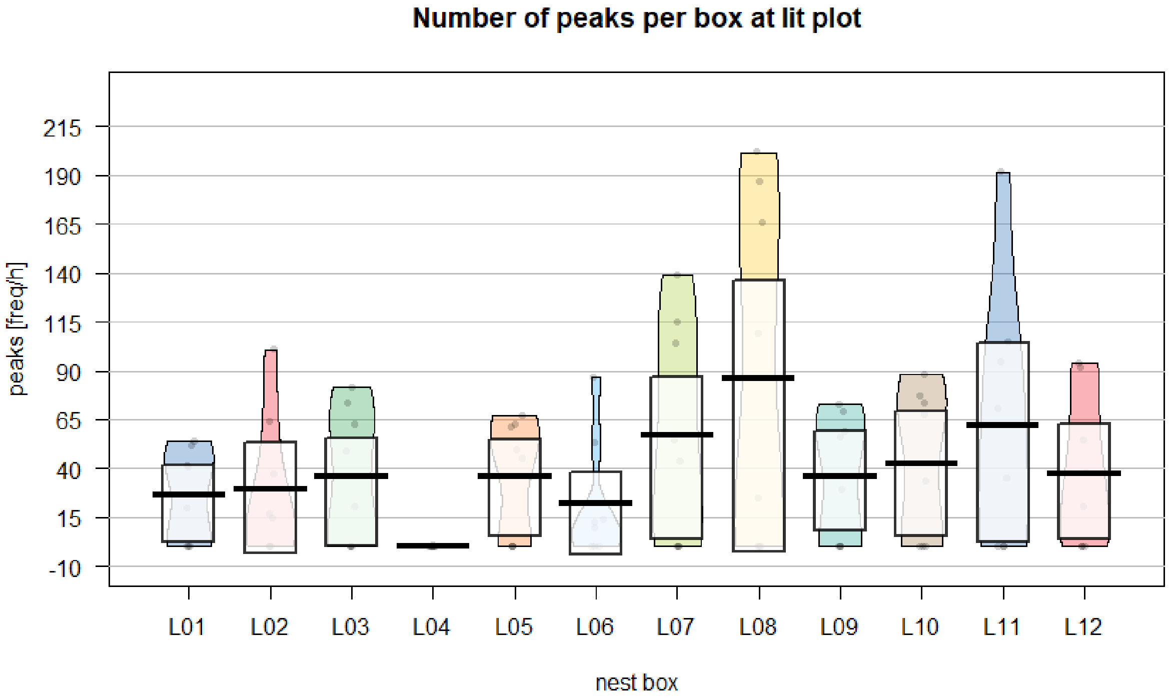
Appendix 1: Number of Peaks in each box 18.05.2017, morning, dark site



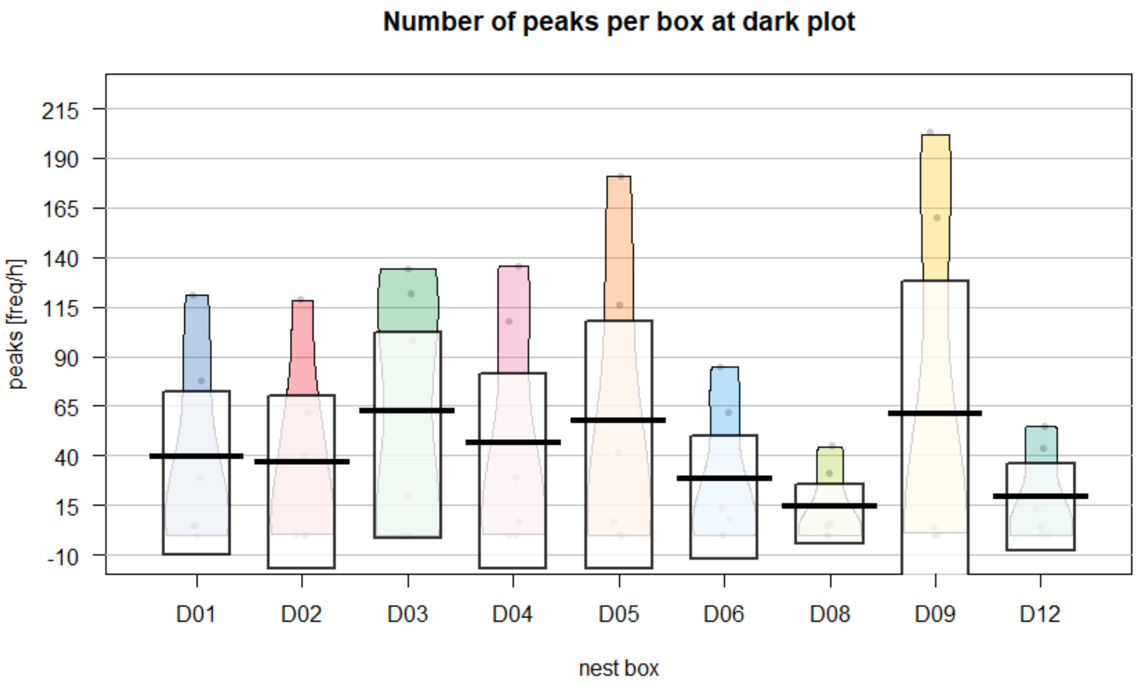
Appendix 2: Number of Peaks in each box 18.05.2017, morning, lit site



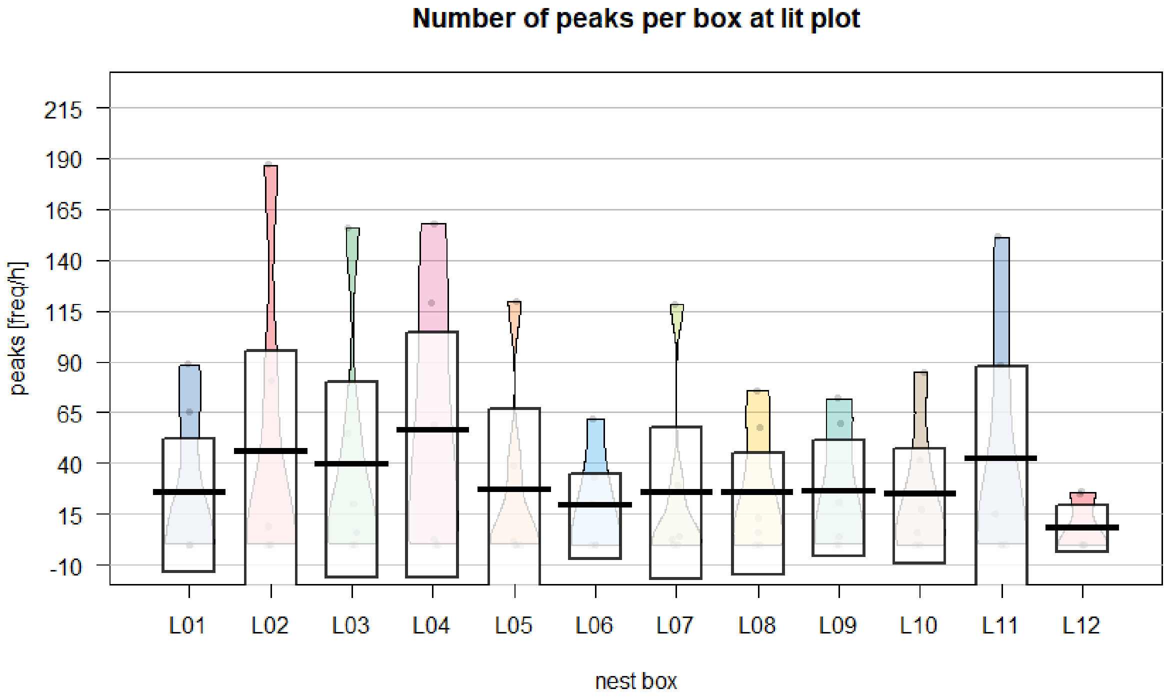
Appendix 3: Number of Peaks in each box 18.05.2017, evening, dark site



Appendix 4: Number of Peaks in each box 18.05.2017, evening, lit site



App endix 5: Number of Peaks in each box 23.05.2017, dark site



Appendix 6: Number of Peaks in each box 23.05.2017, lit site