Norwegian University
of Life Sciences

Master's Thesis 2019 30 ECTS
Faculty of Environmental Sciences and Natural Resource Management

Neighboring Colonies of Brandt's Bat *Myotis brandtii* and Whiskered Bat *M. mystacinus* Changed Their Roost Activity Throughout the Breeding Season

Karoline Manneråk Birkeland
Teacher Education in Natural Sciences

Acknowledgements

Thanks to Katrine for all your good advice, supporting words and help with my thesis.

Thanks to Jeroen for expert knowledge on how to handle bats, and where to find them. Thanks for all the help with writing and revising this thesis.

Thanks to Rune, Joakim and Kristian for sharing your knowledge about data collection and analysis.

Thanks to my fellow student April for all your help with data collection, English proofreading and (more or less) serious talks during the long working nights.

Thanks to Richard and Mahdieh for helping me find suitable statistical methods.

Thanks to Karoline and Claire, my roommates throughout the field season, who helped me with the statistics and sent me relevant literature even after we split up.

Thanks to Håvard who helped me to sample data and revising my spreadsheets, even though he did not have to.

Thanks to The Norwegian Environmental Agency (Miljødirektoratet) for funding my thesis as a part of the SCANDBAT project.

Thanks to friends, family and my boyfriend for all your loving support and understanding the last year.

Contents

1. Abstract

Little is known about bats in Norway, although they constitute > 20 % of our terrestrial mammal species; 13 bats species are registered, but it is not known if all of these reproduce in the country. Many European bat populations are in decline, probably due to factors like environmental contamination, habitat loss and fragmentation, changes in human land use and disturbance at roosts and hibernacula. Female bats form social colonies in the breeding season and can use several roosts that are spatially aggregated. This clumped distribution can make them particularly vulnerable to disturbances and habitat changes. Thus, more knowledge about maternity roost ecology, dynamics and behavior is needed for evidence-based management and conservation.

The goal of this study was to monitor colonies of two bat species in southeast Norway throughout the breeding season, to increase our understanding of seasonal variation in bat activity. Furthermore, I wanted to investigate if bat activity at and nearby the maternity roosts, was linked to climatic factors such as temperature, humidity and light.

I monitored one colony of Brandt's bats *Myotis brandtii* and one colony of whiskered bats *M. mystacinus,* which both consisted of several roosts. We counted number of bats flying out from the roosts and passing through nearby vegetation corridors several times throughout the breeding season, and we logged echo localization calls every night. Additionally, we monitored temperature, humidity and light continuously throughout the same period at two roosts.

I found that (1) time of first emergence varied throughout season for both species, and was also influenced by temperature; (2) there was a positive relationship between bat activity at the roosts and temperature in the beginning of the season; (3) individual bats changed roosts during the breeding season; (4) there was a difference between colonies of *M. brandtii* and *M. mystacinus* in number of bats exiting the roosts and type of vegetation corridor that was used most frequently.

Long term research and monitoring of environmental conditions is important to determine if the roosting behavior of *M. brandtii* and *M. mystacinus* observed in this study – and the differences observed between the two species - are indeed typical patterns which can inform management. In particular, it would be important to find out whether individuals of *M. brandtii* and *M. mystacinus* normally change roosts during the breeding season, or if that is a response to unusual environmental conditions in the year of the study.

2. Introduction

The order Chiroptera (bats) is one of the most species rich vertebrate groups and consists of more than 1100 species (Wilson & Reeder, 2005). Bats constitute an ecologically diverse group and can be found almost anywhere in terrestrial habitats from the arctic circle in the north (Rydell et al., 1994) to South Africa and Chile in the south (Bat Conservation Trust, s.a.-a). Bats represent a major component of European biodiversity. To date, 53 bat species occur in the geographic range of the EUROBATS Agreement (comprising Europe and neighbouring countries: http://www.eurobats.org/about_eurobats/parties_and_range_states). Many European bat species have experienced declining populations (Mickleburgh et al., 2002). The causes of population declines are likely complex, and may include disturbance at maternity colonies and hibernacula, environmental contamination with pesticides, habitat loss and fragmentation, and changes in land use (Stone et al., 2013).

As predators that rely almost exclusively on insects and spiders, Norwegian bats use echo localization calls to detect their prey (Ghose & Moss, 2003). Since bats are nocturnal, it can be hard to detect them by visual observation. Instead one can use ultrasound detectors (bat detectors) which detect the bats' echo localization calls (Rydell et al., 2017). In Norway, however, the evenings are lighter during summer due to the high latitudes, making it possible to actually see the bats emerging and flying in corridors. Many bats have several different echo localization calls, depending on whether the bat is searching for or is in pursuit of invertebrate prey, and the bat detectors can distinguish between these calls (Rydell et al., 2017). Often, but not always, the echo localization patterns (sonograms) can be used for species determination. Since all bats in Norway are insectivores, they can be detected using bat detectors.

All European bat species are to a large extent subject to the same general disturbances and can provide a reliable indicator of ecosystem function and health (Jones et al., 2009). Bats are suppressors of pest insects in several ecosystem types (Federico et al., 2008). Attempts to quantify

the magnitude and economic importance of this ecosystem service have been made for the US (Federico et al., 2008) and a first economic assessment of the role of bat insectivore in European farmlands will be carried out in the next couple of years (https://www.cost.eu/actions/CA18107/#tabs|Name:overview). Examples from outside North America and Europe include the Brazilian free-tailed bat *Tadarida brasiliensis*, which keeps cotton crops free from the insects containing the pest *Bacillus thuringiensis* (Federico et al., 2008). In tropical areas, frugivorous bats also function as important pollinators of plants. For example, common blossom bat *Syconycteris australis* functions as an important pollinator for bumpy satinash tree *Syzygium cormiflorum* in Australia which is a an important food plant for many other species, including bats, birds and possums (Fleming et al., 2009; Skyrail, 2008). Due to the many threats to bat populations and their important ecological role(s), increasing our knowledge and understanding of bat ecology is important to prevent biodiversity loss and to sustain ecosystem services.

Managing a diverse group of animals like bats is considered challenging (O'Shea et al., 2003). Of course, there are ecological and conservational differences between a bat living in the tropics and a bat living in more temperate environments. However, the differences in ecology and behavior can be substantial even for bats living in the same area. For example, Daubenton's bat *Myotis daubentonii* and Natterer's bat *M. nattereri* are two related species, which can co-exist in the same area (Dietz & Kiefer, 2016a). While *M. daubentonii* is known to forage over water, as well as in forests, *M. nattereri* is only known to forage in close vicinity to vegetation (Dietz & Kiefer, 2016c; Dietz & Kiefer, 2016d). Thus, if the forest in an area should disappear this might be more crucial for *M. nattereri* than for *M. daubentonii*. All in all, more knowledge is needed on all bat species to cover the diversity of bats, in order to make informed management plans.

Although there is substantial among-species diversity, European bats share several common features, such as the ability to use echo localization and the ability to fly (Dietz & Kiefer, 2016a). Moreover, many species share several behavioral characteristics such as swarming and living in social

groups. All Norwegian bat species are categorized as social bats (Dietz & Kiefer, 2016a) and live in social groups, also called colonies (Bat Conservation Trust, s.a.-b). A colony can often consist of many different roosts (Lewis, 1995). As a rule, a maternity roost consist of several pregnant female bats that live together during pregnancy, gestation and until their young are old enough to fly on their own (Isaksen et al., 2009). There are several benefits of living together, such as information sharing, group rearing and defense (Scott et al., 2018). Whereas some of the benefits of living in colonies might be related to resource limitation, others are considered as being kin-selective (Scott et al., 2018). Previous studies carried out in Norway have found that after the young can fly on their own, both adults and young typically swarm in front of mines or screes, probably to exchange information and to reproduce (mate) (Isaksen et al., 2009). Hence, due to their social behavior, bat populations will have a clumped distribution in space. The clumped spatial distribution can make bats particularly vulnerable to habitat disturbance, both natural disturbances, such as wild fires, and human-caused disturbances.

In this thesis, I have studied the roost ecology of the two bat species Brandt's bat *M. brandtii* and whiskered bat *M. mystacinus* in Nittedal, Norway. Little is understood about how these two cryptic species differ in ecology and behavior, especially in Norway (Isaksen et al., 2009). Since both species are known for roosting in buildings (Dietz & Kiefer, 2016a), they are facing the risk of habitat and roost destruction. In addition, environmental factors such as temperature, light and humidity can also influence the colony dynamics and social behavior. In this thesis, I ask the following questions:

I. Does the time of roost emergence vary throughout the maternity season?
II. Is the time of roost emergence influenced by environmental conditions such as light, humidity and temperature?
III. Do neighboring *M. brandtii* and *M. mystacinus* colonies differ with respect to time of roost emergence and use of nearby vegetation corridors?

3. Materials and methods

3.1 Study area and study species

3.1.1 Study area

Data collection was done in Nittedal municipality in Akershus county (Viken county from 2020), Norway. Nittedal consists of a gully with the river Nitelva running through it (Borch & Erikstad, 2015), and has a long agricultural history due to the abundance of marine clay in the area (Erikstad, 1992). There are five main nature types in Nittedal: bog, scree, cultural landscape, wetlands and forest (Fjeldstad et al., 2002). The bogs and riparian forests are found in close vicinity of Nitelva, and there are also some bogs on top of the hills. Agricultural lands dominate along the hill sides with smaller forest patches scattered around, whereas the mountain ridges are covered with forests. The forests are dominated by coniferous trees and managed for timber production, but there are also some boreal deciduous forests, and smaller patches of temperate deciduous and primary forest scattered around (Fjeldstad et al., 2002).

The two bat colonies monitored in this study were located on the east side of the river Nitelva. Both of these colonies were found (by tracking radio-tagged female bats) during the previous field season (in 2017; see Eldegard et al. 2017). MBRA1, the first discovered *M. brandtii* roost*,* is located in a house situated in a small housing estate (Figure 1). The roost entrance is facing north-west towards a small creek with trees on both sides. However, many of the trees on the roost side of the creek were cut down in mid-June in 2018 (Eldegard et al., 2018). MMYS1, the first discovered *M. mystacinus* roost*,* was located in a house, which lies closer to agricultural land than MBRA1 (Figure 1). The colony entrance is facing west towards a slope facing the river Nitelva. In addition, Holterbekken creek, which we thought of as a possible vegetation corridor bats utilized for foraging, lies about 200 m away from the main roost. During the field season, we discovered several other roosts that belonged to the two first known roosts (hence, we thought they were part of two multi roost colonies, one for each species) (see Figure 1).

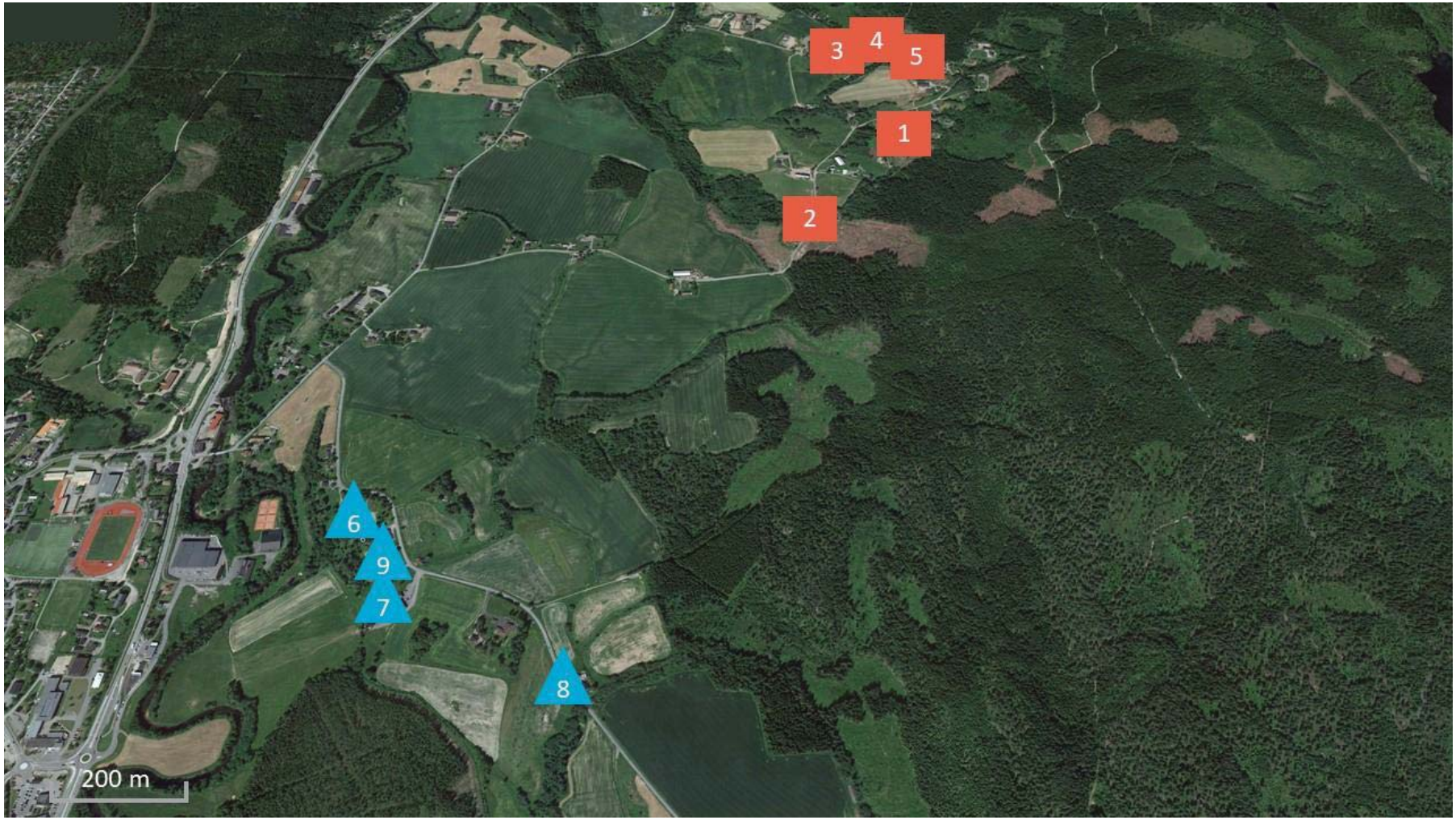

Figure 1: Orthophoto over the study area. Red squares indicate M. brandtii roosts, blue triangles indicate M. mystacinus roosts. Roost 1 and 6 are the first discovered roosts, the other numbers indicate the later discovered roosts. 1 = MBRA1, 2 = MBRA2, 3 = MBRA3, 4 = MBRA4, 5 = MBRA5, 6 = MMYS1, 7 = MMYS2, 8 = MMYS3, 9 = MMYS4. Orthophoto was downloaded from Google Earth.

3.1.2 Study species

The two study species in this project were *M. brandtii* (Brandt's bat, skogflaggermus in Norwegian) and *M. mystacinus* (whiskered bat, skjeggflaggermus in Norwegian), which both belong to the Vespertilionidae family. *M. brandtii* and *M. mystacinus* were considered one species until the early 1970s, but through genetic studies it has been determined that they are two distinct species (Baagøe, 1973 in Berge, 2007). Both species are cryptic and morphologically similar, but by using a combination of phenotypic traits (such as fur color, forearm length and the size difference between the premolars) it is possible to classify most of the captured specimens in the field to the right species (Berge, 2007).

The reproductive cycles of the two species are quite similar; they swarm in the autumn and give birth in June. In fact, this applies to all *Myotis* species (Meschede & Rudolph, 2004). However, female *M. mystacinus* are assumed to be reproductive already in their first year, whereas female *Brandt's bat* are not reproductive until their second year (Dietz & Kiefer, 2016b; Dietz & Kiefer, 2016e). Note, however, that according to Bat Conservation Trust (2010a, b) neither species is reproductive until their second year.

The summer roosts are primarily located in human made buildings for both species (Isaksen et al., 2009), and according to Bat Conservation Trust (2010a, b) they are assumed to prefer older buildings. Sometimes both species share a common roost (Isaksen et al., 2009) and they can also have roosts behind loose bark pockets on trees (Jones et al., 2009). In Norway, bats of both species are known to overwinter solitary, however further south they can overwinter in bigger, both intra and interspecific, groups (Isaksen et al., 2009).

Furthermore, both species forage along forest edges and over water bodies, and their diets consist of a broad range of arthropods (Isaksen et al., 2009). Individuals of both species can have up to 12 hunting grounds away from their primary roosts, however *M. brandtii* has been found to travel

further away from their roost (up to 10 km) (Dietz & Kiefer, 2016b) compared to *M. mystacinus* (up to 5 km) (Dietz & Kiefer, 2016e).

None of the two species are listed on the Norwegian Red List of Species (Nasjonal rødliste), however they are both categorized as Least Concern (LC) which is the first category outside of the red list (Wiig et al., 2015). *M. mystacinus* was categorized as Data Deficient (DD) on the 2010 red list (Swenson et al., 2010), and the LC status today is primarily based on new findings of the species in west Norway and the status as LC in Sweden (ArtDatabanken, s.a.; Wiig et al., 2015). Thus, the authors behind the Norwegian Red List for Species claim that there is too little data to actually know the status of the two species, yet, they categorized both species outside the list (Wiig et al., 2015). According to Bat Conservation trust (2010a, b) *M. brandtii* and *M. mystacinus* are vulnerable to both deforestations, due to loss of feeding habitat, and agricultural pesticides.

3.2 Data collection and data processing

For monitoring the bat activity at the roosts throughout the maternity season, I used two main methodological approaches; automatic logging of bat echolocation calls, and direct observation (i.e., visual observation and acoustic observation by use of hand-held bat detectors).

3.2.1 Bat activity (echo localization calls) at social roosts throughout the season

For continuous monitoring of bat activity at the roosts I used automatic loggers that recorded bat echo localization calls; Batcorders (ecoObs BmbH, https://ecoobs.de/). The Batcorders were set to be active from between 21:00 and 23:00 on the evening one day until between 05:00 and 07:00 the next day, depending on day length (to maximize battery life-time), and recorded bat calls consecutively throughout this period. We deployed one Batcorder at MBRA1 (near the roost exit) and MMYS1 (in an adjacent tree) prior to the reproductive season (16th of May). In addition, we deployed one Batcorder at MMYS2 later in the field season (29th of June). The Batcorder data were collected regularly and transferred to a laptop, and the batteries were changed simultaneously.

3.2.2 Temperature, light and humidity at the social roosts throughout the season

For recording temperature, light and humidity we used HOBO loggers (Onset HOBO, https://www.onsetcomp.com/). I deployed a HOBO logger at MBRA1 and MMYS1 during the first week of the field season; next to the roost exit at both MBRA1 and MMYS1. The HOBOs were programmed to record temperature, light and humidity every five minutes throughout the field season. The HOBO-data were collected at the end of the field season, by transferring the logged environmental data to the laptop. While the HOBO at MBRA1 took recordings throughout the field season, the HOBO at MMYS1 stopped working 29th of June, probably due to water logging/condensation.

In addition, I deployed six iButtons (Maxim iButton, https://www.maximintegrated.com/en/app-notes/index.mvp/id/3892) to record temperature; two in front of the roost exits and four under the roof of the colonies, in total three loggers per on each of the roosts MBRA1 and MMYS1. Unfortunately, the iButtons proved to be unreliable. For example, they recorded temperatures ranging from 60 to 10 °C within an hour. Consequently, the data from the iButtons were not used.

3.2.3 Number of bats exiting the social roosts

I carried out exit counts – i.e. counting the number of individuals leaving the roost at night – at already known roosts (from the previous field season) and other sites where radio tagged bats (see 3.2.6 below) roosted during daytime. As a rule, the counting was done by counting the number of bats exiting the roost in intervals of five minutes, from 30 minutes before sunset until either there had been no activity for the last 15 minutes, or until two hours after sunset. All data were recorded on premade data sheets and transferred to digital spreadsheets the following day. For an overview of observed roost sites and number of bats emerging at each roost site, see Table 1 for *M. brandtii* roosts and Table 2 for *M. mystacinus* roosts. In addition, see Appendix Tables A1.1 and A1.2 for detailed information about all counts carried out for the *M. brandtii* roosts and *M. mystacinus* roosts, respectively.

I also considered using the exit count data from previous field season in my thesis (see Siljedal, 2018). However, the exit count data from 2017 were not directly comparable to the data which I collected in 2018; the data from 2017 included several other bat species and were partly carried out in a different part of the maternity season. The data from the previous year would only add one (*M. brandtii*) and two (*M. mystacinus*) evenings of exits counts to the dataset and were therefore not included in my analyses.

In addition to direct observations of bats by observers placed outside the roost sites, an endoscope (small camera on a flexible wire) was used to check for bats under the rooftiles and metal chimney cover at MBRA1, MMYS1 and MMYS2.

3.2.4 Number of bats passing through vegetation corridors

The bats' spatial emergence patterns (flight route) were observed and sketched during the exit counts, like it was done during the previous field season and described by Siljedal (2018). We used a combination of direct visual observation (due to high latitude and few clouds, summer nights were relatively bright) and hand-held bat detectors. Corridor counts – i.e. counting the number of individuals passing through a corridor at night – were carried out in candidate corridors identified by scouting in the area around the colonies and by inspection of orthophotos of the study area. Available observers distributed in candidate vegetation corridors, which could potentially be used by the bats. In contrast to the exit counts, the bats could pass the observers in two directions in the corridors, thus direction was also recorded. In addition to the direct observations, we also deployed automatic loggers (SongMeters, Wildlife Acoustics) in three different corridors to log bat echolocation calls consecutively through the season, but analysis of the SongMeter data are not included in this thesis.

3.2.5 Time of sunset/sunrise and average temperature in the study area

Data on the time of sunset and sunrise were obtained from http://yr.no Average temperature for Nittedal from the last 60 years was obtained from https://eklima.met.no.

3.2.6 Capturing bats, determining reproductive status and radio tracking

To find new roosts and to monitor the potential spatio-temporal dynamics of already known colonies, bats were captured, radio tagged and tracked. The bats were captured with a harp trap or with mist nets, and the bats were temporarily kept in cotton bags until handling and tagging (Eldegard et al., 2017, 2018). Reproductive status was estimated by looking at the females' bellies (pregnant) and nipples (lactating/postlactating) as explained in Arndt et al. (2018). Bats were tagged using BioTrack Pip4 or PicoPip radio tags (BioTrack, UK), which preferably did not exceed 5 % of the bat's body weight. See Kristiansen (2018) for details on the handling and tagging procedure. Manual tracking was done on foot with personnel following the bats using Sika receivers and Yagi antennae (BioTrack, UK), as described by Kristiansen (2018). By radio tracking individually tagged bats, we aimed to find previously unknown social roosts, and to document movements of individuals between roosts in the study area. Of animal welfare reasons, we took a break from the capturing and radio tagging after we caught our first pregnant bat on the 25th of June until 3rd of July, to avoid stressing the bats around the time when they were presumed to give birth.

3.3 Data preparation and analysis

All statistical analyses were done with the software RStudio version 3.4.3 if not stated otherwise (R Core Team, 2017). Before I carried out any statistical analyses, I explored the data following the recommended procedures in Ieno and Zuur (2015).

3.3.1 Bat activity at social roosts throughout the season

I extracted the data from the Batcorders using the computer program bcAdmin (Version 2.35 (1549)), bcAnalyze (Version 1.16 (305)) and batIdent (Version 1.03)) running the package "kernlab" from the randomForest library (Kristiansen, 2018). I then converted the datafiles into .csv files for further explorations in R. I used the dplyr, zoo, TTR, forecast, stats and MASS packages in R (Hyndman et al., 2019; R Core Team, 2017; Ryan & Ulrich, 2018; Ulrich, 2018; Venables & Ripley, 2002; Wickham et al., 2018; Zeileis & Grothendieck, 2005). I analyzed number of recordings over time by using time series

analysis following Srivastava (2015) and Shumway and Stoffer (2017) (see Appendix II – one component – for a detailed explanation). To test whether the number of recordings was significantly different over time I used generalized additive models (GAM) (with an ANOVA test). To determine whether the variation in number of bat recordings over time was correlated with variations in temperature, I used multiple time series analysis following Srivastava (2015) and Shumway and Stoffer (2017) (see Appendix II – Two components – for a detailed explanation). To test whether number of bat recordings and temperature co-varied throughout the observation period, I used GAM analysis (with an ANOVA test).

3.3.2 Temperature, light and humidity at the social roosts throughout the season

I extracted the data from the HOBO loggers using HOBOware (https://www.onsetcomp.com/hoboware-free-download). I then converted the datafiles into .txt files for further explorations in R. I used the dplyr, zoo, TTR, forecast, stats and MASS packages in R (Hyndman et al., 2019; R Core Team, 2017; Ryan & Ulrich, 2018; Ulrich, 2018; Wickham et al., 2018; Zeileis & Grothendieck, 2005). Since the logger at MMYS1 stopped working from 29th of June, I compared the logged temperatures at the two sites for the period both loggers were working. I compared graphical plots of time versus temperature from the two loggers, and also consulted a statistician. The graphs looked very similar. Thus to avoid interpolating errors (Lange, 2005), the recordings done at MBRA1 could be used for MMYS1 as well (see Figure A1.1, A1.2 and A1.3 in Appendix I for the comparison of the plots of time versus; temperature, light and humidity). MMYS2 did not have any logger that logged environmental conditions. Consequently, the input HOBO data used in the analyses were the same for MBRA1, MMYS1 and MMYS2. I calculated nightly average temperature/light/humidity, where one night is from 12:00 one day to 12:00 the next day. In addition, I extracted minimum and maximum temperature per night because this could potentially be more important than the average temperatures for bat activity and time of emergence. I analyzed the possible relationship between time of first emergence and the amount of light/humidity by using

a Spearman's correlation test at MBRA1 and MMYS1. Due to the low sample size, I pooled the observations from the two species (roosts).

3.3.3 Number of bats exiting the social roosts

I obtained the data by transcribing the handwritten datasheets into .csv files for further explorations in R. I used the dplyr, zoo, TTR, forecast, stats and MASS package in R (Hyndman et al., 2019; R Core Team, 2017; Ulrich, 2018; Venables & Ripley, 2002; Wickham et al., 2018; Zeileis & Grothendieck, 2005). I analyzed number of bats exiting the roosts by using time series analysis following Srivastava (2015) and Shumway and Stoffer (2017). I analyzed number of bats exiting the roosts in relation to temperature by using multiple time series analysis following Srivastava (2015) and Shumway and Stoffer (2017). Due to the low sample size, it was not possible to run a GAM analysis.

3.3.4 Number of bats passing through vegetation corridors

I obtained the data by transcribing the handwritten datasheets into .csv files for further explorations in R. I tested whether the usage of the different corridors was significantly different by using a multinomial test with a Monte Carlo permutations approach. I analyzed if the number of bats passing through a vegetation corridor varied throughout the observation period by using time series analysis following Srivastava (2015) and Shumway and Stoffer (2017).

3.3.5 Weather and climate conditions

I obtained the data from http://yr.no/ and https://eklima.met.no. Then I converted the data into .txt files for further explorations in R. I used the dplyr package in R (Wickham et al., 2018). The data consisted of daily average temperatures in Nittedal municipality. I analyzed the fluctuations in average temperature and field temperature over time by using multiple time series analysis following Srivastava (2015) and Shumway and Stoffer (2017).

3.4 Permits

We collected permits for handling and radio tagging bats prior to the field season. The Norwegian Environmental Agency (Miljødirektoratet) granted us capturing and handling permission, the Norwegian Food Safety Authority (Mattilsynet) granted us the permission to radio tag the bats, and the Norwegian Communications Authority (Nasjonal kommunikasjonsmyndighet) granted us the permission for using the 142 MHz band for radio tracking. All staff members that were in direct contact with the bats were provided with rabies vaccines (Eldegard et al., 2018).

4. Results

4.1 Bat activity at social colonies throughout the season

The number of recordings of bat calls per night varied throughout the season, with more activity in June (average of 114 calls per night) than in August (average of 47 calls per night) (Figure 2). Variation in number of recordings throughout the season was confirmed by the GAM analysis ($F_{7,87}$=5.6 with p<0.01 for MBRA1 and $F_{6,92}$=4.6 with p<0.01 for MMYS1). For the total observation period, MBRA1 had a higher average of number of calls than MMYS1 and MMYS2 (average of 99±126 (s.d.), 56±60 (s.d.) and 23±34 (s.d.) numbers of calls per night, respectively), and a higher number of activity peaks.

For both MBRA1, MMYS1 and MMYS2, bat activity was associated with temperature and date for, but the influence of temperature on bat activity depended on date (GAM; MBRA1: temperature × date: χ^2_8= 2677.1, p<0.001, temperature: χ^2_1= 20.4, p<0.001; date: χ^2_1= 2.2 p=0.14; deviance explained=62%, MMYS1: temperature × date: χ^2_2= 2827.6, p<0.001; temperature: χ^2_4= 31.5, p<0.001; date: χ^2_6= 31.8, p<0.001; deviance explained= 49%, MMYS2: temperature × date: GAM: χ^2_5=1453.1, p<0.001; temperature: GAM: χ^2_1= 17.0, p<0.001; date: χ^2_1= 5.5, p<0.05; deviance explained=71%; Figure 3-5).

Due to the significance of the temperature × date interactions, I did separate GAM analyses on temperature and date to see if bat activity was associated with either alone. Bat activity was associated with date (MBRA1: χ^2_8= 127.3, p<0.001, deviance explained=64%; MMYS1: χ^2_6= 39.2, p<0.001, deviance explained=38%; MMYS2: χ^2_4= 61.6, p<0.001, deviance explained=63%). Bat activity was also associated with temperature for three roosts, based on the deviance explained values, temperature explained less of the total variation in the number of recordings than date (MBRA1: χ^2_1= 11.7, p<0.001, deviance explained=11%; MMYS1: χ^2_3= 11.2, p<0.05, deviance explained=15%; MMYS2: χ^2_3= 18.6, p<0.01, deviance explained=30%).

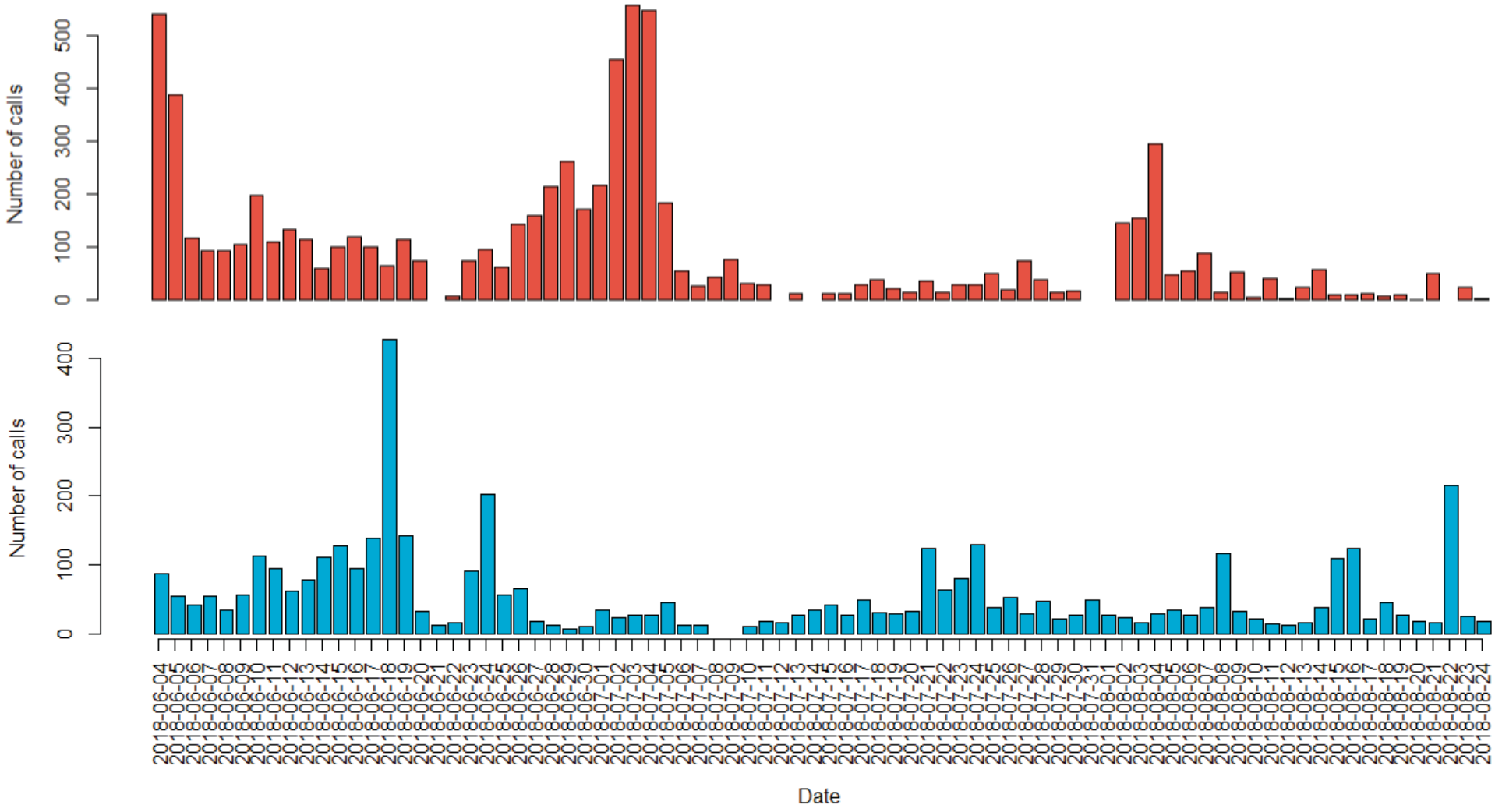

Figure 2: Number of bat calls recorded per night at; upper: M. brandtii roost MBRA1, lower: M. mystacinus roost MMYS1. The Batcorders were set to be active from between 21:00 and 23:00 on the evening one day until between 05:00 and 07:00 the next day, depending on day length. Note the difference in range of the y-axis.

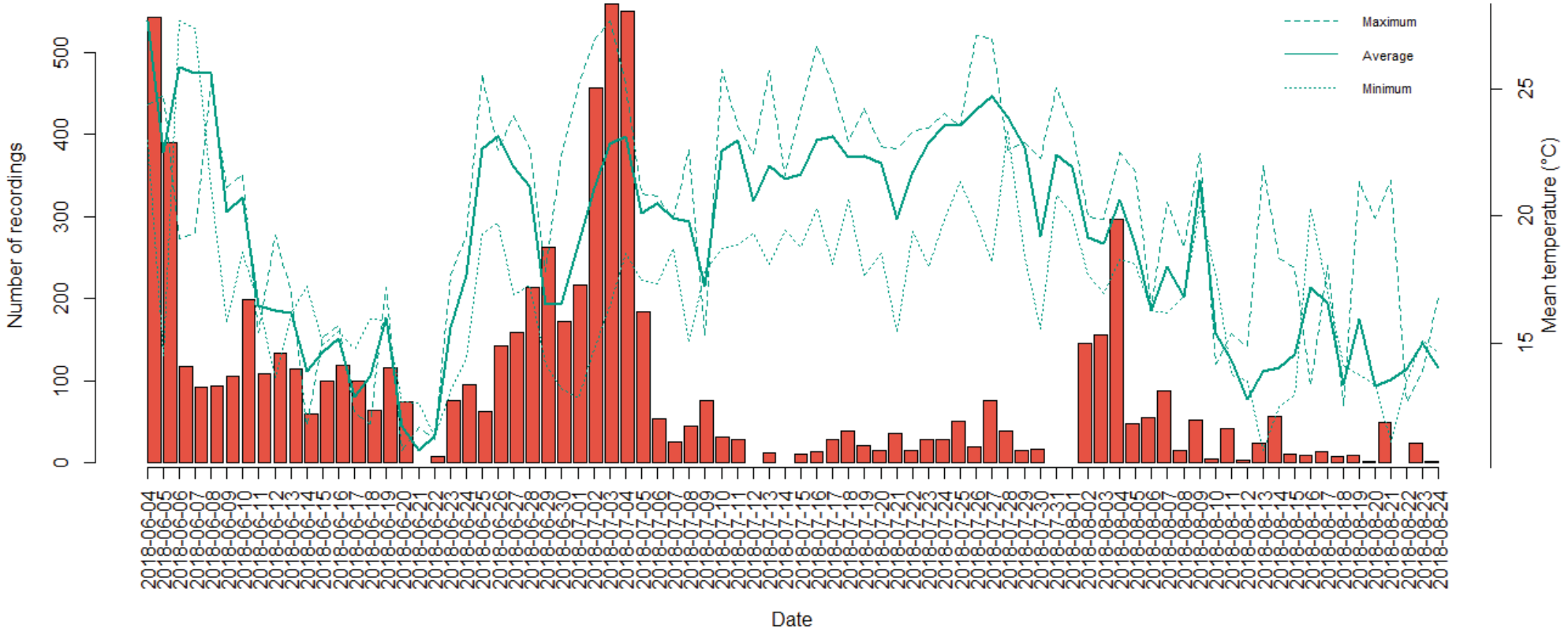

Figure 3: Number of bat calls recorded per night at the M. brandtii roost MBRA1 and temperature measured at the roost exit. Solid line indicates mean temperature per night, dashed line indicates maximum temperature per night and dotted line indicates minimum temperature per night. The Batcorders were set to be active from between 21:00 and 23:00 on the evening one day until between 05:00 and 07:00 the next day, depending on day length. The Batcorder was active in the period between 4th of June and 24th of August.

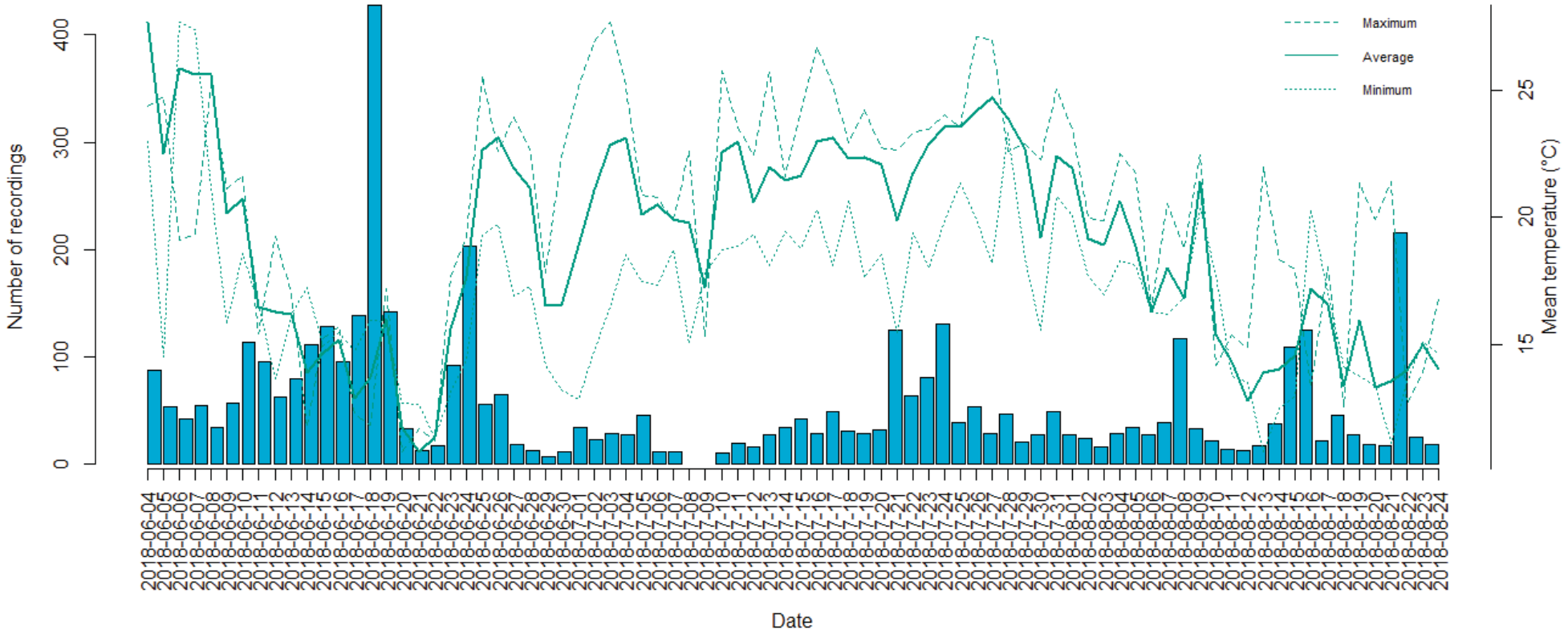

Figure 4: Number of bat calls recorder per night at MMYS1 and temperature measured at the roost exit of the MBRA1 roost. Solid line indicates mean temperature per night, dashed line indicates maximum temperature per night and dotted line indicates minimum temperature per night. The Batcorders were set to be active from between 21:00 and 23:00 on the evening one day until between 05:00 and 07:00 the next day, depending on day length. The Batcorder was active in the period between 4th of June and 24th of August.

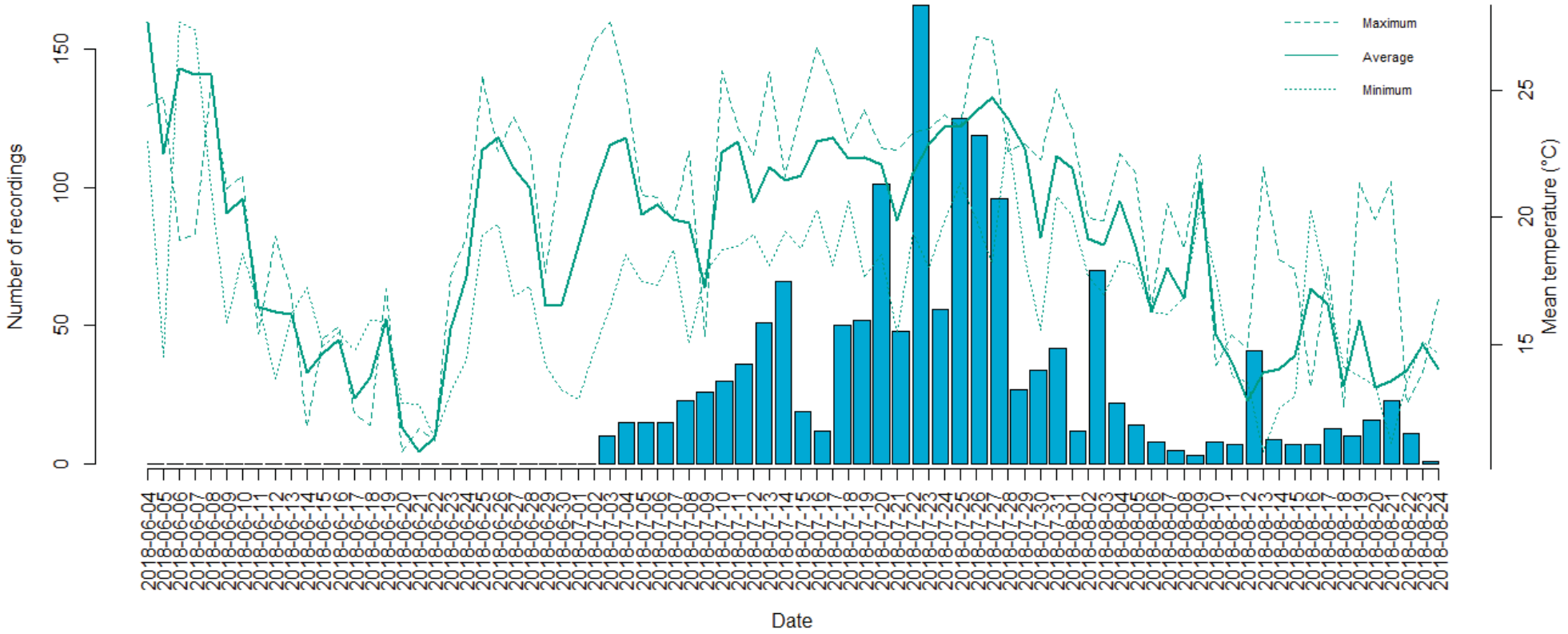

Figure 5: Number of bat calls recorder per night at MMYS2 and temperature measured at the roost exit of the MBRA1 roost. Solid line indicates mean temperature per night, dashed line indicates maximum temperature per night and dotted line indicates minimum temperature per night. The Batcorders were set to be active from between 21:00 and 23:00 on the evening one day until between 05:00 and 07:00 the next day, depending on day length. The Batcorder was active in the period between 2nd of July and 24th of August.

4.2 Number of bats exiting and temperature, light and humidity at the colonies

Overall, I counted a higher number of exiting bats at MBRA1 (49 at the most) than at MMYS1 (35 at the most). Somewhere between 2nd and 11th of July for MBRA1, and 19th and 29th of June for MMYS1 the bats stopped exiting from their primary roosts, i.e. no bats were observed exiting from these roost during the exit count sessions, and the bats appeared to have moved to other roosts (see Tables A1.1 and A1.2). These observations fit with the marked drop in recorded bat calls, as recorded by automatic loggers, after 4th of July at MBRA1 (see Figure 3), and after 25th of June at MMYS1 (see Figure 4).

During the field season we discovered previously unknown roost sites, which the bats were using in addition to the two first roosts. The additional roost sites were found by tracking radio-tagged individuals. For *M. brandtii* the roosts were MBRA2, MBRA3, MBRA4, and MBRA5 (Table 1, Figure 1) and for *M. mystacinus* the roosts were MMYS2, MMYS3 and MMYS4 (Table 2, Figure 1). However, we cannot say for sure that we found all the roosts utilized by the colonies. All the exit counts for the different roosts are listed in Table A1.1 for *M. brandtii* and Table A1.2 for *M. mystacinus*.

Table 1: Exit count information for the M. brandtii roosts, with roost name and type, maximum number of counted bats, and the number of evenings exit counts were carried out at each site.

Roost name	Type	Bats counted (maximum)	Days counted
MBRA1	House	49	8
MBRA2	House	5	4
MBRA3	Shed	1	2
MBRA4	House	34	6
MBRA5	House	16	1

Table 2: Exit count information for M. mystacinus roosts, with roost name and type, maximum number of counted bats, and the number of evenings exit counts were carried out at each site.

Roost name	Type	Bats counted (maximum)	Days counted
MMYS1	House	35	9
MMYS2	House	24	3
MMYS3	House	23	6
MMYS4	House	5	1

Figure 6 shows number of bats counted at MBRA1 and MMYS1 at different dates throughout the season. There was more activity early in the season, and there was no activity after 11th of July at MBRA1 and 29th of June at MMYS1. These observations fit with the marked drop in recorded bat calls, as recorded by automatic loggers, after 4th of July at MBRA1 (see Figure 3) and after 25th of June at MMYS1 (see Figure 4). On average, I counted a higher number of bats at MBRA1 (16.2 ± 22.2 (s.d.)) than at MMYS1 (11.1 ±14.9 (s.d.)).

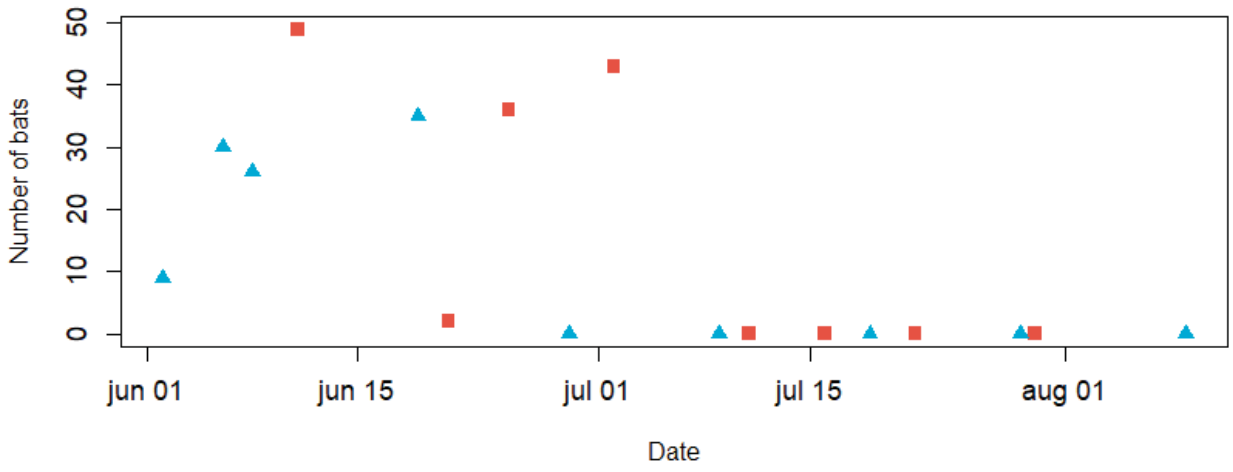

Figure 6: Number of bats observed exiting the roost at night at different dates at M. brandtii roost MBRA1 (red squares) and M. mystacinus roost MMYS1 (blue triangles).

Figure 7 shows the number of bats counted and temperature throughout the season at MBRA1. In the first part of the maternity season, there appeared to be a positive association between temperature and number of *M. brandtii* bats counted; the higher the temperature, the more bats exited (time series analysis; Figure 7). On the 21st of June the average temperature was 10.8°C (the lowest temperature measured during the field season), and only two bats were observed. In contrast, on the 2nd of July, the average temperature was 21.0 °C and 43 bats were counted.

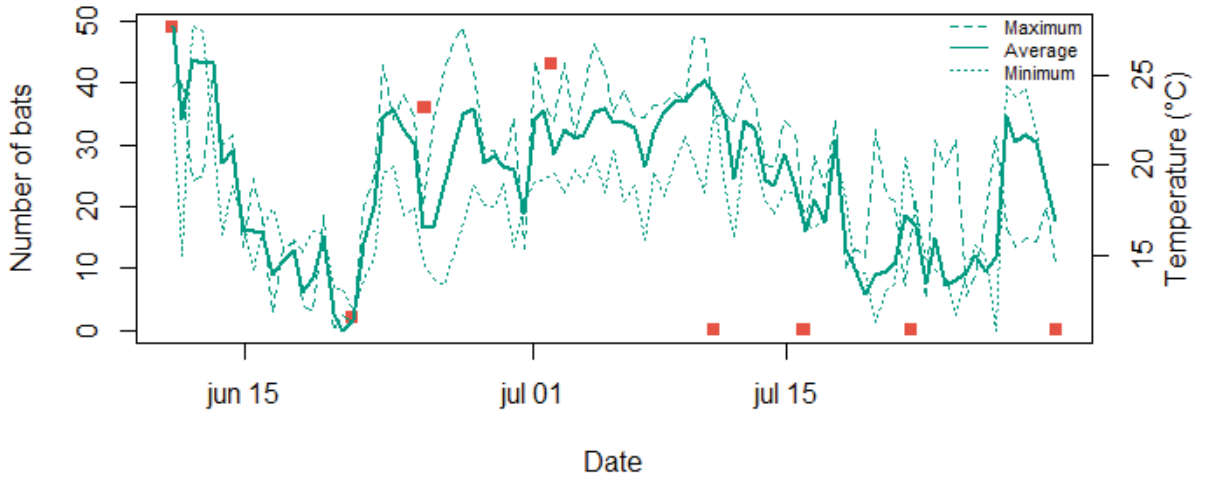

Figure 7: Number of bats observed exiting the roost at different dates at the M. brandtii roost MBRA1 (red squares) and temperature at the roost exit. Solid line indicates mean temperature per night, dashed line indicates maximum temperature per night and dotted line indicates minimum temperature per night. A night is defined as 12:00 one day until 12:00 the next day.

Figure 8 shows number of bats counted at MMYS1 at different dates throughout the season and temperature at the roost exit. According to the time series analysis, there was no clear association between number of bats counted and temperature. However, the time series analysis indicated that bat activity and temperature were more closely associated in the beginning of the season than later in the season.

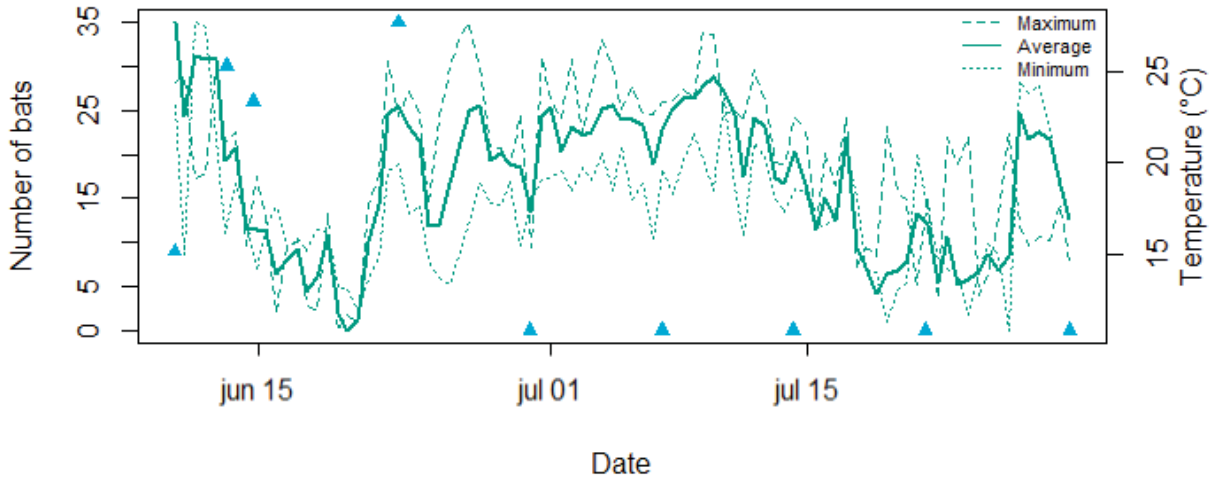

Figure 8: Number of bats observed exiting the roost at different dates at the M. mystacinus roost MMYS1 (blue triangles) and temperature at the roost exit. Solid line indicates mean temperature per night, dashed line indicates maximum temperature per night and dotted line indicates minimum temperature per night. A night is defined as 12:00 one day until 12:00 the next day.

I found no association between amount of light (photosynthetic activity) during a specific date and time of first emergence (first bat leaving the roost in the evening) (Spearman correlation test: r_s=0.095, N=8, p=0.84; Figure 9).

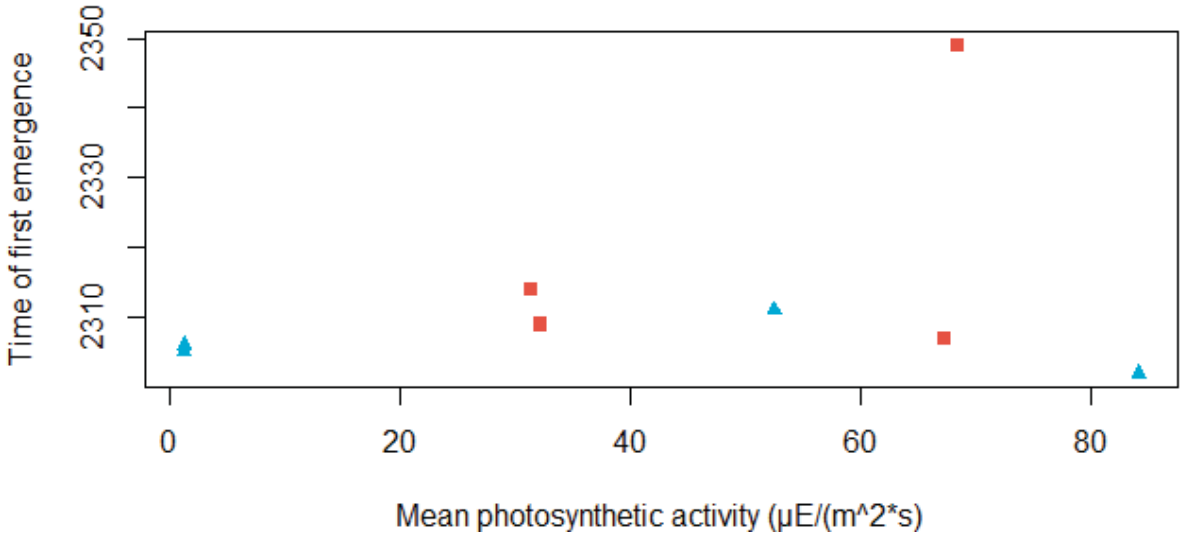

Figure 9: Time of first emergence with mean photosynthetic activity at MBRA1 (red squares) and MMYS1 (blue triangles).

I found no association between humidity a specific date and time of first emergence (first bat leaving the roost in the evening) (Spearman correlation test: r_s=0.26, N=8, p=0.53; Figure 10).

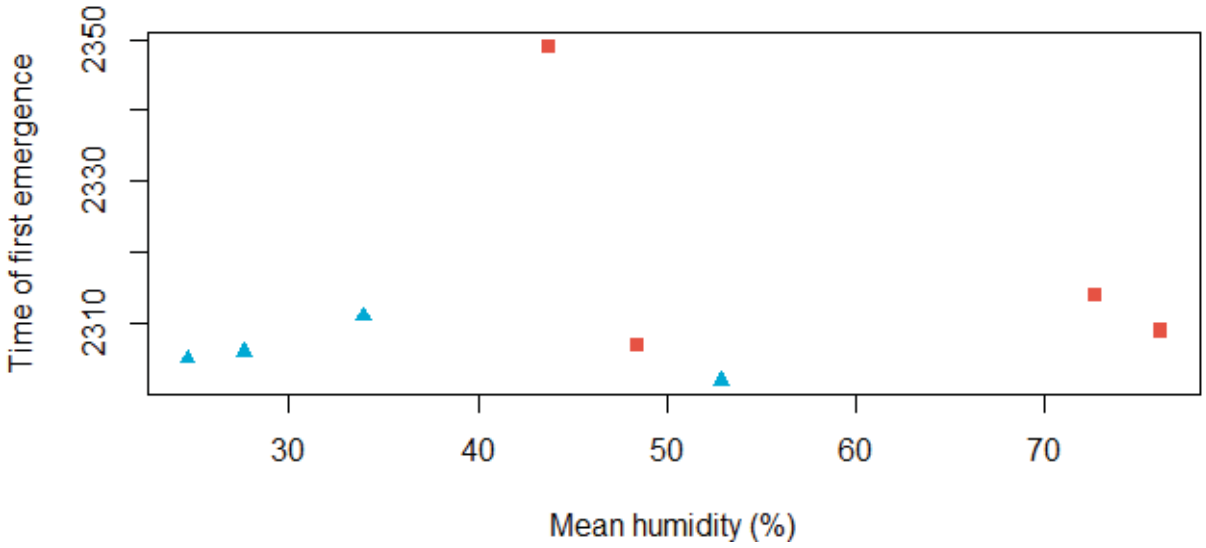

Figure 10: Time of first emergence with mean humidity at MBRA1 (red squares) and MMYS1 (blue triangles).

4.3 Trapped bats and their reproductive status

Table 3 shows the different individuals we tagged with radio transmitters, their reproductive status when they were trapped, how many roosts we tracked them to and how many days we tracked them. We radio tagged 10 *M. brandtii* and 12 *M. mystacinus* females during the 2018 field season.

Table 3: Radio tagged adult females of M. brandtii and M. mystacinus in 2018. Tagging date, reproductive status, number of different roosts recorded used by each individual and how many days the individual was tracked.

Date	Species	Individual	Reproductive status	Number of roosts	Days radio tracked
8.6.18	*M. brandtii*	MBRA_I1	Non- reproductive	1	3 *
13.6.18	*M. brandtii*	MBRA_I2	Non-reproductive	2	6 **
14.6.18	*M. brandtii*	MBRA_I3	Non-reproductive	1	7 (13)
5.7.18	*M. brandtii*	MBRA_I4	Lactating	3	8
5.7.18	*M. brandtii*	MBRA_I5	Lactating	2	8
20.7.18	*M. brandtii*	MBRA_I6	Non-reproductive	3	11
23.7.18	*M. brandtii*	MBRA_I7	Post-lactating	2	8
4.8.18	*M. brandtii*	MBRA_I8	Post-lactating	1	16
4.8.18	*M. brandtii*	MBRA_I9	Post-lactating	3	16
14.8.18	*M. brandtii*	MBRA_I10	Non-reproductive	2	11
5.6.18	*M. mystacinus*	MMYS_I1	Non-reproductive	2	1 **
5.6.18	*M. mystacinus*	MMYS_I2	Non-reproductive	1	6 **
11.6.18	*M. mystacinus*	MMYS_I3	Non-reproductive	1	3 ***
12.6.18	*M. mystacinus*	MMYS_I4	Non-reproductive	2	4 **
25.6.18	*M. mystacinus*	MMYS_I5	Non-reproductive	3	11 **
25.6.18	*M. mystacinus*	MMYS_I6	Pregnant	2	5 **
11.7.18	*M. mystacinus*	MMYS_I7	Non-reproductive	3	9
11.7.18	*M. mystacinus*	MMYS_I8	Post-lactating	2	4 **
16.7.18	*M. mystacinus*	MMYS_I9	Post-lactating	1	3**
21.7.18	*M. mystacinus*	MMYS_I10	Post-lactating	3	8 **
20.8.18	*M. mystacinus*	MMYS_I11	Post-lactating	1	7 ****
20.8.18	*M. mystacinus*	MMYS_I12	Post-lactating	2	7 ****

* Disappeared (lost contact with the radio transmitter), ** Lost radio transmitter before the battery was dead, *** Radio transmitter failed, **** Data collection was done before the radio transmitter stopped working

4.4 Number of bats passing through vegetation corridors

We found three main exits at MBRA1, and all bats flew in the same direction when leaving the roost in the evening (Figure 11). In contrast, we found two main exits at MMYS1 where the bats flew in two different directions on their way to their hunting grounds (Figure 12). The spatial configuration of the roosts and associated vegetation corridors are shown in Figure 13 (*M. brandtii*) and 14 (*M. mystacinus*).

Figure 11: The photo illustrates where the bats exited from, how many bats emerged from the different exits, and what direction they flew in after exiting at MBRA1. Counting of exiting bats carried out on the 11th of June. Photo: Joakim Siljedal.

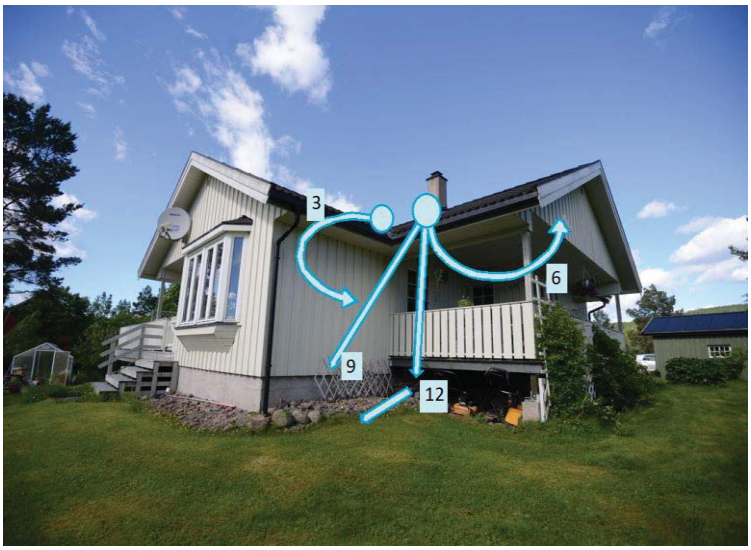

Figure 12: The photo illustrates where the bats exited from, how many bats emerged from the different exits, and what direction they flew in after exiting at MMYS1. Counting of exiting bats carried out on the 6th of June. Photo: Joakim Siljedal.

We investigated seven candidate movement corridors near the *M. brandtii* roosts. Five of the seven corridors were located in forests or forest patches (i.e., an open "funnel" between trees in the forest). Four of these five corridors were also in close vicinity of cropland (i.e., a row of trees/bushes on the cropland). One corridor was in a garden (i.e., a row of trees in the garden). The highest number of bats observed in a single corridor during one night was observed in the "pure" forest corridor (11 bats; Table 4). In addition, we counted bats in three other corridors (two of them were forest patches near cropland and one was a garden (Table 4).

Table 4: Corridor count information for M. brandtii corridors. We defined a corridor as a place that lied in close vicinity from a roost with a certain amount of vegetation or other type of shelter, that could potentially be used for movement to and from the roost and to and from hunting sites. The table shows corridor name and type, coordinates of geographic location, habitat type, maximum number of bats counted, and number of nights when passing bats were counted in each corridor.

Corridor	UTM32V_E, UTM32_N	Habitat	Bats counted (max)	Number of nights
MBRA_C1	605641, 6658286	Cropland near road	0	2
MBRA_C2	605952, 6659492	Forest patch, near arable	3	1
MBRA_C3	606169, 6660053	Forest patch, near arable	0	1
MBRA_C4	605927, 6660068	Forest	11	2
MBRA_C5	606310, 6660068	Garden	2	1
MBRA_C6	696239, 6660059	Forest patch, near arable	2	1
MBRA_C7	606098, 6659984	Forest patch, near arable	0	1

We explored seven candidate corridors near the *M. mystacinus* roosts. Five of the seven corridors were found in croplands. Two of these four corridors were also in close vicinity of forest patches. One corridor was in a garden, in addition to one in a creek. We counted bats in five of the seven corridors, where the maximum number of bats was 37 (in corridor transecting cropland), but also a forest patch corridor and the creek corridor had many bats passing by (36 and 23 respectively) (Table 5).

Table 5: Corridor count information for M. mystacinus corridors. We defined a corridor as a place that lied in close vicinity from a roost with a certain amount of vegetation or other type of shelter, that could potentially be used for movement to and from the roost and to and from hunting sites. The table shows corridor name and type, coordinates of geographic location, habitat type maximum number of bats counted, and number of nights when passing bats were counted in each corridor.

Corridor	UTM32V_E, UTM32_N	Habitat	Bats counted (max)	Number of nights
MMYS_C1	605465, 6658971	Cropland	4	1
MMYS_C2	605638, 6658376	Cropland	37	1*
MMYS_C3	606354, 6659972	Creek near forest	23	1*
MMYS_C4	605073, 6658710	Garden	3	1
MMYS_C5	605073, 6658618	Cropland	0	1
MMYS_C6	605024, 6658846	Forest patch, near cropland	36	5
MMYS_C7	605376, 6658795	Forest patch, near cropland	0	1

*Since the number of bats counted was high, we placed out an automatic logger (SongMeter, Wildlife Acoustics) in the corridor and prioritized to use the personnel in other possible corridors and for other tasks.

For *M. brandtii* we observed bats flying in the following corridors: MBRA_C2, MBRA_C4 and MBRA_C6 (Figure 13). For *M. mystacinus* we found bats flying in the following corridors: MMYS_C1, MMYS_C2, MMYS_C3, MMYS_C4 and MMYS_C6 (Figure 14). MMYS_C2, MMYS_C3 and MMYS_C6 had significantly more bats flying in them than the other corridors (multinomial Monte Carlo permutation test; $p<0.01$). According to the time series analysis, we observed a clear spatio-temporal displacement − with most bats exiting the roosts early and thereafter passing through the corridors later in the same night − at four of the nine nights of observation; that is 2nd and 11th of July for *M. brandtii* (Panel B and C in Figure 15), and 19th of June and 9th of July for *M. mystacinus* (Panel D and F in Figure 15).

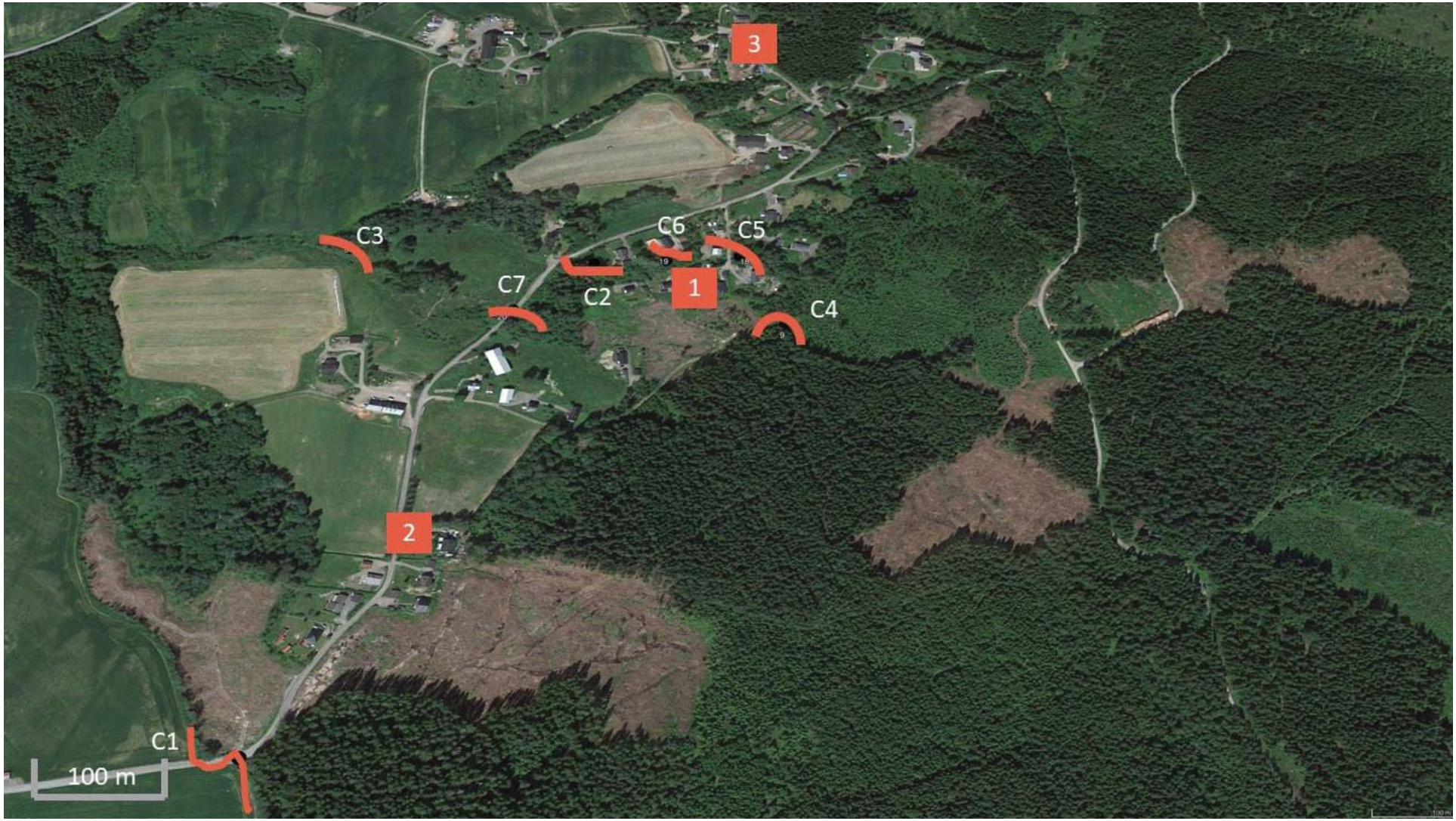

Figure 13: Ortophoto showing the locations of the M. brandtii corridors. Corridors are shown as red lines and roosts are shown as red squares. 1 = MBRA1 (primary roost), 2 = MBRA2, 3 = MBRA4, C1 = MBRA_C1, C2 = MBRA_C2, C3= MBRA_C3, C4 = MBRA_C4, C5 = MBRA_C5, C6 = MBRA_C6, C7 = MBRA_C7. Orthophoto was downloaded from Google Earth.

Figure 14: Ortophoto showing the locations of the M. mystacinus corridors. Corridors are shown as blue lines and roosts are shown as blue triangles. 1 = MMYS1 (primary colony), 2 = MMYS2, 3 = MMYS3, C1 = MMYS_C1, C2 = MMYS_C2, C3= MMYS_C3, C4 = MMYS_C4, C5 = MMYS_C5, C6 = MMYS_C6, C7 = MMYS_C7. Orthophoto was downloaded from Google Earth.

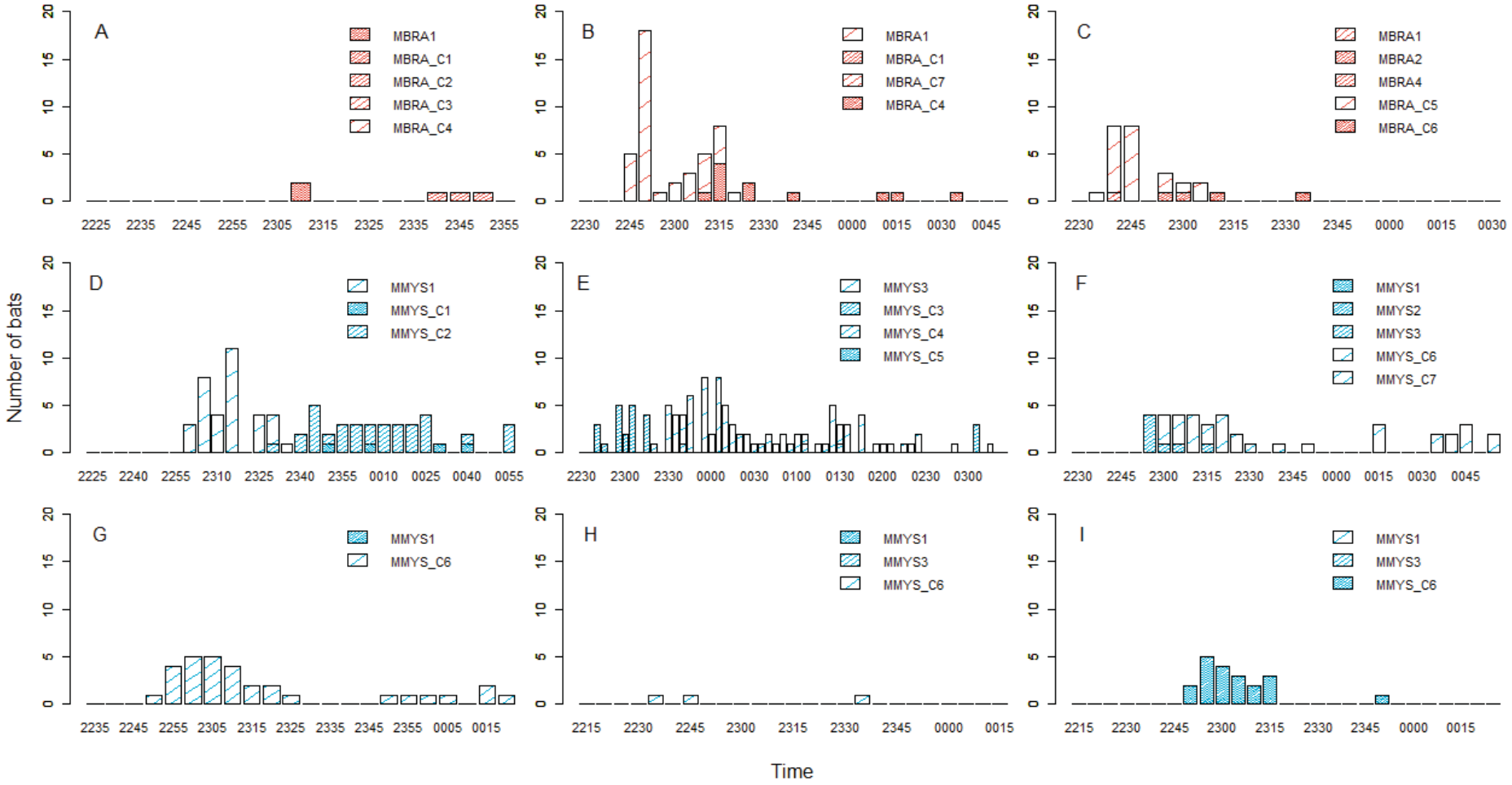

Figure 15: Roost and corridor counts (number of bats observed) carried out at M. brandtii roosts (MBRA1, MBRA2, MBRA4) and corridors (MBRA_C1-C7) (red) and M. mystacinus roosts (MMYS1-3) and corridors (MMYS_C1-C7) (blue). Each panel represent one night where two or more observers were placed out at roosts or in corridors, counting the number of animals flying in a certain direction. The dates for the counts: A = 21.06.2018, B = 02.07.2018, C = 11.07.2018, D = 19.06.2018, E = 23.06.2018, F = 09.07.2018, G = 19.07.2018, H = 29.07.2018, I = 09.08.2018. Note that the bar fillings are not consistent, combinations are selected for maximum visibility; legend shows all locations with observers counting bats; if the counting yielded 0 bats, no bar is visible at a given time; the time scale on the x-axis, and the width of the bars are not consistent for the different panels.

4.5 Weather and climate conditions

The summer of 2018 was generally warmer than the average for the period 1961-1990, with only two shorter periods being colder (Figure 16). This observation was also confirmed by the time series analysis.

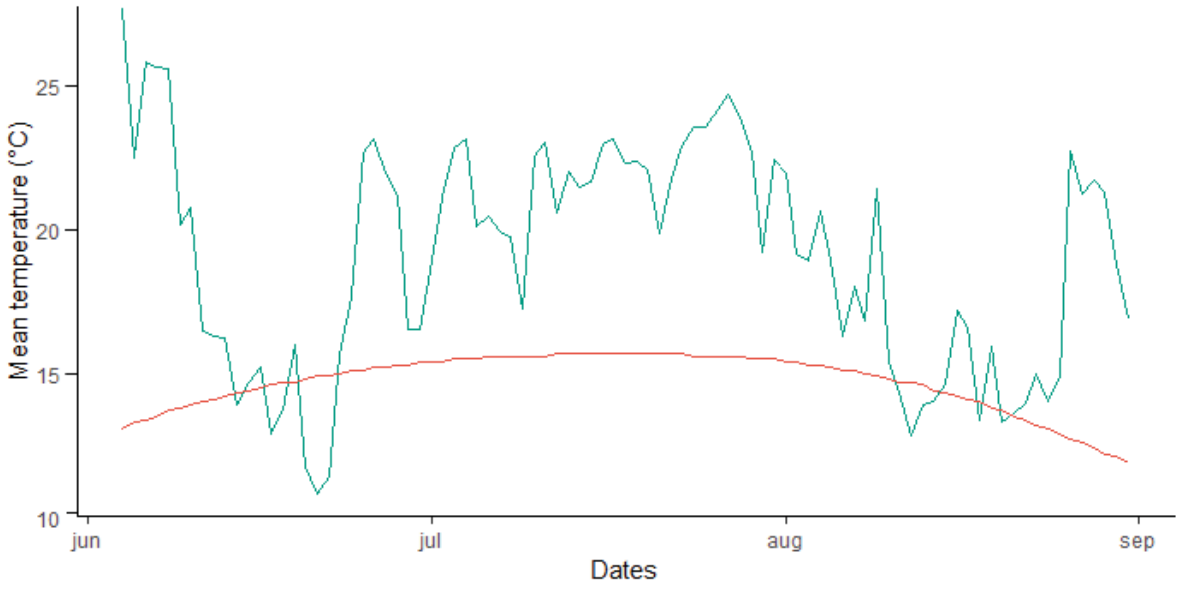

Figure 16: Average temperature for Nittedal in the period 1961-1990 (red line), and temperatures measured at the MBRA1 roost exit (green line).

For the most part, bats at both the MBRA1 and MMYS1 started making echo localization calls after sunset (average of 42 ± 49 (s.d.), 34 ± 62 (s.d.) minutes after sunset, respectively; Figure 17). At three separate occasions bats at MMYS1 made calls much earlier than sunset (16th, 17th and 22nd of May). Other than that, only in a short period between late May and early to mid-June, did the bats make calls before sunset. From mid-June and throughout the season, none of the colonies had recordings of echo localization calls before sunset, except from 3rd of July at MBRA1. These outliers were also detected in the time series analysis. In addition, bats at MBRA1 made their first calls very late on the 12th of August. Recall, however, there were no bats exiting the roosts after early to mid-June for neither roosts, the activity registered must be from bats passing by the roosts.

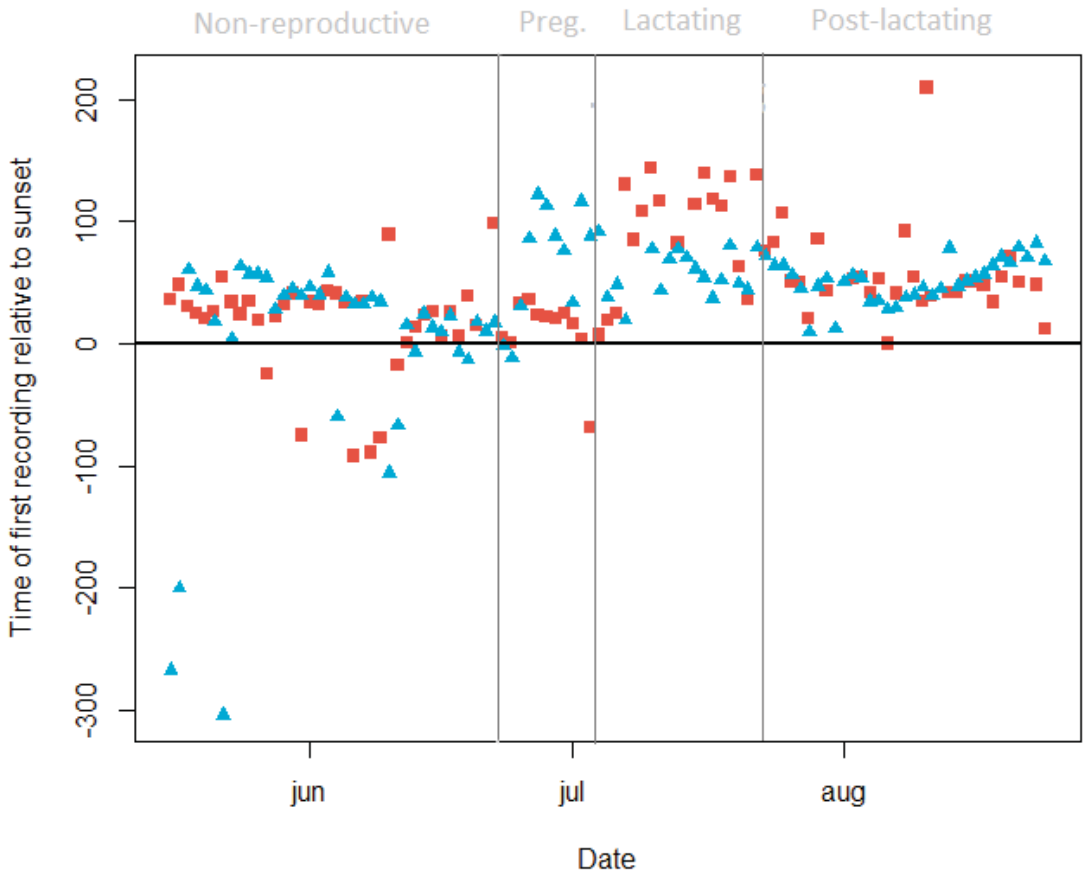

Figure 17: Time of first recording of bat echolocation calls on the Batcorders relative to sunset throughout the season at the MBRA1 roost (red squares) and the MMYS1 roost (blue triangles). Sunset equals value 0 in the y-axis, before sunset equals negative numbers and after sunset equals positive numbers. The different stages of the reproductive season (non-reproductive, pregnant, lactating, post-lactating) are based on information from the captured bats showing visible signs of a given reproductive stadium (see Table A3.1 (M. brandtii) and Table A3.2 (M. mystacinus) in Appendix III).

5. Discussion

I found strong evidence that time of emergence varied throughout the season for both *M. brandtii* and *M. mystacinus*. I also found that time of emergence was influenced by temperature, but not by light and humidity. The neighboring roosts of *M. brandtii* (MBRA1) and *M. mystacinus* (MMYS1) both exhibited higher activity when the temperature was high in the beginning of the season, whereas temperature-bat activity patterns differed more between the two roosts later in the season. Bats from the *M. brandtii* colony appeared to utilize forest corridors more than bats from the *M. mystacinus* colony, whereas the opposite was true for cropland corridors.

5.1 Time of roost emergence

I found that on average, the time of first recording was 42 after sunset for MBRA1, whereas Häusler (2003a) found that *M. brandtii* exited between 4 and 23 minutes after sunset. I found that on average, the time of first recording was 34 minutes after sunset for MMYS1, which is quite similar to the findings of Häusler (2003b) who found that *M. mystacinus* exited between 15 and 30 minutes after sunset. However, it seemed like the bats exited earlier in the less energy consuming periods (non-reproductive) than in the more energy consuming periods (pregnant and lactation). This somewhat unexpected finding could have several explanations. On one hand *M. daubentonii* has been found to emerge 15-30 minutes after sunset, probably due to the activity peak of their main prey Diptera (Rydell et al., 1996). In comparison Rydell et al. (1996) found that the slightly larger bat brown long-eared bat *Plecotus auritus* which primarily feed on moths, did not emerge until an hour after sunset (Rydell et al., 1996). According to Rydell et al. (1996), peak activity time of the studied moths was later than that of the studied Dipteras. Furthermore, *M. daubentonii* was more limited by the risk of predation (Rydell et al., 1996). Since *M. brandtii* and *M. mystacinus* are almost the same size as *M. daubentonii,* which is a common species in our study area, and the three species have at least partly overlapping diets (Dietz & Kiefer, 2016a), it would not be surprising if their roost emerging ecology was similar as well. On the other hand, my observations contrast those of Arndt et al. (2018), who found that Indiana bat *M. sodalis* emerged earlier during the more energy consuming

periods of the breeding season (that is lactation) in Indianapolis (see also Frick et al., 2012). However, Nittedal is at latitude 60°N while Indianapolis is at latitude 39°N, and the sun will stay closer to the horizon for a longer period of time in Nittedal, yielding a longer lasting twilight period (Ask an astronomer, 2019). Thus, the difference in latitude, and thus the period of light at twilight, might explain these seemingly contradicting findings of early/late emergence in energy consuming periods.

Another potential explanation for why I did not observe an earlier emergence in the more energy consuming periods could be random variation due to the low sample size. With only four datapoints (exit counts) per roost, even small variations in number of observed bats could change the trend line. Several factors contributed to the low sample size, including observers being occupied with other data collection and avoiding possible conflicts with landowners. With such a small sample size, it was hard to detect a general emergence pattern with respect to amount of light.

Another explanation could be that during the early season (June) the nights are at their shortest, hence the bats need to exit before sunset to ensure the food consumption they need. However, I cannot say for sure that time of first recording on the automatic logger corresponds to time of first emergence of bats from the roosts. Since we did not count any bats leaving MBRA1 and MMYS1 after 9th and 11th of July, we know for sure that the roosts were empty. Therefore, the recordings might be from bats passing by or hunting.

5.2 Time of roost emergence and environmental conditions

I found that both date and temperature influenced on number of recordings, based on the GAM analysis. However, it seemed that date – that is time in season – was the most important factor. Temperature on the other hand seemed to only modify how time in season influenced number of recordings. Ecologically speaking time in season seems to be the single most important factor to determine number of recordings. However, one cannot exclude environmental factors as they clearly contribute to determine number of recordings, but they seem to be of lesser importance than time in season.

I found a relationship between number of bats exiting the roost and temperature at MBRA1 and MMYS1, as well as between bat activity – as recorded with automatic logging of echolocation calls – and temperature. As an example, only two bats emerged from the MBRA1 when average temperature was 10,8°C degrees on 21st of June, compared to 43 bats exiting at 21,0°C 2nd of July. An explanation for this can be that the insect activity is lower when the temperature is lower, since insects are ectothermic and their body temperature are greatly affected by the outdoor temperature (Mellanby, 1939). Thus, when it is cold outside, the insect abundance will be lower and the feeding effort of the bats might be high relative to the prey consumption. This would explain why fewer bats exited the roosts when the temperature was lower.

There were no bats exiting MBRA1 or MMYS1 after 11th and 9th of July, respectively. In addition, I observed less insects the last weeks of the field season than in the first. Although higher daily temperature is often associated higher insect activity, previous studies have also found that if the season in total is warmer and drier than normal, the total insect activity can decrease (Frick et al., 2012). This fits well with my observations. Also, water availability may be limited, which in turn can lead to physiological stress for the bats (Frick et al., 2012). Frick et al. (2012) observed that *T. brasiliensis* exited as early as 1.5 hours before sunset during dry summers, probably to search for water. Given that the summer of 2018 was unusually dry and warm, it could be that the bats in our study area did the same.

As the temperature increased during the summer, we decided to measure the temperature inside the roosts with iButtons, to get more information about potential relationships between e.g. temperature and offspring survival. The iButtons were small enough to be placed under the roof tiles where I suspected that the roosts were. I also placed iButtons on the loft at MMYS1. Unfortunately, the iButtons proved to be unreliable. To compensate for this loss of information, we used an endoscope to check for bats under the roof tiles and chimney fitting. We wanted to check if the reason why there were no bats exiting the roosts, and why very few young bats were caught in the

mist nets, was that they had died (as a consequence of high temperatures). However, we did not detect any bats by using the endoscope. Therefore, I think it is more likely that the bats had moved, which we also revealed by tracking some of the radio tagged bats, e.g. MBRA_I4. Nevertheless, we cannot completely rule out the possibility that the bats were roosting in other parts of the roof that we did not reach with the endoscope. Because I was not able to measure the temperature inside the roosts, I can only relate the sudden disappearance of individuals from certain roosts to the outdoor temperature.

According to our results, time of first emergence was not affected by amount of light or humidity. I saw that bats at the MMYS1 started roost emergence almost at the same time (around 23:05), when mean photosynthetic activity was <10 and >80 $\frac{\mu E}{m^2 s}$. As for the MBRA1 roost, there was a difference of 42 minutes in time of first emergence between two different nights that was almost as humid and bright at (43 and 48 % humidity and 67 and 68 $\frac{\mu E}{m^2 s}$, respectively). However, I cannot say for sure that light and humidity did not affect time of emergence, mainly due to a low sample size. *T. brasiliensis* bat colonies in Texas were found to emerge significantly earlier during dry than moist summers (Frick et al., 2012). Frick et al. (2012) conclude that *T. brasiliensis* show great plasticity with respect to time of emergence and climate, and that this might be the case for other bat species as well. Future studies should include a bigger sample size to find out if light and humidity affects time of first emergence in *M. brandtii* and *M. mystacinus*.

5.3 Use of vegetation corridors near roosts

I found evidence for temporal displacements between roosts and corridors for both species. Counts of bats shown in panels B and C for *M. brandtii* and panels D and F for *M. mystacinus* in Figure 15 clearly demonstrates a displacement where the activity started at the roosts earlier than in the corridors. For counts shown in panels B, C and D the number of bats exiting the roost was higher than the number of bats passing through the corridor. This temporal displacement provides evidence that vegetation corridors are used for commuting between roosts and foraging habitat. This is in

accordance with a previous study, which also found that vegetation corridors were important for commuting between roosts for *Myotis* species (Walsh & Harris, 1996). It should be noted that because *Myotis* species sound similar on hand held bat detectors, some of the bat observations at roosts and in nearby corridors may have been of individuals of other species than the focal species (or that the individuals are from other but the focal roost from the same species). Moreover, a study done on vespertilionid bats in Britain found that vegetative corridors also could be used as important foraging areas (Walsh & Harris, 1996). This proved especially important in areas with a high proportion of tree monocultures, as some of the areas east in Nittedal were. In addition, small bats as *Myotis* have been found to use vegetation corridors for wind shelter and as protection against predators (Limpens & Kapteyn, 1991). However, if the corridor was used as anything else but commuting and/or protection from predators, there would have been continuous activity in the corridors, which we did not observe. This indicates that the observed corridors were used primary as commuting routes and/or protection from predators.

5.4. Changes in roost site during the breeding season

During the radio-tracking of individuals, we discovered that bats from the same colony utilized different roosts. e.g. MBRA_I4, a lactating *M. brandtii*, roosted in MBRA2 the first two days of tracking (that is 5th and 6th of July), however during the third night of tracking she returned to MBRA2 at 02:02 before she left and showed up MBRA4 at 02:11. The observer tracking MBRA_I4 wrote in his field notes that MBRA_I4 might have moved her young from MBRA2 to MBRA4. MBRA_I4 used MBRA4 as the only roost after this night. This movement might have been triggered by hot temperatures inside the roost. The temperatures during the first three nights was 20.1°C, 20.5°C and 19.8°C, which is about 5°C warmer than the average nighttime temperature in the area at this time of year (Meteorologisk institutt, s.a.). Pregnant and neonatal *M. sodalis* have been found to have poorer thermoregulation than other bats of the same species, thus shifting roosts might be crucial for the survival of newborn bats (Callahan et al., 1997). Similarly, MBRA_I4 shifting roost might be an important strategy for keeping her young alive. However, Callahan et al. (1997) states that bats

would benefit from living in warmer roosts the rest of the season to be warm enough to hunt efficiently when the evening comes. However, they do not state what temperature is "warm enough", and I suggest that that warmer than "warm enough" could indeed be unfavorable for the bats.

In addition to avoiding unfavorable microclimate, bats are also known to change roosts to avoid predators, other disturbances and ectoparasites, and to reduce the distance to nearest foraging habitat (Lewis, 1995). In fact, bats roosting in trees show a higher roost lability – that is, changing roosts – than bats living in human buildings (Lewis, 1995). According to Lewis (1995), lactating bats would especially benefit from high roost lability due to their hairless attractiveness to ectoparasites. When we trapped bats, we recorded type and number of parasites, and we more often than not observed bats with ectoparasites during the field season. This might explain why MBRA_I4 chose to move, possibly with her offspring; to avoid ectoparasites both on herself and her pup. Indeed, the ability to adapt to the changes in the environment, such as switching roosts, is generally assumed to be of significant importance for individuals to increase their overall fitness, in particular in relatively long-lived species (Gugger, s.a.), such as bats.

None of the houses were particularly old, that is, none of them were built before the 1950's. Thus, the assertion made by Dietz and Kiefer (2016a) that both *M. brandtii* and *M. mystacinus* prefer older buildings was not supported in this study. Also, it could be that the age of the building *per se* is not the most important thing; the apparent preference for older buildings may just be a consequence of older buildings being more accessible to bats; i.e., more openings where bats can get in and easier access to the attic/roof.

5.5 Similarities and differences in roosting ecology of *M. brandtii* and *M. mystacinus*

Little is known about the roosting ecology of the two cryptic species *M. brandtii* and *M. mystacinus*. The fact that they were not recognized as two different species until the mid-70's means that empirical data from older studies are not reliable in terms of species-specific information. Unlike many other cryptic species, *M. brandtii* and *M. mystacinus* are not closely related and could

therefore possibly show bigger differences in roosting ecology than more closely related cryptic species (Berge, 2007). Even with today's technology, distinguishing the two spices can be hard. According to Rydell et al. (2017) automatic loggers (such as Batcorders and SongMeters) cannot distinguish between echo localization calls from different species of the *Myotis* genus. As a result, our species identifications for the colonies are solely based on the bats that were captured (see Appendix III), measured, tagged and tracked back to their respective colonies. In fact, we had some individuals that may be characterized as outliers, since some of their biometrics were significantly outside the "normal range". Since we know that the two species can share roosts (Isaksen et al., 2009). I cannot rule out the possibility that some individuals were misidentified. However, we collected pellet and hair samples from the captured individuals – for use in another study – and the species identifications will be validated with DNA analyses at a later stage.

The activity patterns relative to temperature differed somewhat between the two roosts. I found that there was higher activity when the temperatures were relatively low at MMYS1, whereas there was a comparably higher activity when temperatures were relatively high at MBRA1. Since I know that there were no bats exiting the roosts after early to mid-June for neither roosts, the activity registered must be from bats passing by the roosts. Since Norwegian *Myotis* species are indistinguishable based on acoustic detector data only (Rydell et al., 2017), there is no way to tell if the species passing by is the same species as the ones using the roost. Even so, assuming that the majority of the bats passing by belong to the same species as the ones using the roost itself, one can conclude that the temperature-bat activity patterns differ between the two roosts.

6. Conclusions

The main findings of this study were that time of first emergence from social roosts of *M. brandtii* and *M. mystacinus* varied through the season, and that time of emergence was related to temperature. Neighboring colonies of *M. brandtii* and *M. mystacinus* showed similar patterns with respect to time of emergence in the beginning of the maternity season, but not later in the season. In addition, the bats of the different colonies appeared to use different types of vegetation corridors for movement between roosts and hunting areas.

Although the limited sample size limits the general conclusions that can be drawn, my study has revealed some interesting patterns that should be investigated further. In particular, the apparent dynamic nature of the use of roost sites – with individuals seemingly shifting roost sites during the maternity season – should be investigated further to determine whether this is a common pattern, and if so, what environmental factors influence this dynamic. Also, a larger sample size would provide more information about roost site characteristics, both the actual roost site, and the surrounding areas (configuration of vegetation corridors etc.). I would also recommend long-term monitoring of some breeding colonies to detect potential influence of climate change on bat populations.

7. References

Arndt, R. J., O'Keefe, J. M., Mitchell, W. A., Holmes, J. B. & Lima, S. L. (2018). Do predators influence the behaviour of temperate-zone bats? An analysis of competing models of roost emergence times. *Animal Behaviour*, 145: 161-170. doi: 10.1016/j.anbehav.2018.09.014.

ArtDatabanken. (s.a.). *Myotis mystacinus*. Available at: https://artfakta.artdatabanken.se/?&s=myotis%20mystacinus&v=1 (accessed: 08.04.2019).

Ask an astronomer. (2019). *Why is twilight shorter near the equator?* Available at: http://curious.astro.cornell.edu/about-us/161-our-solar-system/the-earth/day-night-cycle/20-why-is-twilight-short-near-the-equator-intermediate.

Bat Conservation Trust. (2010a). Brandt's bat. In *UK bats*.

Bat Conservation Trust. (2010b). Whiskered bat. In *UK bats*.

Bat Conservation Trust. (s.a.-a). *Bats of the world*. Available at: https://www.bats.org.uk/about-bats/what-are-bats/bats-of-the-world (accessed: 12.02.2019).

Bat Conservation Trust. (s.a.-b). *Flight, food and echolocation*. Available at: https://www.bats.org.uk/about-bats/flight-food-and-echolocation (accessed: 12.02.2019).

Berge, L. (2007). *Resource partitioning between the cryptic species Brandt's bat (Myotis brandtii) and the whiskered bat (M. mystacinus) in the UK*. Docotral thesis. United Kingdom: University of Bristol.

Borch, H. & Erikstad, L. (2015). *Hvordan bruke vannmiljøtiltak i raviner. To eksempler fra Nittedal*. NIBIO rapport. Ås: NIBIO.

Callahan, E. V., Drobney, R. D. & Clawson, R. L. (1997). Selection of Summer Roosting Sites by Indiana Bats (*Myotis sodalis*) in Missouri. *Journal of Mammalogy*, 78 (3): 818-825. doi: 10.2307/1382939.

Dietz, C. & Kiefer, A. (eds). (2016a). *Bats of Britain and Europe*. 1st ed. United Kingdom: Bloomsbury.

Dietz, C. & Kiefer, A. (2016b). Brandt's Bat. In *Bats of Britain and Europe*. United Kingdom: Bloomsbury.

Dietz, C. & Kiefer, A. (2016c). Daubenton's Bat. In *Bats of Britain and Europe*. United Kingdom: Bloomsbury.

Dietz, C. & Kiefer, A. (2016d). Natterer's Bat. In *Bats of Britain and Europe*. United Kingdom: Bloomsbury.

Dietz, C. & Kiefer, A. (2016e). Whiskered Bat. In *Bats of Britain and Europe*. United Kingdom: Bloomsbury.

Eldegard, K., Sørås, R., Bischof, R., Støen, O. G., Ordiz, A., Kristiansen, K. F., Siljedal, G. J. & van der Kooji, J. (2017). *Bats in Norway. Filling knowledge gaps (SCANDBAT)*.

Eldegard, K., Sørås, R., Kristiansen, K. F., Siljedal, G. J., McKay, A. I. R., Birkeland, K. M., Bischof, R., Hald, H. A., Stawski, C., Skåra, K. H., et al. (2018). *Bats in Norway. Filling knowledge gaps (SCANDBAT)*. Ås: Norwegian University of Life Sciences.

Erikstad, L. (1992). Recent changes in the landscápe of the marine clays, Østfold, southeast Norway. *Norwegian Journal of Geography*, 46 (1): 19-28. doi: 10.1080/00291959208552279

Federico, P., Hallam, T. G., McCracken, G. F., T., P. S., Grant, W. E., Correa-Sandoval, A. N., Westbrook, J. K., Medellín, R. A., Cleveland, C. J., Sansone, C. G., et al. (2008). Brazilian free-tailed bats as insect pest regulators in transgenic and conventional cotton crops. *Ecological applications*, 18 (4): 826-837. doi: 10.1890/07-0556.1.

Fjeldstad, H., Gaarder, G. & Homble, K. (2002). *Biologisk mangfold i Nittedal Kommune*. Miljøfaglig Utredning Rapport. Oslo: Miljøfaglig Utredning as.

Fleming, T. H., Geiselman, C. & Kress, W. J. (2009). The evolution of bat pollination: a phylogenetic perspective. *Annals of Botany*, 104: 1017-1043. doi: 10.1093/aob/mcp197.

Frick, W. F., Stepanian, P. M., Kelly, J. F., Howard, K. W., Kuster, C. M., Kunz, T. H. & Chilson, P. B. (2012). Climate and weather impact timing of emergence of bats. *PLoS ONE*, 7 (8). doi: 10.1371/journal.pone.0042737.

Ghose, K. & Moss, C. F. (2003). The sonar beam pattern of a flying bat as it tracks tethered insects. *J Acoustic Soc Am.*, 114. doi: 10.1121/1.1589754.

Gugger, P. (s.a.). *How can long-lived organisms adapt to a changing environment?* . Available at: https://www.umces.edu/research-highlights/how-can-long-lived-organisms-adapt-changing-environment (accessed: 22.04.2019).

Hyndman, R., Athanasopoulos, G., Bergemir, C., Caceres, G., Chhay, L., O'Hara-Wild, M., Petropoulos, F., Razbash, S., Wang, E. & Yasmeen, F. (2019). *forecast: Forecasting functions for time series and linear models. R package version 8.5*. Available at: http://pkg.robjhyndman.com/forecast.

Häusler, U. (2003a). *Grosse Bartfledermaus Myotis brandtii*. Stuttgart: Verlag Eugen Ulmer.

Häusler, U. (2003b). *Kleine Bartfledermaus Myotis mystacinus*. Stuttgart: Verlag Eugen Ulmer.

Ieno, E. N. & Zuur, A. F. (2015). *A Beginner's Guide to Data Exploration and Visualisation with R*. Newburgh: Highland Statistics Ltd.

Isaksen, K., Klann, M., van der Kooij, J., Michaelsen, T. C., Olsen, K. M., Sarholm, T., Sunding, C. F., Sunding, M. F. & Syvertsen, O. P. (2009). *Flaggermus i Norge - Kunnskapsstatus og forslag til nasjonal handlingsplan*. Oslo: Norsk Zoologisk forening.

Jones, G., Jacobs, D. S., Kunz, T. H., Willig, M. R. & Racey, P. A. (2009). Carpe noctem: the importance of bats as bioindicators. *Endangered species research*, 8: 93-115. doi: 10.3354/esr00182.

Kristiansen, K. F. (2018). *Hide and seek: A pilot study on day roosts in autumn and hibernacula for Vesper bats in southeast Norway*. Master's thesis. Ås: Norwegian University of Life Sciences.

Lange, H. (2005). Time-series Analysis in Ecology. *Encyclopedia of Life Sciences*. doi: 10.1038/npg.els.0003276.

Lewis, S. E. (1995). Roost Fidelity of Bats: A Review. *Journal of Mammalogy*, 76 (2): 481-496. doi: 10.2307/1382357

Limpens, H. G. J. A. & Kapteyn, K. (1991). Bats, their behaviour and linear landscape elements. *Myotis*, 29: 39-48.

Mellanby, K. (1939). Low temperature and insect activity. *Proceedings of the Royal Society B*, 127 (849). doi: 10.1098/rspb.1939.0035.

Meschede, A. & Rudolph, B. (2004). *Fledermäuse in Bayern*. Verlag Eugen Ulmer.

Meteorologisk institutt. (s.a.). *eKlima*. Available at: http://sharki.oslo.dnmi.no/portal/page?_pageid=73,39035,73_39049&_dad=portal&_schema=PORTAL (accessed: 22.04.2019).

Mickleburgh, S. P., Hutson, A. M. & Racey, P. A. (2002). A review of the global conservation status of bats. *Oryx*, 36 (1): 18-34. doi: 10.1017/S0030605302000054

O'Shea, T. J., Bogan, M. A. & Ellison, L. E. (2003). Monitoring Trends in Bat Populations of the United States and Territories: Status of the Science and Recommendations of the Future. *Wildlife Society Bulletin*, 31 (1).

R Core Team. (2017). R: A language and environment for statistical computing. *R Foundtaion for Statistical Computing*.

Ryan, J. A. & Ulrich, J. M. (2018). *xts: extensible Time Series. R package version 0.11-2.* Available at: https://CRAN.R-project.org/package=xts.

Rydell, J., Strann, K. B. & Speakmann, J. R. (1994). First record of breeding bats above the Arctic Circle: northern bats at 68-70°N in Norway. *Journal of Zoology*, 233 (2): 335-339. doi: 10.1111/j.1469-7998.1994.tb08597.x.

Rydell, J., Entwistle, A. & Racey, P. A. (1996). Timing of foraging flights of three species of bats in relation to insect activity and predation risk. *OIKOS*, 76 (2): 243.252. doi: 10.2307/3546196

Rydell, J., Nyman, S., Eklöf, J., Jones, G. & Russo, D. (2017). Testing the performances of automated identification of bat echolocation calls: A request for prudence. *Ecological Indicators*, 78: 416-420. doi: 10.1016/j.ecolind.2017.03.023.

Scott, D. D., Boston, E. S. M., Lundby, M. G., Buckley, D. J., Gager, Y., Chaplain, C. J., Teeling, E. C., Montgomery, W. I. & Prodohl, P. A. (2018). Relatedness, parentage, and philopatry within a

Natterer's bat (*Myotis nattereri*) maternity colonny. *Population Ecology*, 60 (4): 361-370. doi: 10.1007/s10144-018-0632-7

Shumway, R. H. & Stoffer, D. S. (2017). *Time Series Analysis and Its Applications*. 4th ed. USA: Springer.

Siljedal, G. J. (2018). *The hunt for maternity colonies: a pilot study of using radio telemetry to track bats in southeast Norway.* Master's thesis. Ås: Norwegian University of Life Sciences.

Skyrail. (2008). *The Bumpy Satinash*. Available at: https://www.skyrail.com.au/about/news/skyrail-nature-diary/about/news/1050-the-bumpy-satinash (accessed: 13.03.2018).

Srivastava, T. (2015). *A Complete Tutorial on Time Series Modeling in R*. Available at: https://www.analyticsvidhya.com/blog/2015/12/complete-tutorial-time-series-modeling/ (accessed: 28.03.2018).

Stone, E. L., Jones, G. & Harris, S. (2013). Mitigating the Effect of Development on Bats in England with Derogation Licensing. *Conservation Biology*, 27 (6): 1324-1334. doi: 10.1111/cobi.12154.

Swenson, J. E., Bjørge, A., Kovacs, K. M., Syvertsen, O. P., Wiig, Ø. & Zedrosser, A. (2010). *Pattedyr (Mammalia)*. Available at: https://artsdatabanken.no/Files/13972/Norsk_r_dliste_for_arter_2010_(PDF) (accessed: 08.05.2019).

Ulrich, J. (2018). *TTR: Technical Trading Rules. R package version 0.23-4.* Available at: https://CRAN.R-project.org/package=TTR.

Venables, W. N. & Ripley, B. D. (2002). *Modern Applied Statistics with S*. New York: Springer.

Walsh, A. L. & Harris, S. (1996). Foraging Habitat Preferences of Vespertilionid Bats in Britain. *Journal of Applied Ecology*, 33 (3): 508-518. doi: 10.2307/2404980

Wickham, H., Francois, R., Henry, L. & Müller, K. (2018). *dplyr: A Grammar of Data Manipluation. R package version 0.7.8.* Available at: https://CRAN.R-project.org/package=dplyr.

Wiig, Ø., Bjørge, A., Isaksen, K., Kovacs, K. M., Swenson, J. E. & Syvertsen, P. O. (2015). *Pattedyr (Mammalia)*. Available at: https://www.artsdatabanken.no/Rodliste/Artsgruppene/Pattedyr (accessed: 15.01.2019).

Wilson, D. E. & Reeder, D. M. (2005). *Mammal Species of the World*. 3. ed. Baltimore: The John Hopkins University Press.

Zeileis, A. & Grothendieck, G. (2005). zoo: S3 Infrastructure for Regular and Ireegular Time Series. . *Journal of Statistical Software*, 14 (6): 1-27. doi: 10.18637/jss.v014.i06.

Appendix I

Figure A1.1, A1.2 and A1.3 show temperature, light and humidity recorded with HOBO-loggers at the *M. brandtii* roost MBRA1 and *M. mystacinus* roost MMYS1 throughout the maternity season. The date versus temperature, light and humidity graphs from the two colonies almost always follow the same patterns. For this reason, the data from the MBRA1 HOBO-logger were used in the analyses of the relationship between bat activity and temperature, light and humidity for both colonies, as the MMYS1 HOBO-logger stopped working 29th of June.

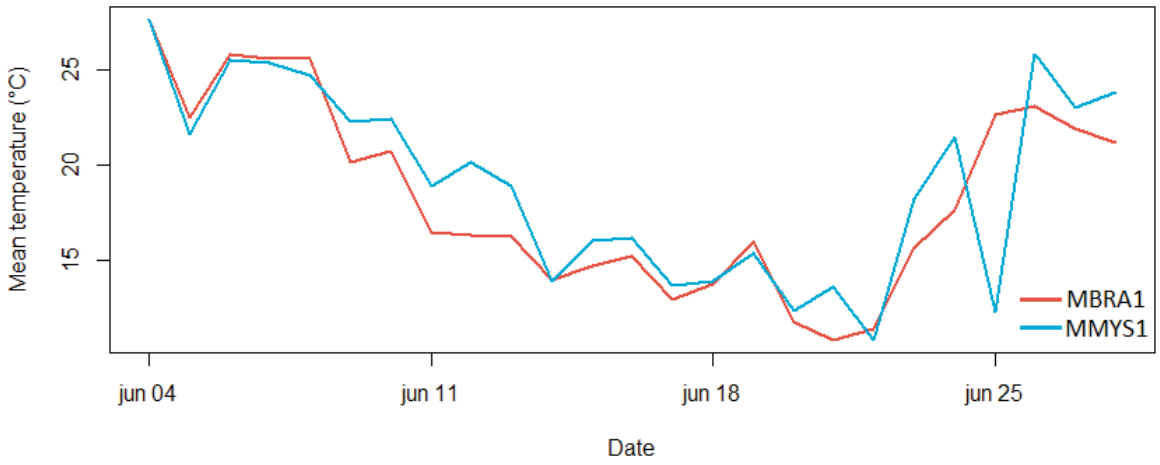

Figure A1.1: Logged temperatures (logged with HOBO loggers) in the period June 4th to June 29th at the MBRA1 and MMYS1 roosts.

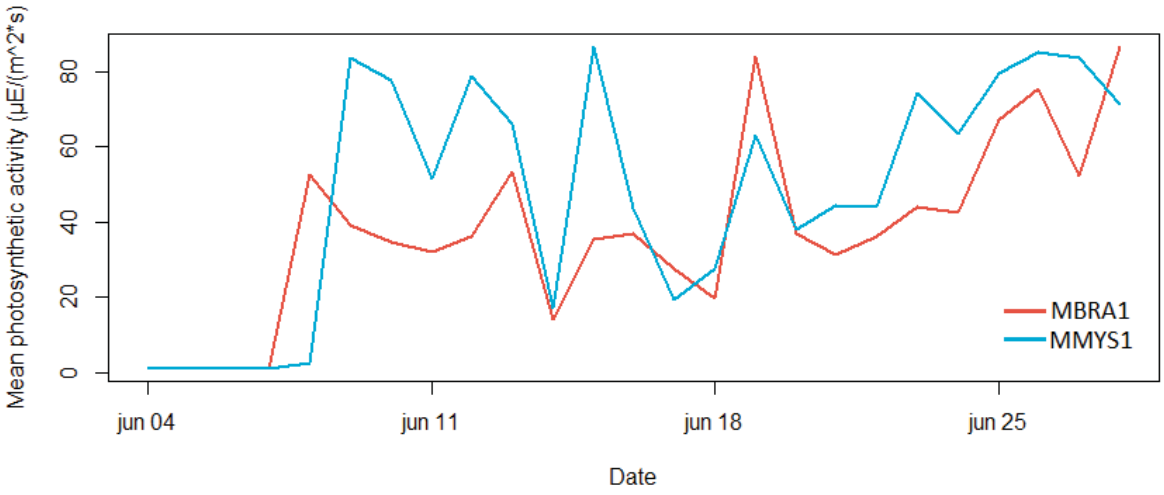

Figure A1.2: Logged photosynthetic activity (logged with HOBO loggers) in the period 4th of June to 29th at the MBRA1 and MMYS1 roosts.

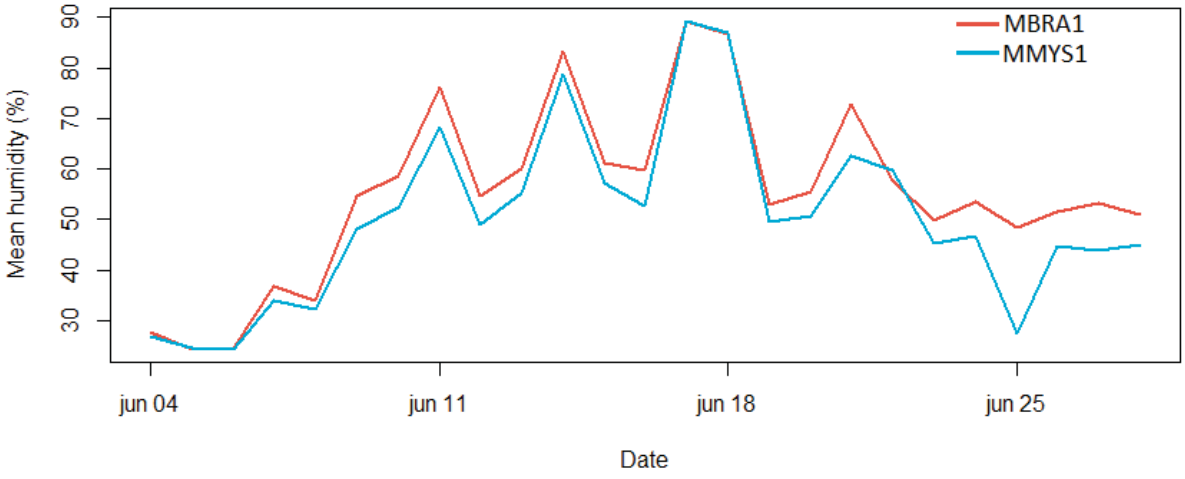

Figure A1.3: Logged humidity (logged with HOBO loggers) in the period 4th of June to 29th of June at the MBRA1 and MMYS1 roosts

Table A1.1 shows how many bats I observed at different dates at the *M. brandtii* roosts (roost MBRA1, MBRA2 etc.). I observed a much higher number of bats at MBRA1 and MBRA4 than MBRA2 and MBRA3. I carried out observations of bat activity only once at each of the roosts MBRA3 and MBRA5.

Table A1.1: Number of bats observed exiting at night from M. brandtii roosts at specific dates. Blank cells indicate that observations of the roost were not carried out on that specific date.

Date	MBRA1	MBRA2	MBRA3	MBRA4	MBRA5
11.6	49				
21.6	2				
25.6	36				
2.7	46				
9.7				34	
11.7	0	0		22	
16.7	0			0	
22.7	0	4	1	0	16
30.7	0			0	

Table A1.2 shows how many bats I observed at different dates at the *M. mystacinus* roosts (roost MMYS1, MMYS2 etc.). I observed a much higher number of bats at MMYS1 and MMYS2 than MMYS4. I carried out observations of bat activity only once at MMYS4.

Tabell A1.2: Number of bats observed exiting at night for M. mystacinus roosts at specific dates. Blank cells indicate that observations of the roost were not carried out on that specific date.

Date	MMYS1	MMYS2	MMYS3	MMYS4
2.6	9			
6.6	30			
9.6	26			
14.7				5
19.6	25			
27.6		24		
29.6	0		9	
9.7	0	0	7	
19.7	0			
29.7	0		3	
9.8	0		0	

Appendix II

Below I show two detailed examples of how I carried out the time series analyses; one example of a one component time series analysis, and one example of a two component time series analysis.

```
R-codes are shown in blue color.

My own comments from the R scripts are shown in green color.
```

Time series example – one component – bat activity over time

I needed several R packages to do the time series analysis:

```
library(zoo)
library(xts)
library(TTR)
library(forecast)
library(stats)
library(MASS)
```

First, I needed to convert the data into time series (ts) format.

```
#------------------------------------------------------------------------
#-------------1: Batcorder activity through season-------------
#------------------------------------------------------------------------

#ONE COMPONENT, SINGEL VARIATE
####MBRA1=ASKVEIEN####

#Preparing the data
batc_ask <- read.csv("batcorder_act_ask.csv", sep=";", dec=",") #colleting
the dataset
```

```
head(batc_ask)

tail(batc_ask)


batc_ask$ï..date <- NULL #removes the date column that is separated with
punctuations

batc_ask$date_r <- as.Date(batc_ask$date_r, format="%Y-%m-%d", tz="GMT")
#converting the date column to as.Date-format

str(batc_ask) #checking the structure of the dataset

#Plotting the rawdata
plot(batc_ask$nr.rec~batc_ask$date_r, type="l")
```

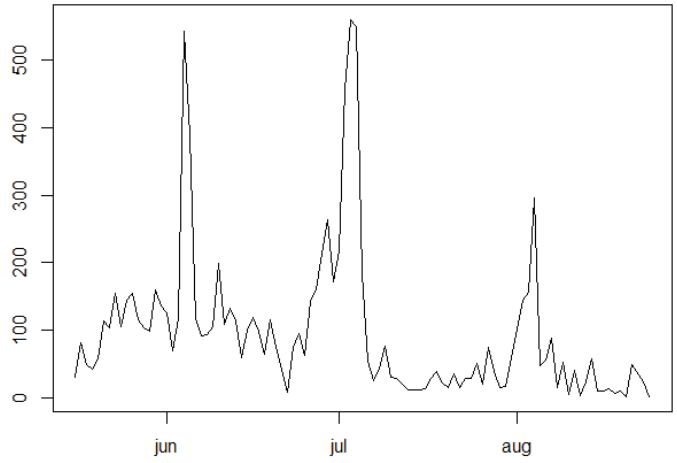

Figure A2.1: Illustrates the raw data.

The raw data plot is shown in Figure A2.1.

Since the model was multiplicative (that is, different number of bats will occur during different times in the season), I needed to log-transform the dataset.

```
batc_ask$nr.rec <- log(batc_ask$nr.rec)
```

I converted the data into matrix format to make the time series format easier to read.

```
batc_ask.mx<-
matrix(batc_ask[,2],ncol=1,nrow=length(batc_ask[,2]),dimnames=list(as.chara
cter(format(batc_ask$date_r,"%Y-%m-%d")),c("nr.rec"))) #Converting the
dataset to matrix format


batc_ask_ts <- ts(batc_ask.mx) #Creating the time series dataset

plot.ts(batc_ask_ts, ylab="Log (nr.rec)")
```

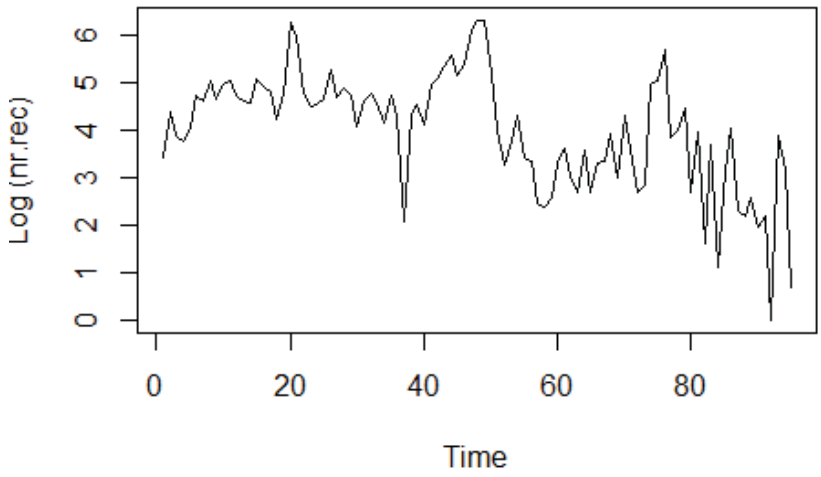

Figure A2.2: Illustrates the log-transformed time series of the raw data. The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc.

The time series plot above (Figure A2.2) looks like a normal line plot; however, the format is now time series. Note that time series analysis is often carried out on datasets which span over several seasons, and then the goal often is to find the general trend over time and predicting the future (that is, forecasting). However, my time series dataset was for one season only, and forecasting the autumn season based on the maternity season bat activity data, was not ecologically meaningful.

Since there were a lot of day-to-day variation, I decomposed the data to find the general trend. When decomposing a function, the goal is to do as few decompositions as possible, while at the same time removing the small day-to-day variations. In my analysis, I decomposed seven times.

```
#Decomposing the data

batc_ask_ts_SMA7 <- SMA(batc_ask_ts,n=7) #Procedure: Try-and-fail to you
get a more or less smooth curve

plot(batc_ask_ts_SMA7)
```

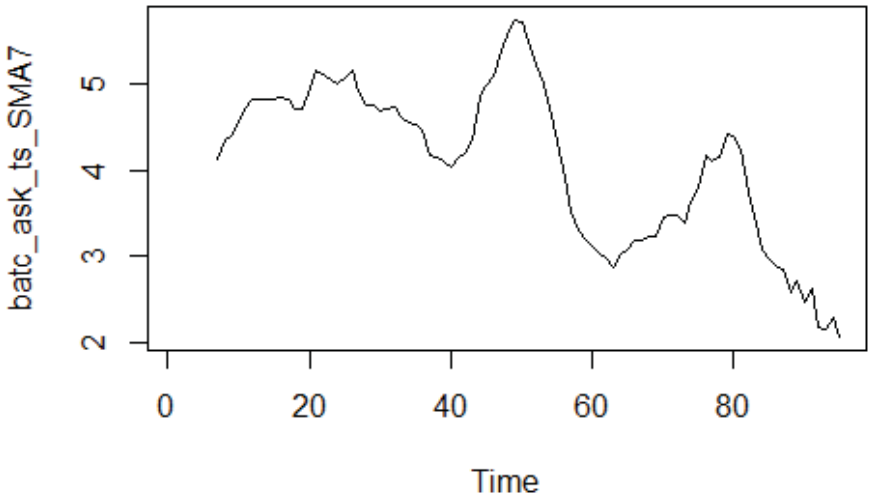

Figure A2.3: Illustrates the 7th decomposed degree of the log transformed time series. The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc.

My interpretation of the decomposed time series (Figure A2.3):

1) Increase from ca 16th of May to ca 5th of June, then a plateau.

2) Decrease from ca 14th of June until 25th of June.

3) Increase from ca 25th of June to 5th of July. I interpret this increase in activity as the period where the bats were feeding their young and therefore flew back and forth between the roost and the hunting ground(s). This would result in more recordings on the Batcorder (that is, more bat calls).

4) (Steep) decline from 5th of July to 23rd of July, then a plateau. I interpret this decrease in activity as the time where the bats leave the roost.

5) Increase from ca 1st of August until 6th of August, then a plateau. This increase in activity might have been male bats swarming the colony (during the exit counts several bats were observed flying around the roost even though no bats exited)

6) Decrease from ca 15th of August until 20th of August. I interpret this as the time where bats start looking for screes and mines to swarm around before winter, and therefore the activity at the roost would decrease.

When working with time series, the next step is often fitting an ARIMA model to forecast what will happen in the future. However, since I only have data for one season, and the bats leave the roosts around August, there would not be any ecological meaningful interpretation of such a forecast. Even so, I did the first steps of fitting an ARIMA model, as seen below, to check for autocorrelation.

```
#Preparing for ARIMA-modelling
batc_ask_ts_forecast_HW <- HoltWinters(batc_ask_ts, gamma=FALSE)
batc_ask_ts_forecast2 <- forecast(batc_ask_ts_forecast_HW)

#removing missing observations (NA's) to fit an ARIMA model
batc_ask_ts_forecast2$residuals <- na.omit(batc_ask_ts_forecast2$residuals)
```

I wanted to check for autocorrelation, that is, whether one datapoint in time depended on the previous one. To do so I needed to see the Total Correlation Chart (TCC) of ACF/PACF. In general, there are two different outcomes of TCC; it can either wear off gradually, or it can wear off straight away (possibly with alternations). If the shape of the TCC is gradually wearing off, we call it an AR-series (short for Auto Regression); if the TCC cuts off straight away however, we call it a MA-series (short for Moving Average).

If it is an MA-series, I can use the bar that makes the steep cut of (and its lag-value) as the value of MA. The blue line in the TCC indicates values that are significantly different from zero, and where ever the TCC has a cut of, and passes the blue line, that lag-value is probably the MA-value.

However, if it is an AR-series, I have to check the PACFs (Partial Auto Correlation Function) TCC.

```
#Checking for autocorrelation and partial autocorrelation
acf(batc_ask_ts_forecast2$residuals, lag.max=20)
```

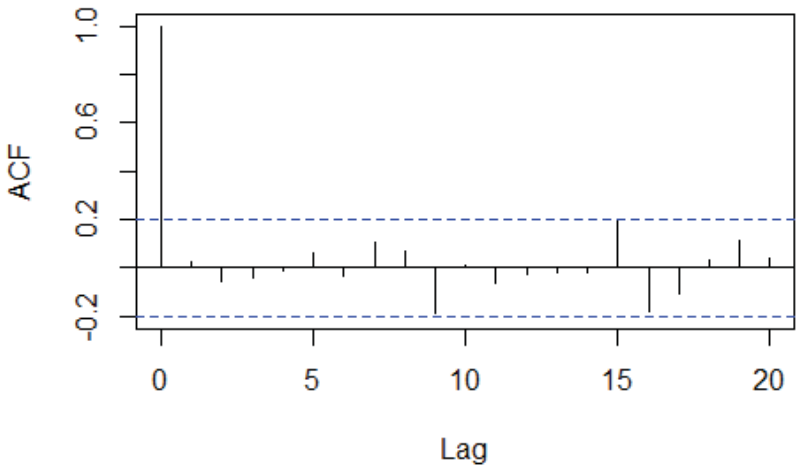

Figure A2.4: Total Correlation Chart that illustrates the autocorrelation of the time series.

Since the TCC cut's off straight away, I know it's an MA-series, with a value of 0, since the first bar (lag 0) is where the cut off happens. In addition to interpret the TCC, I used a Ljung-box test to find the p-value. If the p>0,05, there is little evidence of non-zero autocorrelation, which indicates that there is a big chance of autocorrelation.

```
Box.test(batc_ask_ts_forecast2$residuals, lag=20, type="Ljung-Box")
```

The p-value=0.58, thus there is little evidence of non-zero auto correlation. In other words, there is evidence of autocorrelation, that is one point in the dataset is dependent on the previous one (as seen in Figure A2.4).

I did not do the rest of the time series analysis, as this is used for forecasting what will happen in the future (based on several periods of data).

Time series example – two components – bat activity and temperature over time

I needed several packages to do the time series analysis:

```
library(zoo)
library(xts)
library(TTR)
library(forecast)
library(stats)
library(MASS)
```

First, I needed to prepare the data for being converted into time series (ts) format.

```
#-------------------------------------------------------------------------
#-------------2: Batcorder activity through season with temperature--------
#-------------------------------------------------------------------------

#TWO COMPONENTES/MULTIVARIATE

####MBRA1=ASKVEIEN####

batc_ask_temp <- read.csv("batc_hobo_ts.csv", sep=";", dec=",") #colleting
the dataset

head(batc_ask_temp)
tail(batc_ask_temp)

batc_ask_temp$ï..date <- NULL #removes the date column that is separated
with punctuations
batc_ask_temp$haug_rec <- NULL #Removing the MMYS1-column
batc_ask_temp$date_r <- as.Date(batc_ask_temp$date_r, format="%Y-%m-%d",
tz="GMT") #converting the date column to as.Date-format

colnames(batc_ask_temp)[2] <- "nr.rec" #Changing the name of column nr.2
str(batc_ask_temp) #checking the structure of the dataset
```

```
#Plotting the raw data

par(mar=c(8,4,1,4))

lab_1 <- seq(as.Date("2018-06-04"), as.Date("2018-08-24"), by="days")

plot(batc_ask_temp$nr.rec~batc_ask_temp$date_r, type="l", lty=1, xlab=NA,
ylab=NA)

par(new=T)

plot(batc_ask_temp$mean_temp~batc_ask_temp$date_r, type="l", lty=2,
axes=FALSE, xlab=NA, ylab=NA)

axis(side = 4, seq(5,30,5))

axis(side=1, labels=lab_1, at=1:82, las=2)

mtext(side = 4, 'Mean temperature (°C)', line=3)

mtext(side = 1, "Date", line=3)

mtext(side = 2, "Number of recordings", line=3)
```

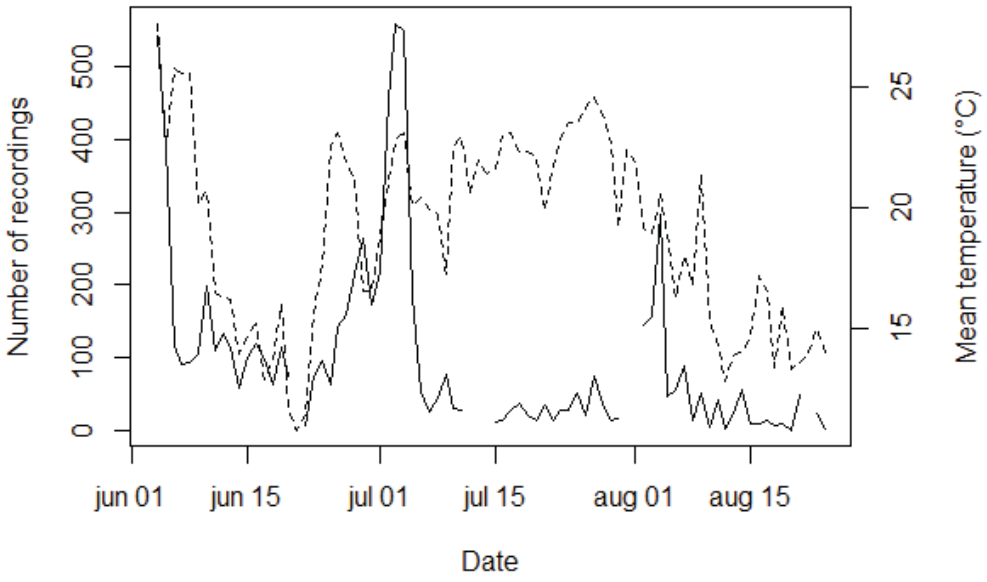

Figure A2.5: Illustrates the raw data.

The raw data plot is shown in Figure A2.5.

Since the model was multiplicative (that is, different number of bats will occur during different times in the season), I needed to log-transform the dataset.

```
batc_ask_temp$nr.rec <- log(batc_ask_temp$nr.rec)

batc_ask_temp <- na.omit(batc_ask_temp) #Removing missing (NA) values

head(batc_ask_temp) #Checking my dataset
```

I converted the data into matrix format to make the time series format easier to read. NB! Since there are two different components to this time series, i.e., number of recordings and temperature, I created two separate time series.

```
#Two matrices, one for nr.rec and one for temperature
batc_ask_nr.rec.mx <- matrix(c(batc_ask_temp$nr.rec),ncol=1,
dimnames=list(as.character(format(batc_ask_temp$date_r,"%Y-%m-%d")),
c("nr.rec")))
batc_ask_temp.mx <- matrix(c(batc_ask_temp$mean_temp),ncol=1,
dimnames=list(as.character(format(batc_ask_temp$date_r,"%Y-%m-%d")),
c("mean_temp")))
```

```
batc_ask_nr.rec_ts <- ts(batc_ask_nr.rec.mx)
plot.ts(batc_ask_nr.rec_ts)
```

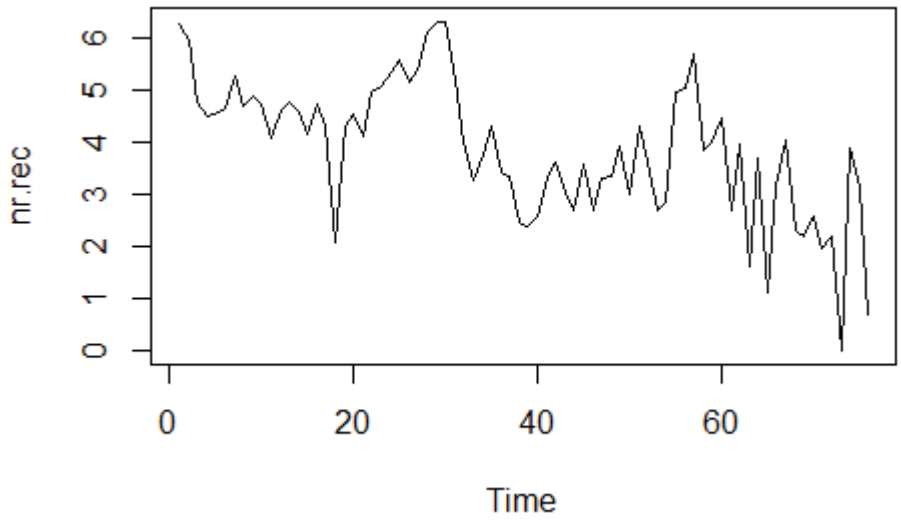

Figure A2.6: Illustrates the log-transformed time series of the raw data (nr.rec. = number of recordings). The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc.

Figure A2.6 shows the log-transformed activity data over time, and Figure A.7 shows the log-transformed temperature data over time.

```
batc_ask_temp_ts <- ts(batc_ask_temp.mx)
plot.ts(batc_ask_temp_ts)
```

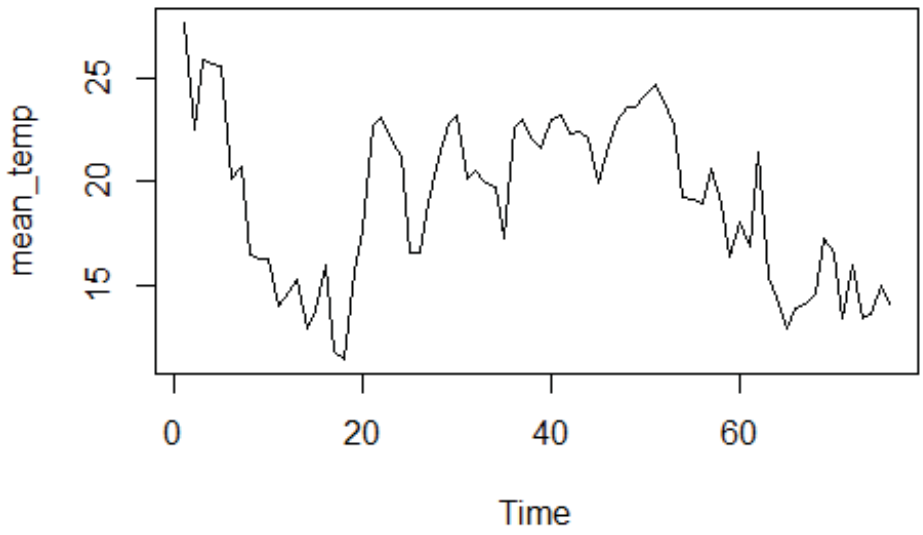

Figure A2.7: Illustrates the log-transformed time series of the raw data (temperature). The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc.

```
plot.ts(cbind(batc_ask_nr.rec_ts, batc_ask_temp_ts))
```

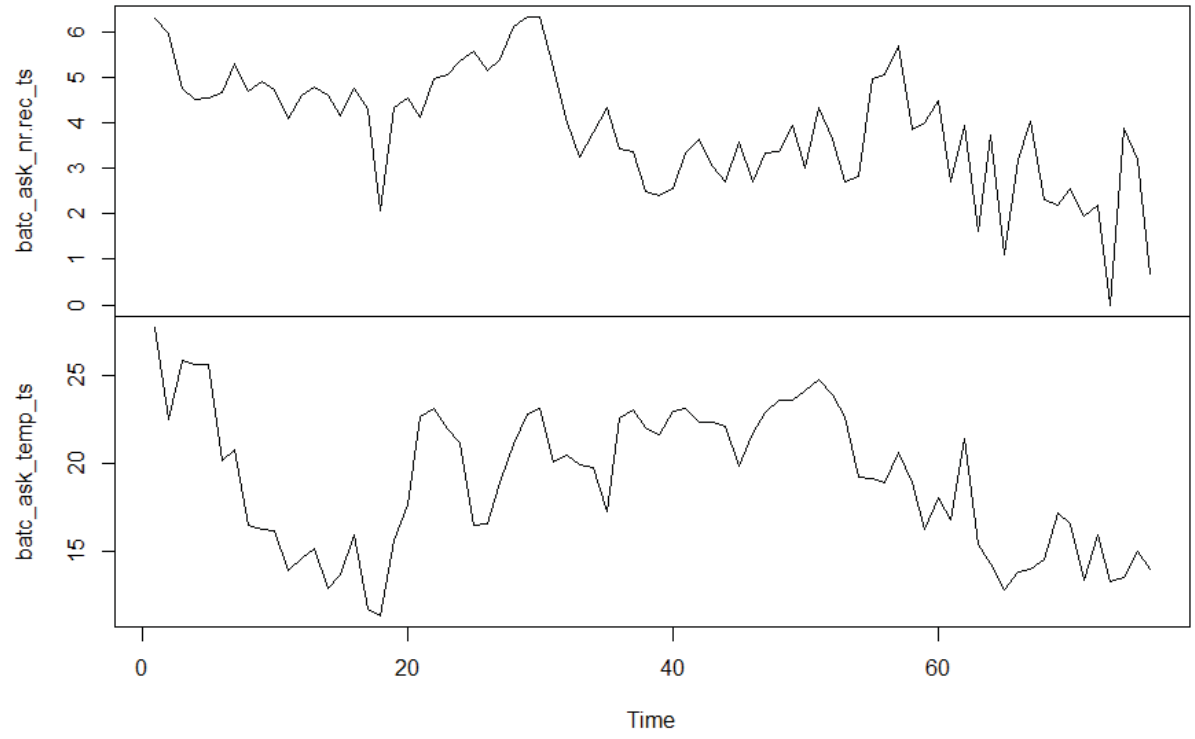

Figure A2.8: Illustrates the log-transformed time series of both raw data (number of bat recordings and temperature). The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc.

The time series plots in Figure A2.8 look exactly like normal line plots, however, the format is now time series. There is one graph for number of recordings over time (Figure A2.6), one graph for temperature over time (Figure A2.7), and in Figure A2.8 the bat recordings graph is placed on top of the temperature graph. Be aware that time series are often done over several seasons, and then the

goal often is to find the general trend over time. However, this time series dataset is for one season only.

Since there were a lot of day-to-day differences, I decomposed the data to find the general trend. When decomposing, the goal is to do as few decomposings as possible while at the same time removing the small day-to-day variations. In this analysis, I decomposed eight times.

```
#Decomposing the data
batc_ask_nr.rec_ts_SMA8 <- SMA(batc_ask_nr.rec_ts, n=8) #Try-and-fail to
you get a more or less smooth curve
plot(batc_ask_nr.rec_ts_SMA8)
```

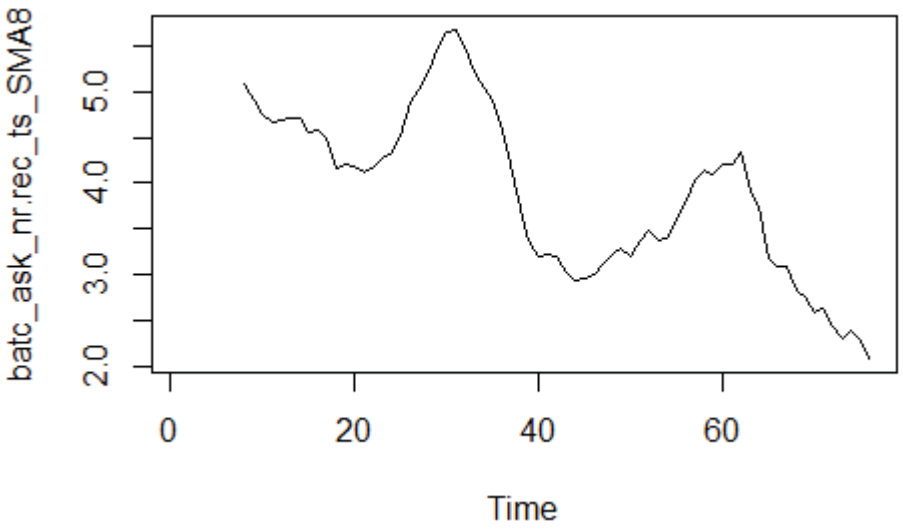

Figure A2.9: Illustrates the 8th decomposed degree of the log-transformed time series (number of recordings). The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc. The numbers on the y-axis refers to the log-transformed number of recordings.

My interpretation of the decomposed time series (Figure A2.9):

1) Decrease from ca 4th of June to 21st of June.

2) Increase from 22nd of June to 3rd of July. I interpret this increase in activity as the period where the bats feed their young and therefore flies back and forth between the roost and the hunting ground(s). This would yield a higher activity level on the Batcorder (that is, more bat calls).

3) (Steep) decline from 3rd of July to 6th of July, then a plateau until 31st of July. I Interpret this decrease in activity as the time where the bats leave the roost.

4) Increase from 31st of July to 3rd of August. I am not sure how to interpret this increase in activity, but it might have been male bats swarming the roost (during the exit counts several bats was observed flying around the colony even though no bats exited).

5) Decrease from 3rd of August to 24th of August. I interpret this as the time where bats start looking for screes and mines to swarm around before winter, and therefore the activity at the roost would decrease.

```
batc_ask_temp_ts_SMA8 <- SMA(batc_ask_temp_ts,n=8) #Try-and-fail to you get a more or less smooth curve
plot(batc_ask_temp_ts_SMA8)
```

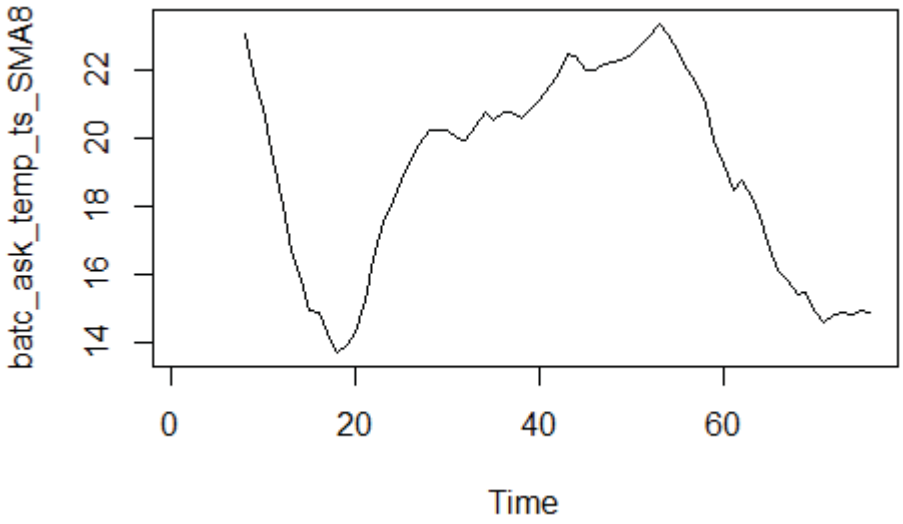

Figure A2.10: Illustrates the 8th decomposed degree of the log-transformed time series (temperature). The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc. The numbers on the y-axis refers to the log-transformed temperatures.

My interpretation of the decomposed time series (Figure A2.10):

1) (Steep) decline from 4th of June to 21st of June.

2) (Steep) increase from 21st of June to 25th of June, then a smaller increase from 25th of June to 26th of July.

3) (Steep) decrease from 26th of July to 12th of August, then a plateau until 24th of August

```
plot.ts(cbind(batc_ask_nr.rec_ts_SMA8, batc_ask_temp_ts_SMA8), main="General trends")
```

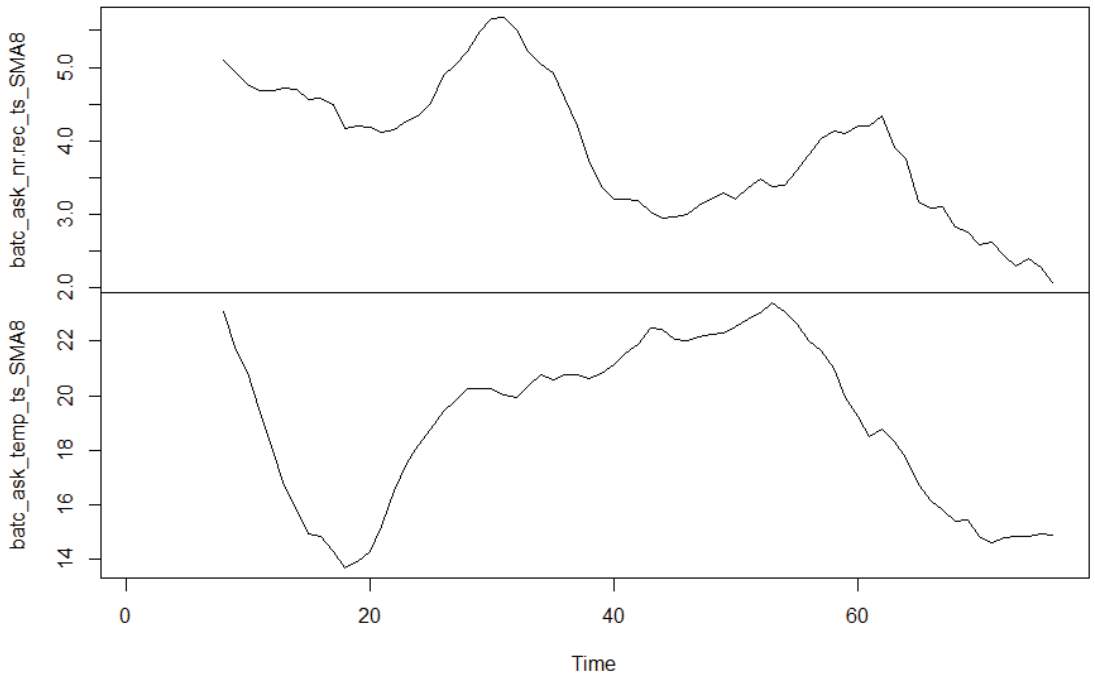

Figure A2.11: Illustrates the 8th decomposed degree of both log-transformed time series. The numbers on the x-axis refers to day number x after 16th of May (start). Thus 16th of May = day 0, 17th of May = day 1 etc. The numbers on the upper y-axis refers to the log-transformed number of recording, while the numbers on the lower y-axis refers to the log-transformed temperatures.

According to Figure A2.11, there seems to be some covariance between number of bats and temperature, at least in the beginning of season. Both the number of bat recordings and temperature graphs are decreasing until 21st of June, then they are increasing until 5th of July. However, from here the number of bats is decreasing while the temperature is increasing again. From 26th of July the temperature is decreasing, and number of recordings is lagging a bit behind but decreasing as well from 31st of July.

Since I have two time series, and therefore two components, I can in addition to run ACF also run CCF (Cross Correlation function). CCF is used to find at which lags (time displacements between the two time series) the correlation between the two time series is strongest.

```
par(mfrow=c(3,1))
acf(batc_ask_nr.rec_ts)
acf(batc_ask_temp_ts)
ccf(as.numeric(batc_ask_nr.rec_ts), as.numeric(batc_ask_temp_ts))
```

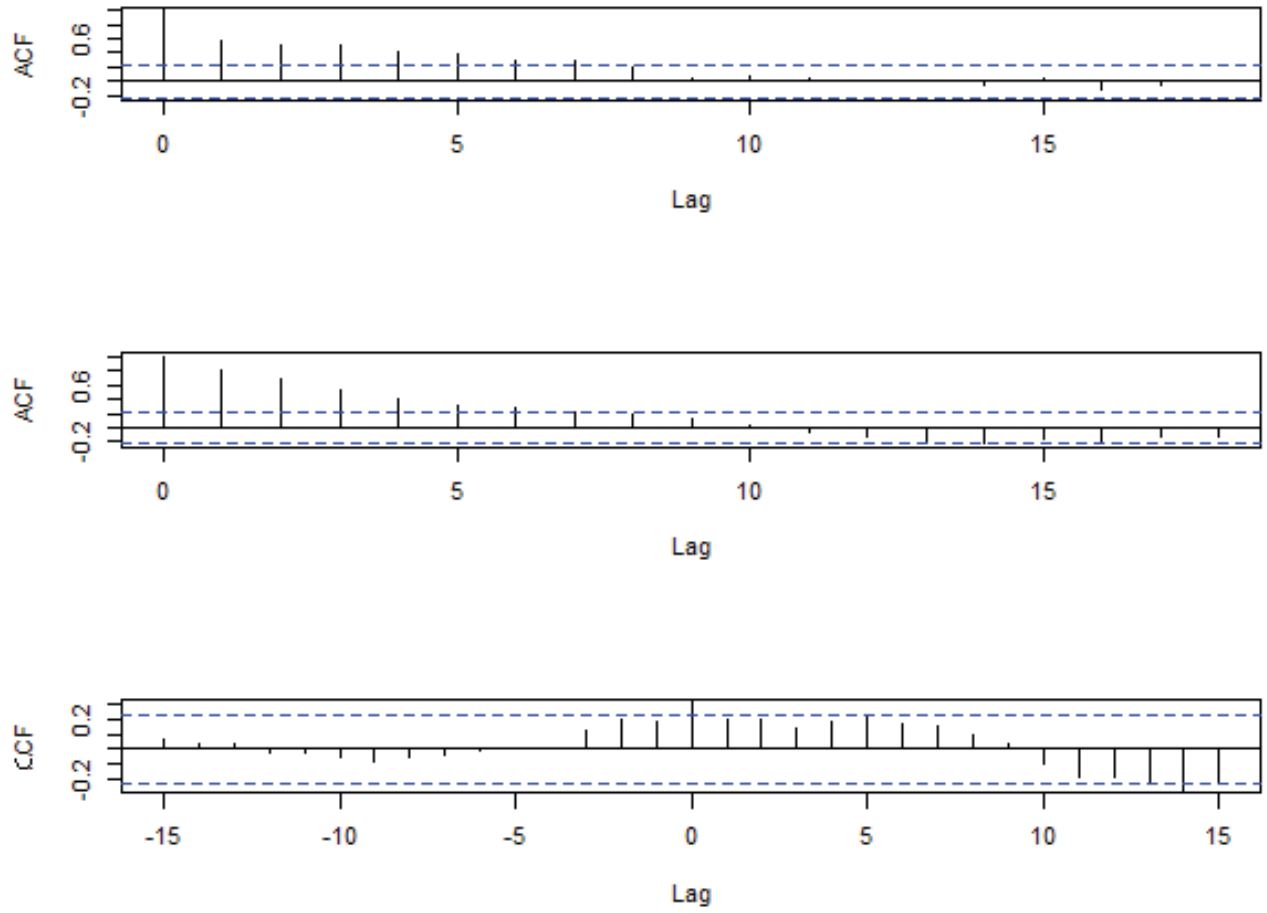

Figure A2.12: Total Correlation Charts that illustrates the autocorrelation and cross correlation for the time series. Upper = autocorrelation for number of recordings, middle = autocorrelation for temperature, lower = cross correlation for both.

Since the TCC gradually wears off in the upper and middle panel of A2.12, I know they are AR-series.

Since AR-series don't cut off, I cannot use, Ljung-box-test, and need to check the PACF instead.

Additionally, I can see that the correlation between the two time series is at it's strongest around lag 0. This means that the two time series are strongest correlated when there is no time displacements in neither time series, that is their original time series.

```
par(mfrow=c(1,2))
pacf(batc_ask_nr.rec_ts)
pacf(batc_ask_temp_ts)
```

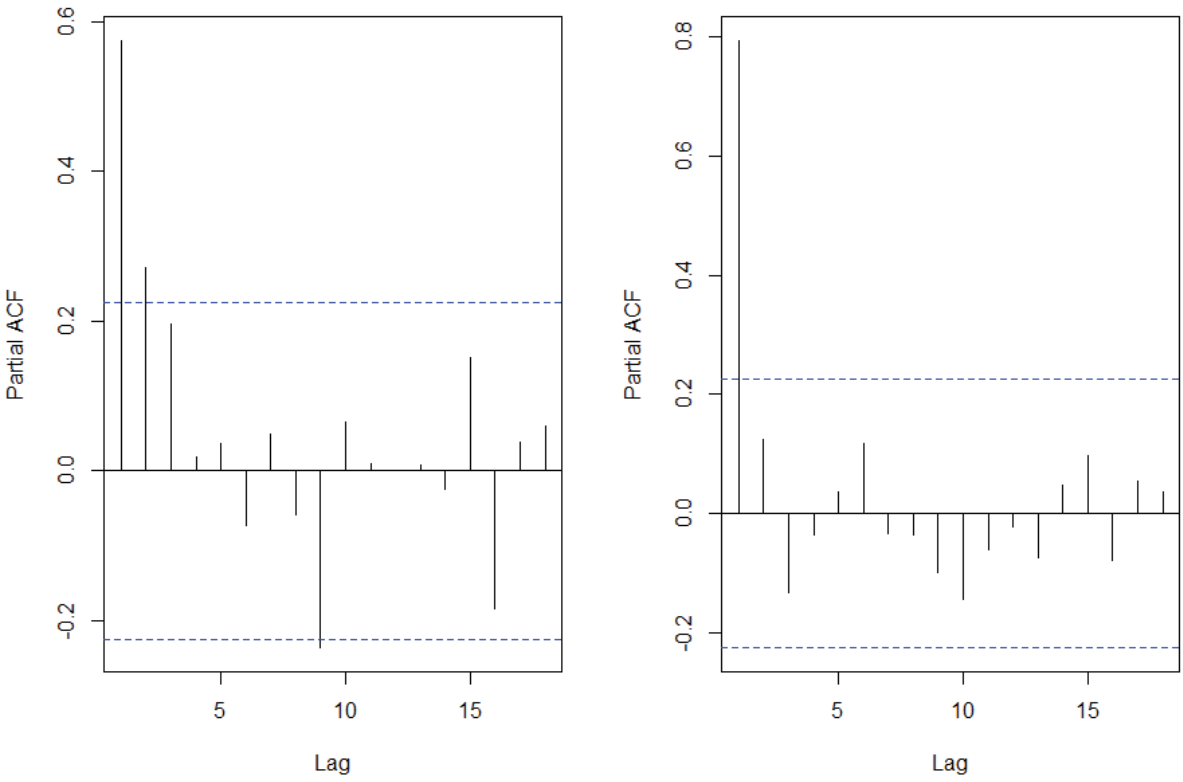

Figure A2.13: Illustrates the partial autocorrelation for the time series. Left = partial autocorrelation for number of recordings, right = partial autocorrelation for temperature.

Since the TCC of PACF cuts off straight away in both the left and right panel of A2.13, I know the values of the AR (2 and 1 respectively).

To make it all more clearly, I plotted all ACF together in Figure A2.14.

```
par(mfrow=c(1,1))
acf(cbind(batc_ask_nr.rec_ts, batc_ask_temp_ts)
```

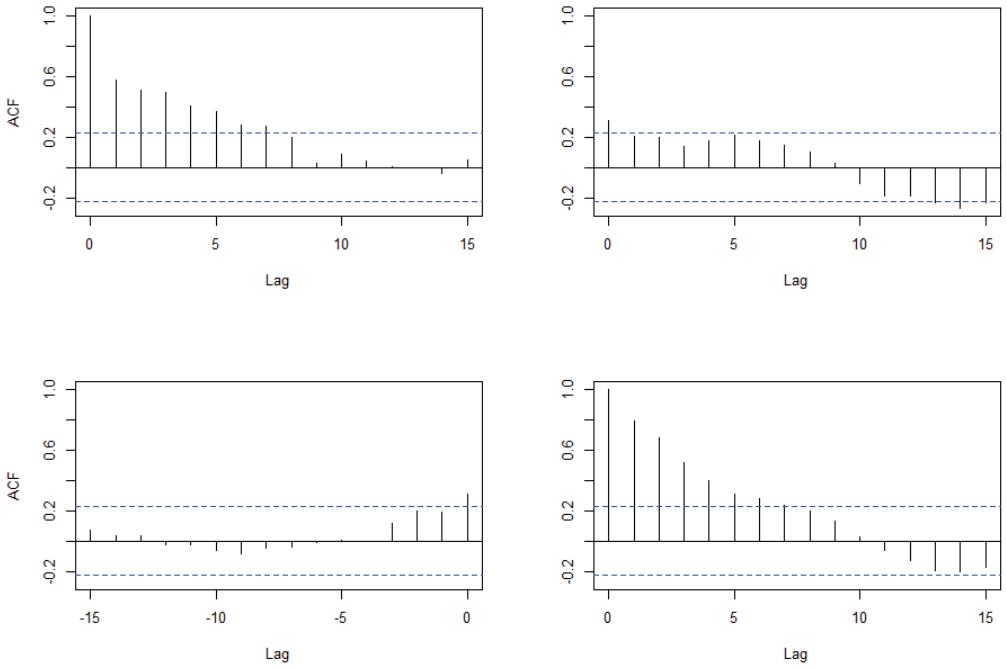

Figure A2.14: Illustrates autocorrelation for the time series. Upper left: ACF for number of recordings; upper right; ACF for number of recordings and temperature, lower left: temperature and number of recordings; lower right: temperature.

Figure A2.14 shows the autocorrelation for number of recordings, number of recordings and temperature, temperature and number of recordings, and temperature. Since all TCC's weared off gradually, I know that they all are AR-series. Therefore, I needed to plot the PACF's as well (Figure A2.15).

```
pacf(cbind(batc_ask_nr.rec_ts, batc_ask_temp_ts))
```

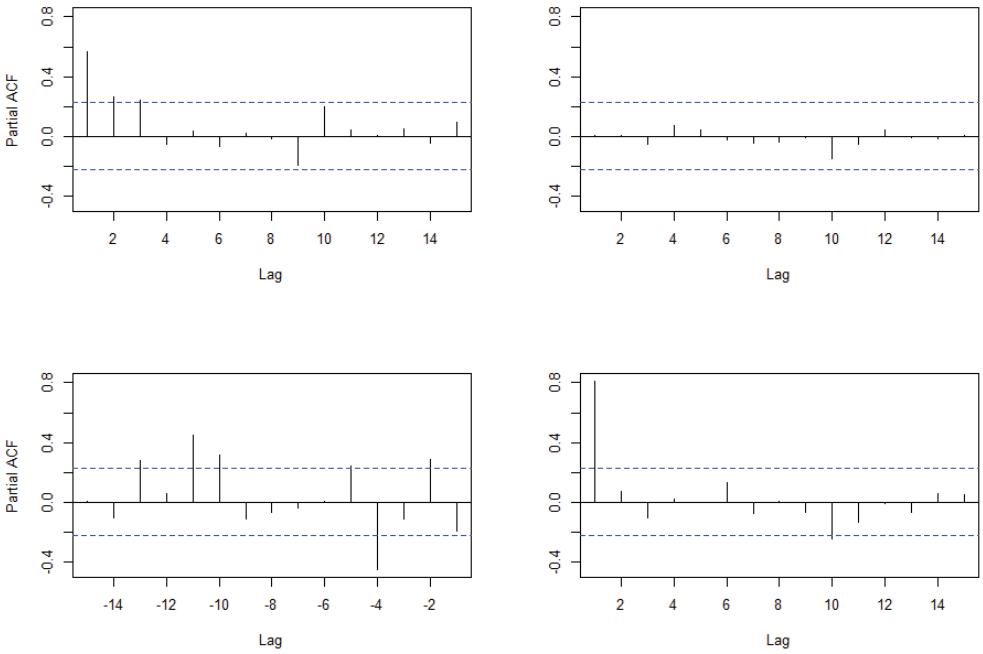

Figure A2.15: Illustrates the partial autocorrelation for the time series.

Figure A2.15 shows the partial autocorrelation for number of recordings, number of recordings and temperature, temperature and number of recordings, and temperature. Since the TCC of PACF cuts in the upper left and lower right panel, I know the values of the AR (3 and 1 respectively). The upper right and lower left are for both time series at once and does not have any real meaning.

Hence, the number of recording time series is an AR(3)-series, and the temperature time series is an AR(1)-series.

I did not do the rest of the time series analysis, as this is used for forecasting what will happen in the future (based on several periods of data).

In addition to interpret the TCC for both time series, I used a Ljung-box test to find the p-value. If the p>0,05, there is little evidence of non-zero autocorrelation, which indicates that there is a big chance of autocorrelation.

```
#Number of recordings
batc_ask_nr.rec_forecast_HW <- HoltWinters(batc_ask_nr.rec_ts, gamma=FALSE)
batc_ask_nr.rec_forecast2 <- forecast(batc_ask_nr.rec_forecast_HW)
batc_ask_nr.rec_forecast2$residuals <-
na.omit(batc_ask_nr.rec_forecast2$residuals)
Box.test(batc_ask_nr.rec_forecast2$residuals, lag=20, type="Ljung-Box")
#Temperature
batc_ask_temp_forecast_HW <- HoltWinters(batc_ask_temp_ts, gamma=FALSE)
batc_ask_temp_forecast2 <- forecast(batc_ask_temp_forecast_HW)
batc_ask_temp_forecast2$residuals <-
na.omit(batc_ask_temp_forecast2$residuals)
Box.test(batc_ask_temp_forecast2$residuals, lag=20, type="Ljung-Box")
```

The p-value of both time series is =0.75, thus there is little evidence of non-zero auto correlation. In other words, there is evidence of autocorrelation, that is one point in the dataset is dependent on the previous one (as seen in Figure A2.12 and A2.14).

Appendix III

My study was part of a larger project on bat ecology and physiology. In connection with data collection for other parts of the project, a large number of bats were captured in harp traps and (mainly) mist nets near the monitored roosts. Table A3.1 show the *M. brandtii* bats, and Table A3.2 show the *M. mystacinus* bats captured during the 2018 field season

Table A3.1: M. brandtii captured the summer of 2018. Sex (F/M), number of females and males captured. For bodyweight (g) and forearm length (mm) I report the range (minimum-maximum) if more than one individual was captured. Reproductive status is given as pregnant, lactating, post-lactating or juvenile.

Date	UTM 32V_E	UTM 32V_N	Sex (F/M)	Weight (g)	Forearm-length (mm)	Pregnant	Lactating	Post-lactating	Juvenile
05.06	605622	6658349	3/0	5.8-6.3	33.7-35.4	-	-	-	-
07.06	603924	6664840	0/1	4.4	34.1	-	-	-	-
11.06	605167	6658714	10/1	4.7-7.5	32.3-35.6	-	-	-	-
13.06	606291	6660070	17/1	5.0-8.5	33.1-36.4	-	-	-	-
18.06	605167	6658714	2/0	6.1-6.2	34.8-35.6	-	-	-	-
03.07	606335	6659976	3/1	5.6-7.6	32-7-36.6	-	3	-	-
07.07	606683	6662313	2/0	5.8-6.5	33.5-34.5	-	1	-	-
16.07	605225	6658470	271	6.1 **	34.2-36.0	-	-	1	-
18.07	607328	6660699	0/1	5.9	35.9	-	-	-	-
20.07	606335	6659976	1/1	5.8-6.2	34.9-35.1	-	-	-	-
21.07	606451	6660489	3/2	4.8-6.6	34.1-36-9	-	-	2	1
01.08	616869	6647619	1/1	4.8-6.3	35.7*	-	-	-	2
04.08	606068	6659374	3/1	5.3-6.5	35.2-36.6	-	-	3	-
11.08	605622	6658349	2/0	4.5-5.8	33.7-35.8	-	-	2	-
13.08	604392	6665742	0/1	8.6 ***	38.8 ***	-	-	-	-
14.08	606068	6659374	1/0	6.2	35.0	-	-	-	-
18.08	606344	6659964	1/0	5.7	36.3	-	-	-	-
19.08	606068	6659374	3/0	4.4-6.6	32.8-35.1	-	-	2	-
20.08	605225	658470	0/1	4.4	34.3	-	-	-	1
Total			45/11	4.4-8.5	33.5-36.6	-	4	10	4

*Several individuals had the same values. ** value missing for one or more individuals. *** Possible error in the reported data

Table A3.2: M. mystacinus captured the summer of 2018. Sex (F/M), number of females and males captured. For bodyweight (g) and forearm length (mm) I report the range (minimum-maximum) if more than one individual were captured. Reproductive status is given as pregnant, lactating, post-lactating or juvenile.

Date	UTM 32V_E	UTM 32V_N	Sex (F/M)	Weight (g)	Forearm-length (mm)	Pregnant	Lactating	Post-lactating	Juvenile
05.06	605622	6658349	5/1	4.3-5.0	32.2-35.7	-	-	-	-
07.06	603924	6664840	0/1	4.4	34.1	-	-	-	-
11.06	605167	6658714	10/1	4.7-7.5	32.3-35.6	-	-	-	-
13.06	606291	6660070	1/1	5.0-5.5	33.1-34.1	-	-	-	-
18.06	605167	6658714	7/2	4.4-5.8	32.5-34.8	-	-	-	-
24.06	605167	6658714	7/0	6.7-7.8	31.3-36.9 ***	4	-	-	-
25.06	605809	6658641	1/0	6.8	35.3	1	-	-	-
06.07	605622	6658349	2/0	5.3*	32.2-33.5	-	-	-	-
07.07	606683	6662313	0/1	5.4	33.4	-	-	-	-
10.07	604392	6665742	1/1	4.7-5.5	32.9-34.2	-	-	-	-
11.07	605889	6655147	4/1	4.7-5.6	32.7-35.1	-	-	3	-
13.07	604392	6665742	2/0	5.6-6.2	34.0-34.4	-	1	-	-
14.07	604230	6665128	4/0	5.4-5,9	34.3-35.6	-	1	-	-
15.07	606683	6662313	1/0	6.5	31,7 ***	-	-	1	-
16.07	605225	6658470	19/2	4.5-6.8 ***	31.9-36.5	-	1	17	-
21.07	606451	5550489	2/1	5.1-5.7	34.1-35.9	-	-	2	-
03.08	605889	6655147	3/1	4.4-4.7	33.5-34.7	-	-	1	3
20.08	605225	6658470	7/7	3.9-5.0	32.0-36.1	-	-	6	3
21.08	605889	6655147	0/4	3.9-4.8	33.0-34.4	-	-	-	1
Total			86/25	3.9-7.9	32.0-36.0	5	3	30	7

*Several individuals had the same values. *** Possible wrong reported data

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway