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The hunt for maternity colonies: a pilot study of using radio telemetry to track bats in southeast Norway.

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Abstract

1. There is still a gap of knowledge regarding bats in Norway. More studies are needed to explore which habitats are important for the maternity colonies, and which methods are most suited to find them. This is especially important in the most densely populated area of Norway: the south east. Increased human encroachment and land use change may affect bat in a manner of ways, from putting them under intense pressure, to providing new colony sites.

2. The goal of the study was to find maternity colonies of five common Norwegian bat species (order: *Chiroptera*) in rural and forested areas close to Oslo. Furthermore, we wanted to investigate the numbers of individuals at each colony, their spatial movements upon leaving the colony in the evening, how they moved in the landscape to their foraging ground(s) and lastly, we wanted to see to what extent terrain obstructions and distance influenced the signals we picked up from radio-tagged bats.

3. We conducted a study during summer 2017 to find maternal colonies of our study species: *Myotis brandtii* (brandt's bat), *M. mystacinus* (whiskered bat)*, M. daubentonii* (daubenton's bat)*, Plecotus auritus* (brown long-eared bat) and *Eptesicus nilssonii* (northern bat). We found colonies presumed to be maternity colonies for all species except *Eptesicus nilssonii.* Furthermore, we explored various methodological approaches to locate maternity colonies and recorded flight patterns upon colony exit and movement routes in the landscape to foraging areas. A total of 12 bats were radio-tagged with VHF tags and thereafter manually tracked until a stationary day roost was found. The presence of a colony was confirmed by observation of more than one bat exited the day roost in the evening. In addition, the bats were tracked while outside the colony to collect information on landscape features and/or hunting grounds used by the bats, and the commuting routes used by bats leaving and returning to the colonies. We also carried out a methodological test to quantify if and how the signals from the radio tags were influenced by the position of the tag (height above ground), distance between the tag and the observer (receiver), topography and forest density.

4. We found that VHF telemetry is a useful and relatively efficient method for identifying (social) roosts and maternity colonies during the maternity (summer) season, whereas tracking them to determine spatial movements and habitat use was more resource intensive and often challenging. We found roosts used by multiple bats, assumed to be maternity colonies, in: a barn, aspen trees (2), houses (2), a bridge and a church. We also found that the probability of detecting a signal from the radio tags, as well as the signal strength depended on the distance to the tag, tag position (ground level or elevated), and to the amount of solid ground obstructing the tag signals. Tree density had no significant impact.

5. Our study suggests that VHF telemetry is still a worthwhile method for finding colonies and roosts for bats, but tracking them real-time in a topographically challenging area is both difficult and requires a lot of personnel to collect accurate positions.

Introduction

Bats constitute one fifth of all land-living mammal species in Norway (Isaksen *et al*. 2009), seven of the 12 species are on the national red list (Henriksen & Hilmo, 2015). They are found throughout most of the country, with one species (*Eptesicus nilssonii*) even breeding north of the polar circle (Rydell *et al.* 1994). Bats native to Norway are valuable ecosystem service providers, they hunt pest species, diminish insect populations and have great potential to serve as vital bioindicators (Jones *et al.* 2009). There have been some previous scientific studies that focus on bats in Norway, but most of them have been limited to the west (e.g. Michaelsen *et al*. 2011, 2013, Michaelsen 2016) and the north (e.g. Rydell *et al*. 1994, Frafjord 2013) of the country. During the last 20 years there has been a substantial improvement in increasing our knowledge about bats in Norway (Isaksen *et al*. 2009). Yet, despite significant progress being made, we still have a long way to go.

Norway has been a party of EUROBAT since 1993 (http://www.eurobats.org/), where according to Article 3 of the Agreement Text, Fundamental obligations (http://www.eurobats.org/official_documents/agreement_text#ARTICLEIII): each party shall give due weight to the conservation of bat habitat, safeguard bat populations and promote research that involve bats, among many other stipulations. The point is Norway carries a responsibility as a party of EUROBAT to conduct science-based conservation, which this study will act upon.

Bat populations face many challenges worldwide: climate change, habitat destruction, fragmentation, degradation of drinkable water quality, wind turbines, pesticides, diseases, overhunting and agricultural expansion (Jones *et al.* 2009 and Lesiński *et al.* 2011, Mickleburgh *et al.* 2002); pressure on foraging habitat and roosts due to habitat loss and fragmentation especially so (Mickleburgh *et al.* 2002). As the need by humans for housing and industrial development requires more and more land, more disturbance and more deterioration of habitat will also occur (Kurta & Teramino, 1992).

Humans change the habitat for many species for better or worse, by removing or adding resources vital to their survival, such as hunting habitats. However, critical habitats are not only important for acquiring food; other important habitat features, include roosts sites and maternity colonies. For many bats species, urban environments can provide many suitable roost sites (Geggie & Fenton 1985).

Previous studies have found that many bats have clumped distribution, for example when gathering together in roosts for reproduction (Kunz, 1982).For conservation and management purposes these critical habitats are of vital important to discover, and to understand. The most important type of these critical habitats are the maternity colonies, the very heart of bat reproduction ecology and vital to the continuation of the species. A maternity colony is where bats gather to rear their young. They are similar to regular day roosts in that they protect the bats from predators and provide a sheltered environment with adequate temperature (Vaughan, 1987). However maternity colonies must house the colony when it is at its largest and when the days are the longest. In temperate zones during summer, when the young are born, the nights are at their shortest which means that the bats spend over half the day inside their maternity colony. The roosts provide shelter from the elements and a higher than temperature than the surroundings which minimizes the need to spend energy on heat. They can also provide a short distance to water or foraging grounds. It is therefore not hard to imagine that when the bats find a suitable colony, they will keep returning to it year after year (Entwistle, 1994). Colonies are aggregations; but vary in size, often from day to day. Many bats also swap colonies or utilize several colonies, but at different times (Kunz, 1982), which can lead to conservation issues, potentially leading to assessing empty roost sites as unimportant.

In addition to maternity colonies; foraging areas, corridors, flight routes and spatial usage of bats are all important for conservation purposes (Jones, *et al.* 2009). In order to determine the landscape usage of the bats, we used radio telemetry, i.e. we radio tagged the bats with tiny VHF radio-transmitters and then tracked them based on the signals (van der Kooij, 2012). However, there are some expected challenges with this approach within our study area. According to the manufacturer of our tags, the estimated detection ranges are based on open spaces (http://www.biotrack.co.uk/faqs.php), which means the varying topography of our study area could pose a problem.

For conservation purposes the flight routes are important not only for direct hazards like roads (e.g. Kerth & Melber 2009, Lesiński 2007, Lesiński *et al.* 2011, Michaelsen *et al.* 2011, Schaub *et al*. 2009, Zurcher *et al.* 2010)., but also to determine landscape structures that might serve important roles to the bats: linear structures of trees within large agricultural landscapes as corridors and edge vegetation surrounding rivers, streams are such examples and foraging areas are examples of such features (Isaksen *et al*. 2009). There is a large amount of varying topography within our study area combined with small tag with limited range which could make the process of determining which habitats and landscape features are important difficult. As such, we wish to determine the influence terrain features such as tree density, hills and mountains have on our signals, thereby determining if this study method will work for future studies within the same or similar areas.

This study will focus on locating social roosts and maternity colonies of five common bats species native to southeast Norway: the brown long-eared bat (brunlangøre) *Plecotus auritus*, Daubenton's bat (vannflaggermus) *Myotis daubentonii,* the whiskered bat (skjeggflaggermus) *Myotis mystacinus*, Brandt's bat (skogflaggermus) *Myotis brandtii* and the northern bat (nordflaggermus) *Eptesicus nilssonii*. We wanted to find out if capturing and radio-tagging bats in or on their way to their hunting areas during night, and thereafter tracking the bats throughout the night until they returned to the colony in the morning, is an efficient method to identify social roosts and maternity colonies of various bat species. In addition to locating maternity colonies and recording the characteristics of such sites, our aim is also to quantify colony size (number of individuals) and study spatial movements of bats from when they leave the colony in the evening until they return in the morning. We also carried out a field test to quantify and analyse how topography, tree density and tag position influence the likelihood of picking up signals from the radio-tagged individuals.

Our predictions are that telemetry will still be a useful method to use even within a topographically challenging area for the purposes of finding maternity colonies and important flight patterns within the landscape of our study species. We expect hills, distance and tree density to negatively impact the likelihood of detecting a signal, with hills being the most severe.

Materials and methods

The core study area was Nittedal municipality (fig. 1), Akershus country in southeast Norway. Nittedal is a predominately rural community within a valley of Romeriksåsene, with a river running through its centre. The primary landscape types are agricultural fields and rural residential areas at lower altitudes, with coniferous forests being the primary landscape habitat at higher altitudes of both sides of the valley. The average temperatures and precipitation during the study period is detailed in Table 1. The field work started in June and ended in August 2017 for locating maternity colonies and tracking the bats. The signal detection trials were conducted during November of the same year.

Table 1: Mean temperature, precipitation and wind during the project period measured in Hakadal, within Nittedal municipality, by the Norwegian Meteorological Institute in 2017.

	Temperature		Precipitation			Wind	
Month	Mean	Norm.	Mean	Norm.	Highest + date	Mean	Highest + date
June	13,9°	14,2°	100,2 mm	80,0 mm	29,8 mm 10. Jun	1,4 m/s	5,5 m/s 21. Jun
July	15,4°	15,5°	71,9 mm	89,0 mm	14,5 mm 17. Jul	1,2 m/s	4,8 m/s 13. Jul
August	13,8°	13,8°	184,8 mm	124,0 mm	34,0 mm 10. Aug	1,0 m/s	4,6 m/s 16. Aug
September	10,8°	9,3°	140,8 mm	111,0 mm	33,4 mm 12. Sep	1,0 m/s	4,1 m/s 12. Sep
October	5,2°	4,6°	167,3 mm	105,0 mm	50,3 mm 25. Oct	1,3 m/s	7,9 m/s 30. Oct
November	-0,8°	-1,5°	123,4 mm	106,0 mm	36,9 mm 23. Nov	1,1 m/s	5,6 m/s 24. Nov

For the most part our study area had more precipitation during June and August than the norm and less precipitation in July.

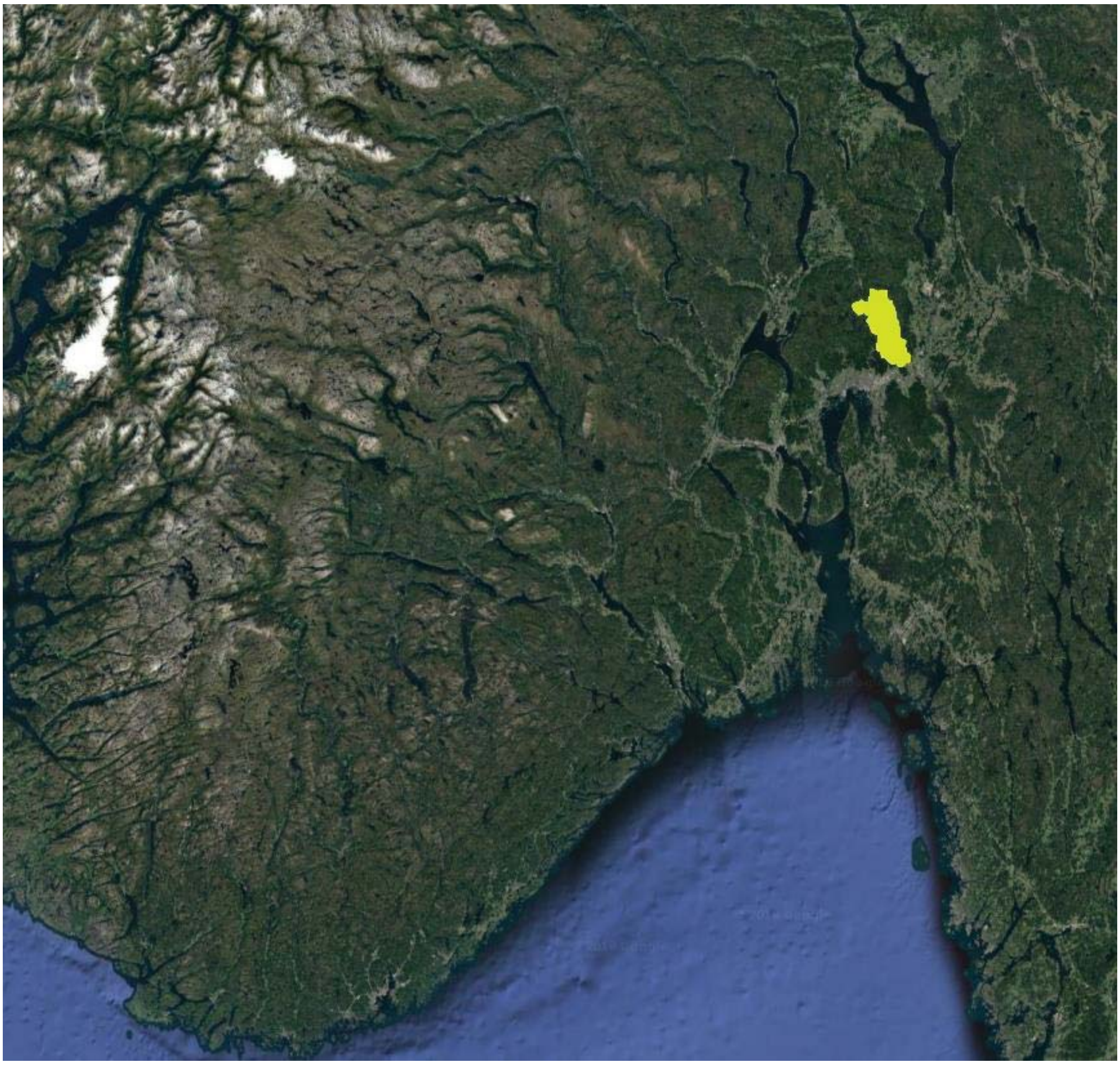

Figure 1. Scale: 1:3 840 000. Map of study area, Nittedal municipality in Akershus county, Norway. Coordinates given in WGS 84 utm zone 32: northeast corner: 603236, 6673334; northwest corner: 593177, 6668621; southeast corner: 611300, 6652858 and finally the southwest: 608878, 6650050.

STUDY SPECIES

The brown long-eared bat, easily recognized by its large ears and relatively broad wings, is a slow flyer with the ability to hover which makes it easier to glean insects. They usually start their nightly activity later than other Norwegian bats and hunt around individual trees or in forests (Entwistle *et al.* 1996). Daubenton's bats belong to the genus *Myotis* or "mouse-eared bats" and can be recognized by the relatively small and brown ears and is most easily distinguished from other *Myotis* due to its unique hunting behaviour right above water surfaces. It can also hunt in forests where it is very difficult to separate from the other

Myotis species of Norway (Sunding, 2007). Whiskered bats and Brandt's bats are among the smallest Norwegian bats and are morphologically very similar, however not very closely related (Ruedi & Mayer, 2001). Whiskered bats in Britain selects grassland (Berge, 2007), while in Norway it seems to prefer woodland more (Sunding, 2007). Brandt's bats tend to select coniferous forests, but both feed primarily on *Diptera* and *Lepidoptera* (Berge, 2007). The northern bat is the most common of the Norwegian bats and has the widest distribution: even beyond the arctic circle (Rydell *et al.* 1994). They are larger than Brandt's bats and whiskered bats and with a larger wingspan and is easy to recognize due to their very characteristic "tap-dancer" echolocation sound. They often hunt in semi-open landscapes but can be found foraging almost anywhere (Sunding, 2007).

BAT CAPTURES

The bats were captured using either mist nets (figure 2) or harp trap (figure 2). We also utilized a bat lure (Apodemus, Netherlands), which replayed calls from several different species of bats to attempt to lure more bats to the capture site. All captures were supervised by Jeroen van der Kooij, who has more than 20 years of experience with bat captures. PicoPip or Pip4 radio tags (Biotrack, U.K.), adhering to the "5% rule" (the tag not exceeding 5% of the total body weight of the bat) as much as possible (Aldridge and Brigham, 1988), was attached to the back of the bats with glue (Sauer-Hautkleber, Manfred-Sauer GMBH) which would dissolve after 3-4 weeks. All captured bats were weighed to the nearest 0.1 grams, their underarm length measured to the nearest 0.1 mm, their gender determined, and their species identified (Haarsma, 2008).

Figure 2: Left: Example of mist net setup across the river Nitelva. Right: Example of harp trap set up across an underpassage used by bats. Pictures by Jeroen van der Kooij.

All captured bats with forearm length and mass are detailed in the appendix. The tagged bats are detailed in table 2, with frequency, forearm length, mass, percentage of tag weight to body weight and for how many days they were tracked.

The capture sites were selected to maximise the chances of finding as many maternity colony sites as possible. We relied on the expertise of Jeroen van der Kooij for selecting capture sites. Usually landscape features that were likely bat corridors or hunting paths ended up as capture sites, along with suitable spots close to roosts or colonies.

The core field crew consisted of: Jeroen van der Kooij, Rune Sørås, Kristian Kristansen and Gunnar Joakim Siljedal. We were also assisted by Janneke Scholten, Charlotte Nicolas, Alex Sattarvandi and Katrine Eldegard.

The traps were monitored as closely as possible without using too much light, which could scare the bats away. To detect bats without the use of light we used hand-held high-frequency audio batdetectors (SSF Bat2 Detector and Magenta Bat 5 bat Detector). Unfortunately, the most prevalent specie, the brown long-eared bat, proved difficult to pick up using detectors, thus occasional checks of the nets with flashlights had to be conducted. All personnel handling the bats were vaccinated against rabies, because bat rabies has recently been detected for the first time in mainline Norway (Moldal et al 2017).

The bats were kept in soft cotton bags while waiting for the glue to dry or in some cases waiting in line as many bats were captured at once. If necessary, they were kept warm by keeping them on the inside of coats or jackets. Prior to release they were fed mealworms to make up for lost hunting time.

Table 2: Overview of radio-tagged Brandt's bats (*M. brandtii)*, whiskered bats (*M. mystacinus*), Daubenton's bats (*M. daubentonii*), brown long-eared bats (*P. auritus*) and northern bats (*E. nilsonii*), during the summer field work period in 2017, BatID = latter numeric of the individual frequencies (142.XXX MHz), Cap. Site (capture site) where the bat was caught with location shown in figure 3, % weight = relative weight of radio-tag in relation to body mass, Ageclass: Ad = adult; Days tracked = number of days the bat was tracked after radio-tagging (* denotes that it was the number of days between the first and last signal capture, i.e. the bat was not tracked every night).

Date of capture	Species	MHZ (142)	Cap. site	Sex	Name	Forearm (mm)	Mass (g)	% Weight	Age class	Days Tracked*
12.06.2017	*M. brandtii*	203	f	F	Grethe	34.9	5.70	6.67	Ad	10
12.06.2017	*M. brandtii*	049	f	F	Nathalia	35.0	5.70	6.67	Ad	8
18.06.2017	*M. mystacinus*	131	f	F	Ingrid	34.5	4.80	6.25	Ad	7
22.06.2017	*M. daubentonii*	303	g	F	Kristin	38.1	12.10	3.64	Ad	7
23.06.2017	*M. daubentonii*	319	c	F	Fleur	38.0	11.20	3.93	Ad	6
26.06.2017	*M. mystacinus*	086	d	F	Lene	35.3	5.85	5.13	Ad	5
28.06.2017	*P. auritus*	290	a	F	Lola	39.4	11.50	3.83	Ad	5
28.06.2017	*P. auritus*	155	a	M	Snurre	39.2	7.80	5.13	Ad	1
29.06.2017	*P. auritus*	284	e	F	Silje	40.0	11.40	3.51	Ad	0
29.06.2017	*P. auritus*	041	e	F	Nemi	38.4	8.80	4.54	Ad	5
30.06.2017	*M. daubentonii*	168	h	M	Janus	39.1	10.00	4.00	Ad	2
30.06.2017	*M. daubentonii*	274	h	M	Klas	37.4	9.60	4.58	Ad	4

Capture site locations for the summer period is shown in figure 3.

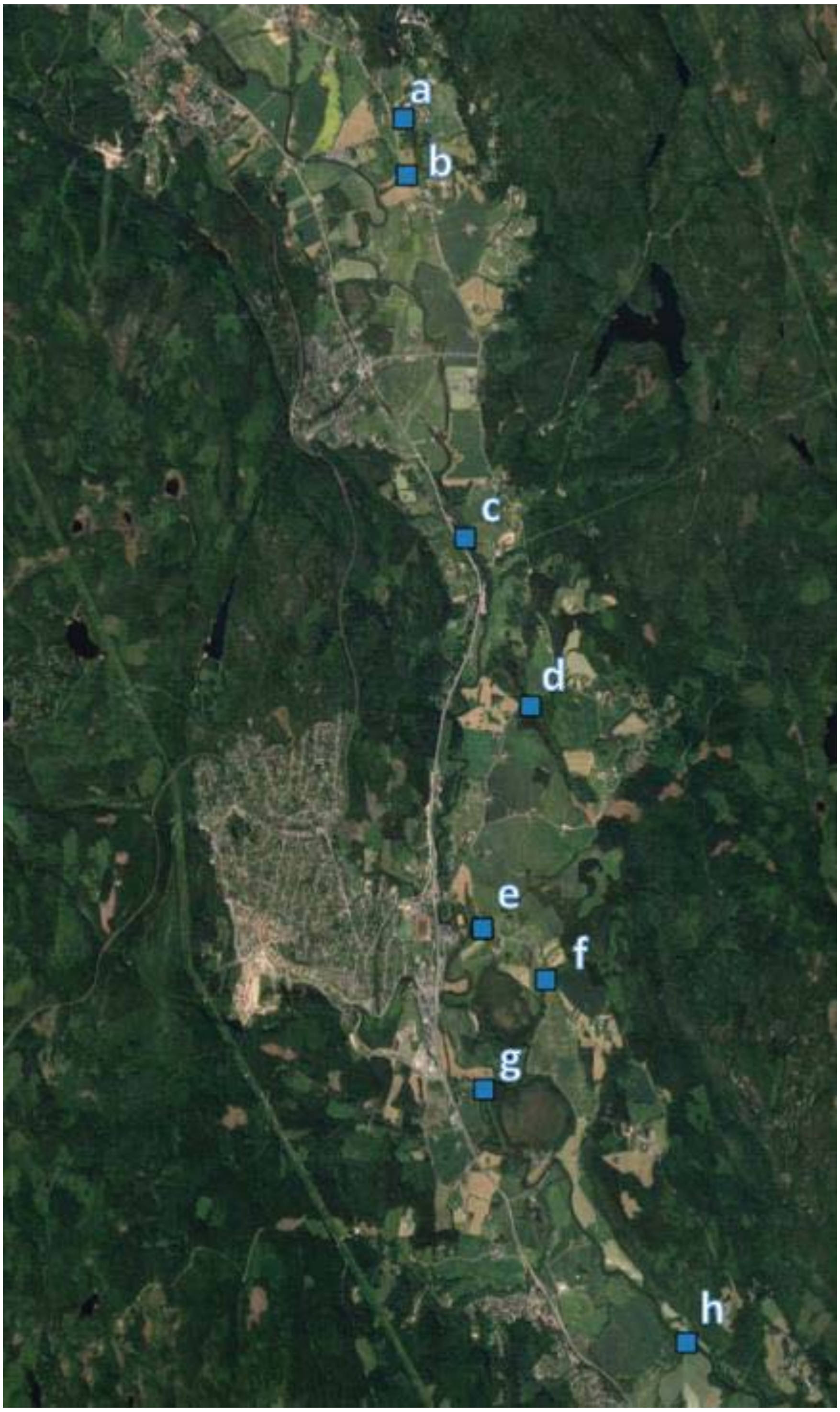

Figure 3: Scale: 1:120 000. Summer capture site overview. All blue squares show capture sites utilized within the study area. The capture sites had the following tagged bats caught: a – #290 (*P. auritus, female*) and #155 (*P. auritus,* male). b – no tagged bat. c – #319 (*M. daubentonii,* female). d – #086 (*M. mystacinus*, female). e – #284 and #041 (*P. auritus,* female). f – #203, #049 (*M. brandtii,* female) and #131 (*M. mystacinus*, female). g – #303 (*M. daubentonii,* female). h – #168 and #274 (*M. daubentonii,* male).

BAT TRACKING

Bats were fitted with tag frequencies in the 142.000 to 142.330 MHz range. We used Sika receivers (Biotrack, UK) along with hand-held 3-element yagi antennae (Biotrack, UK); mostly flexible antennae but also one rigid antenna. In some cases we also used a non-directional whip car antenna. All tracking equipment were checked to function properly before use, for this purpose we kept a test tag in the car. We used combination of cross bearings, triangulation, bat detectors and visual observations to determine bat locations. Bat positions were categorized into four types: 1) On site plots, either directly seeing the bat in combination with matching signal direction or hearing the bat by the use of a bat hand-held detector with matching signal direction. 2) Triangulation plots, which resulted from the centre of a triangle made from three bearings taken at approximately the same time.
3) Cross bearing plots, same as the triangulation plot, but only using two bearings. 4) Strong signal plots, which was the most unreliable and the most scarcely used, where the signal strength suggested the bat was very close to the observer. For these plots the coordinates of the observer were used. The strong signal plots were mostly used at the beginning of the study as it was found to be unreliable. Upon release of a tagged bat, observers were ready to follow on foot or by car while at least one observer would be positioned at high elevation sites in the terrain for better coverage. Through cross-bearing and following the signals, the observers in the car would follow by foot where needed until the bat settled. Observers would then be posted near the roost the following night to determine whether or not it was a colony.

COLONY DETERMINATION

When we observed multiple (16 was the lowest initial bat count for any colony) exiting from a roost, we presumed the colony to be a maternity colony if the tagged bat roosting there was a female in the period of June-August (Sunding, 2007). Likewise, the same was assumed for colonies that were found by roosting male tagged bats. For each colony, we extracted the landscape types coverage calculated within a 100m radius (table 4). Landscape type data was acquired from digital maps/foto from NIBIO (https://www.nibio.no/), and Geovekst/Nittedal. In addition, all names were attempted a proper translation from Norwegian to the CORINE Land Cover (CLC) terminology, a global land monitoring service, as to make the terminology more comparable and easier to understand as per Schøning & Jonassen (1997). All Norwegian terms have been supplied as well. The results of this can be found in table 3 in the results.

COUNTS AND LOCAL MOVEMENTS AT EXITS

When a colony was detected and confirmed (i.e., several bats observed to leave in the evening), each colony had the number of bats counted upon exit in the evening at least once. At least one observer was stationed outside the colony well before the first bats began to exit the colony. The observer then counted and noted down the number of bats leaving in each five-minute interval. Observers positioned themselves in a manner conducive to gaining contrast against the bats making them as easy to count as possible. Count ended after no bat was observed leaving for 15 minutes. In addition to counting the number of exits, the spatial movements of bats leaving the colony were documented by drawing sketches for at least one count for each of the colonies. When tracking bats after the colony was found, we would go over potential routes the bats might take, then we positioned observers accordingly in the field. We would also have some observers tracking the bats using a combination of cross-bearings and homing in (a continual barrage of bearings while moving to find the proper bearing to the bat) to determine and/or exclude bat routes. Preferably this process would repeat for a few days at least, to narrow down the flight routes as precisely as possible.

SPATIAL MOVEMENTS AND USE OF LANDSCAPE FEATURES

Results from accumulated plots, observer position and counts in the field were used to calculate home ranges. The home ranges give us an indication of which area the tagged bats used. To make more detailed maps of movement we used strategically positioned observers to reject potential bat routes within the home ranges. Preferably we would be able to pincer the tagged bats from two opposite directions to exclude any other possible routes or have on site plots with each bat. For certain parts of a bat's flight journey, its specific route could not be determined. In these instances, we included suggestions for where it could potentially go, based on direction from plots we were certain about, notes on observations in the field regarding bat species sightings and/or features in the terrain can dissuade bats from using a particular route (like bright lights for instance, Rydell *et al.* 2017). Not all individuals were followed closely, either due to losing tags, lack of personnel or simply losing track of the bat(s).

SIGNAL DETECTION TRIALS

LiDAR (Light Detection and Ranging) data was used to gather information about tree density and topographical obstructions. Tree density was measured in proportion of 15.2m by 15.2m squares filled by trees. The averages of these proportions were measured for each point, between the observer and the tag. The topography (hills, valleys, mountains etc.) was measured in the same manner as a proportion of line of sight obstructed between the tag and observer (fig. 4), henceforth abbreviated to "PoLoSO" (Proportion of Line of Sight

Obstructed). Hans Ole Ørka of the Norwegian University of Life Sciences extracted and prepared the LiDAR data for analyses. LiDAR is an active remote sensing technique where light is emitted from a sensor and reflected back to the sensor when the laser pulse hits vegetation or the Earth's surface. The scanning produces point clouds (x, y and z coordinates) that can be used to generate models which show density and structure of the vegetation (Davies & Asner 2014) and detailed terrain models.

We conducted six different trials in different landscape types throughout our study area. In each trial one transmitter (same as used on the bats) was placed approximately at 1.70 meter above ground whereas another of the same kind was placed on the ground. Three observers then recorded their own positions at approximately 0, 10, 25, 50, 100, 150, 250, 500, 700 and 1000 meters away from the transmitters, and recorded whether they detected a signal from the radio transmitter or not. If a signal was detected, bearing and receiver display values: signal strength, interference and gain (see Box 1), were recorded. All trials had the same spatial configuration and directions of north, southeast and southwest (Fig. 4).

Box 1. Received display values

Signal strength: A metric between 0-99 for determining the strength of the signal. However, in the field a value below 20 was never observed, although the signal could still be heard without showing up as a value. Sometimes the interference would be so loud that the display showed a continuous value of signal strength without any signal.
Interference: Background noise, with values of 0-8. At 3 or more however, no signal could be heard as the interference noise was too loud.
Gain: A metric between 0-99 used to boost the volume. Used to make sure the signal strength was below 99 and above the interference, so that the signal was not being capped at its maximum value and to keep it easily separable from the interference.
In the field gain was always turned down to make sure the Signal Strength was below 99 and the above the Interference.

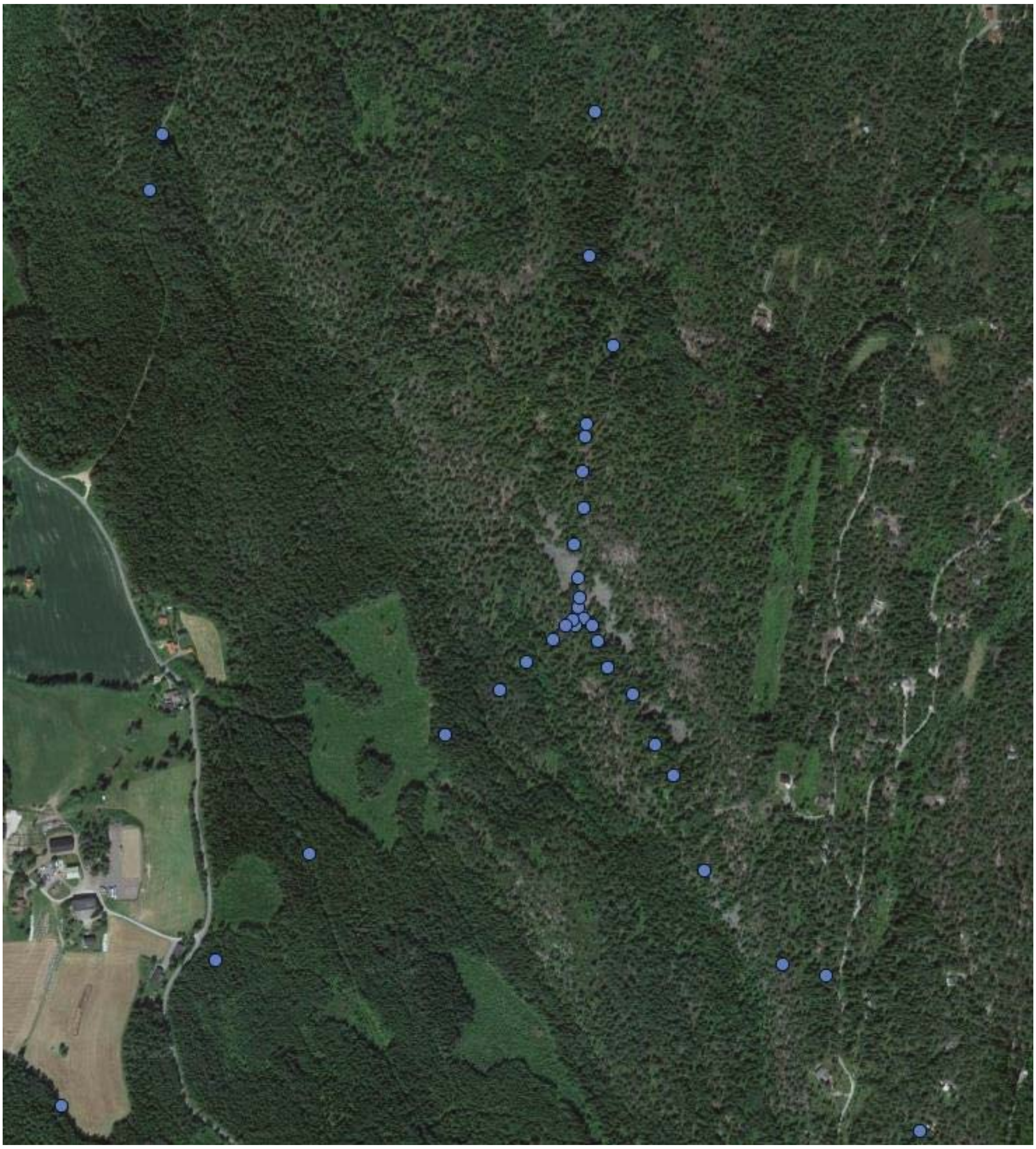

Figure 4: Scale: 1:18448. Example of spatial configuration of transmitter trial positions (one trial). Each blue dot represents one position. Positions were distributed along transects in three directions from the test transmitter at 0, 10, 25, 50, 100, 150, 250, 500, 700 and 1000 meters from the test tags. In each position, we recorded bearing, signal strength, gain and interference (Box 1). We also added additional points if we felt it necessary due to particular landscape features or sudden changes in expected signals.

ANALYSIS

Initial exploration of the dataset followed Zuur *et al*. (2010) for the purpose of finding outliers and collinearity between candidate explanatory variables and to explore relationships between response variables and explanatory variables.

On the Biotrack homepage (http://www.biotrack.co.uk/faqs.php), they mention how the detection ranges are variable to obstructions and that their ranges are meant to be for directly open spaces. Therefore, we wanted to check to what extent distance and types of obstructions influenced the likelihood of detecting a signal and the signal strength. Thus, we came up with two types of obstructions: proportion of trees between the tag and the observer, and the proportion of line of sight obstructed by the terrain (i.e. mountains and hills) see figures 5 and 6.

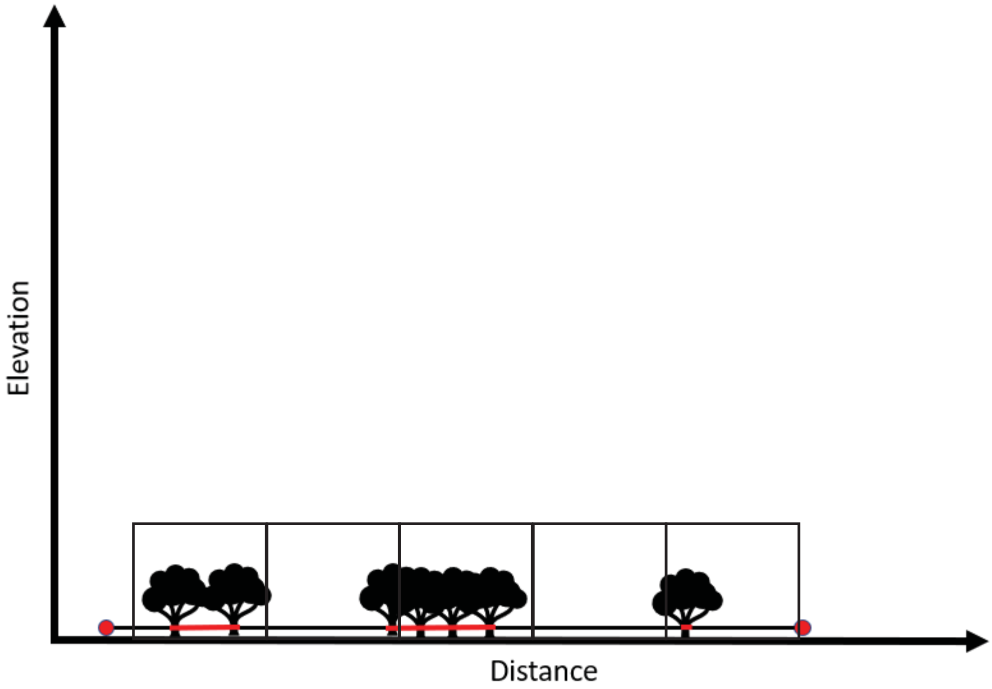

Figure 5: Chart showing how the proportion of tree density was calculated. LiDAR data gave the average tree density for 15.2m squares in the proportion the trees filled the squares. A value of 0.5 meant half of the square was filled with trees. Then the average was calculated for each square between the tag and observer to give the values for "tree density".

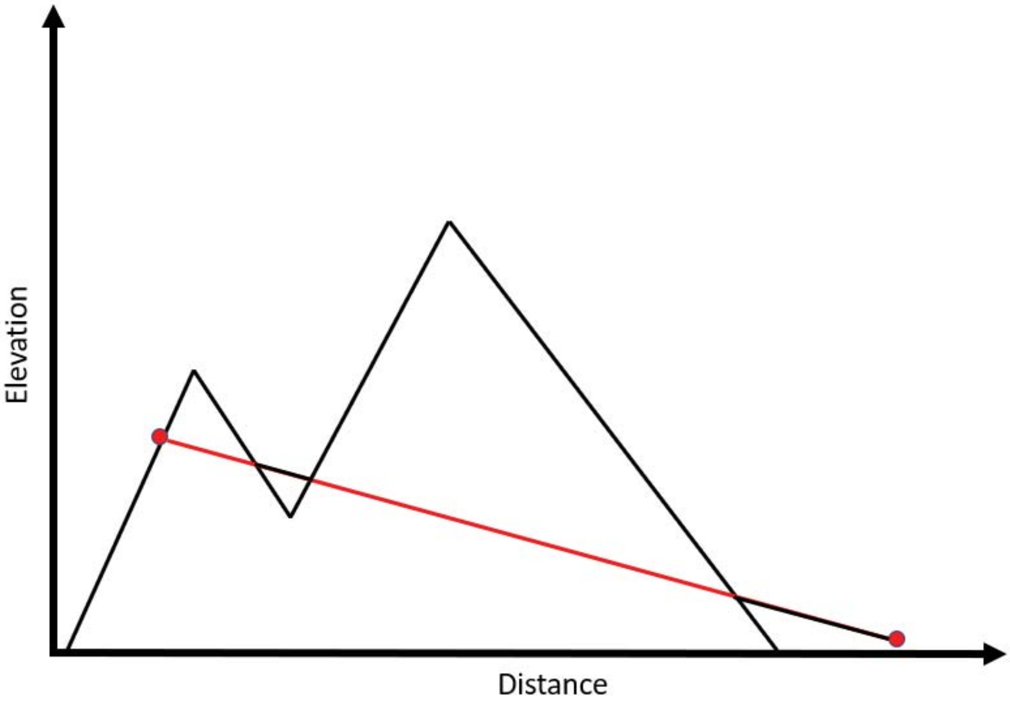

Figure 6: Shows how the proportion of line of sight obstructed (PoLoSO) by terrain features such as mountains and hills were calculated. The distance of the line of sight obstructed (red line) was divided by the total distance (red and black combined) and used as the values for “PoLoSO”. A value of 0.5 when the observer was 100 meters away from the radio tag, would mean 50 meters were obstructed by the terrain.

The programs used for drawing maps and statistical analysis were respectively QGIS Desktop 2.18.10 and RStudio: R version 3.3.2 (2016-10-31) -- "Sincere Pumpkin Patch". (R Core Team, 2016).

R packages used:

Support functions and datasets for Venables and Ripley's MASS (MASS) version 7.3-49, Linear Mixed-Effects Models using 'Eigen' and S4 version (lme4) 1.1-15, raster: Geographic Data Analysis and Modeling (raster), rgdal: Bindings for the 'Geospatial' Data Abstraction Library (rgdal), sp (Pebesma & Bivand, 2005) and the following adehabitat packages (Calenge, 2006): adehabitatHR, adehabitatLT, adehabitatHS and adehabitatMA.

R analysis used:

To analyse factors influencing the likelihood of detecting a signal from a tag, we used a binomial regression for all data points from the transmitter test; 1 meant the signal was heard, 0 meant it was not heard. We assumed a binomial distribution of errors and used the logit link function to fit generalized linear mixed models (GLMMs) in the lme4 library in R (Bates, *et al.*, 2015). Explanatory variables included were distance from the tag to observer (m), Proportion of Line of Sight Obstructed (PoLoSO), proportion of tree density between the tag and the observer identity, tag position (whether ground level or ca. 1.7m above ground), observer identity and the interaction between tag position and distance (most complex model). Other interaction terms were omitted since both tree density and PoLoSO are proportions of distance. Both tag and observer identity were initially included as random effects and ANOVA was used to determine that the best model was better without observer identity and tag position as random effects, in any combination.

Model selection was carried out with the stepAIC function (requires the MASS package in R) and we retained the model with the lowest AIC. The best model for explaining the probability of detecting a signal included distance (to tag), PoLoSO and fixed tag position as explanatory variables to the likelihood of hearing a signal (binomial).

To analyse factors influencing the signal strength, we used a linear mixed model (GLMM) for all data points where we heard a signal from the transmitter test (values between 1 and 99). Explanatory variables included were distance from the tag to observer (m), Proportion of Line of Sight Obstructed (PoLoSO), proportion of tree density between the tag, tag position (whether ground level or ca. 1.7m above ground), observer identity and the interaction between tag position and distance (most complex model). Other interaction terms were omitted since both tree density and PoLoSO are proportions of distance. Both tag and observer identity were initially included as random effects and ANOVA was used to determine that the best model was better without observer identity and tag position as random effects, in any combination.

Model selection was carried out with the stepAIC function (requires the MASS package) and we retained the model with the lowest AIC value. The best model included distance, PoLoSO, fixed observer identity and fixed tag position as explanatory variables to signal strength as the response variable.

To determine home ranges; kernel density plots were used and visualized in QGIS using points from on site plots, strong signals (coordinate of observer), cross-bearing plots and triangulation plots. 50%, 75% and 95% percentiles were used to determine home ranges. Packages required for R were: adehabitatHR, adehabitatLT, adehabitatHS, adehabitatMA (Calenge, 2006). sp (Pebesma & Bivand, 2005), raster and rgdal. The coordinates were loaded in as a spatial point dataframe after excluding outliers. Since the coordinates of the observers were used for the strong signal plots, the homeranges are inflated and was therefore used conjunction with knowledge from previous literature, patterns seen in movement and terrain usage in bats to give a visual representation of landscape usage of our bats in addition to the homeranges.

Results

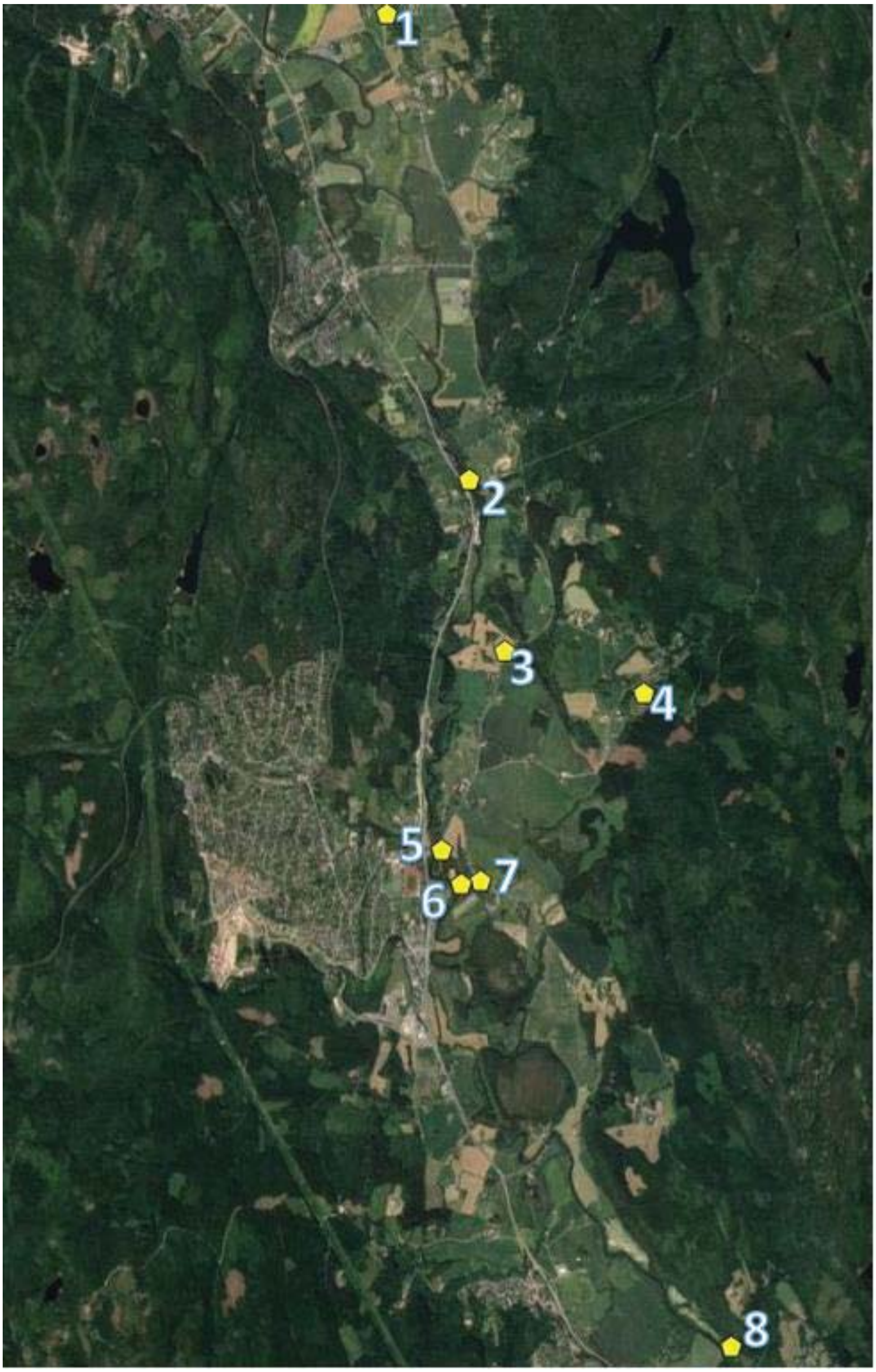

Figure 7: 1:147585. Map of all maternity colonies located (yellow pentagrams). Colonies numbered for ease of recognition in no particular order. Colony number one was not found as part of this study, but was known from van der Kooij (2012).

COLONY SITES IDENTIFIED

All the colonies (except the brown long-eared bat colony at Hakadal church) were found by radio tagging bats on selected capture sites in the landscape (see methods), and thereafter tracking the radio tagged individuals throughout the night after release until they returned to a colony site. Below follows a description of each of the colony sites.

Brown long-eared bats (*P. auritus*)

Hakadal church

The the brown long-eared colony (fig. 7 - colony 1) was located on the eastern side of the building, close to the ceiling of the 2nd floor. The bats used a small passage between the outer roof and in the inner ceiling to crawl along the building for several meters before taking flight. They also used this passage on the way back into the colony. The captured bats utilizing this colony were #290 (female) and #155 (male). This colony was not discovered as a result of radio telemetry, but as the result of a study conducted by J. van der Kooij (van der Kooij, 2012).

Figure 8: Hakadal church colony. *P. auritus* (both sexes were detected to roost within the colony). Chart of how bats used the immediate area after exit. Based on spatial movement data from three days of observations. Detailed movements mapped for 12 bats during one day, additional observers were conferred with to determine if the chart matched their perception. 29 individuals total were counted at this colony and the maximum number of bats counted in one day was 17. Picture by Jeroen van der Kooij.

The brown long-eared bats (fig. 8) utilized only one route of exit. On the other side of the church were powerful lights angled upwards followed by the open space of the graveyard and a road, the bats likely shied away from flying in that direction (Rydell *et al.* 2017). The side shown on the picture by comparison held the most shade and the shortest route to cover. Seemingly all bats underwent a "tentative" circling of a small maple tree before making the relatively long flight across the open field. After making the distance (15 m) they could be seen circling for a little while before disappearing along the thicker vegetation.

Haugestad House

The brown long-eared bat colony (fig. 7 - colony 5) was located where the roof started along the first floor, slightly east of the centre on the south facing wall. The surrounding area was an open pasture for horses, and the bats utilized many different paths, mostly following nearby trees eventually leading them to the river. None of our captured bats were observed to use this colony, but #284 (brown long-eared bat*,* female) and #041 (brown long-eared bat*,* female) did spend time close by it.

The bats exited this colony in such a spread and difference of elevation that a chart could not be made in any congruent manner. All of the bats exited from one singular point in the second floor of the south-facing wall. The majority then flew along a fence leading to either of two lines of trees which eventually lead to the river and a greater density of trees. However, some bats also flew across the open field not seeking any type of cover.

Daubenton's bats (*M. daubentonii*)

Tenniscourt Aspen

The Daubenton's bat colony (fig. 7 - colony 6) was located in an aspen approximately three meters above ground and exited through two small holes. The bats immediately flew to the river close by. The tagged bat utilizing this colony was #303 and was presumed to be a maternity colony as #303 was a female bat.

Due to the difficulty of spotting the exact exit exit (little contrast to the dense background vegetation) and due to the simplicity of the exit (apparently straight path into the nearby vegetation), no chart was made for the colony.

Rud Aspen

The Daubenton's bat colony (fig. 7 - colony 8) was in an aspen tree on a slope within a cow pasture. The bats exited through a hole approximately three meters above ground. They quickly dispersed in almost any direction but seemed to head mostly toward the river close by. One of the tagged Daubenton's bats likely roosted in a different colony after capture, but it was not found. The captured bats utilizing this colony were #274 and #168, both male. The bats exited this colony in such a spread and difference of elevation that a chart could not be made in any congruent manner. Many of the bats would circle the colony tree and nearby trees making it very hard to keep track of them.

Strøm bridge:

The Daubenton's bat colony (fig. 7 - colony 2) was located between a concrete support block and the wooden framework of the bridge itself, closer to the western end, between 2-3 meters above the river surface. The bats tended to fly immediately for the river or along the bridge to the other side of the river, and then down to the water surface before dispersing. One of our tagged Daubenton's bats (#303, female) swapped between the Strøm bridge colony and the Tenniscourt aspen colony. #319 (female) also utilized the Strøm bridge colony, and on at least one occasion at the same time as #303 (female). Both the tagged bats using this colony were female and therefore we presumed it to be a maternity colony.

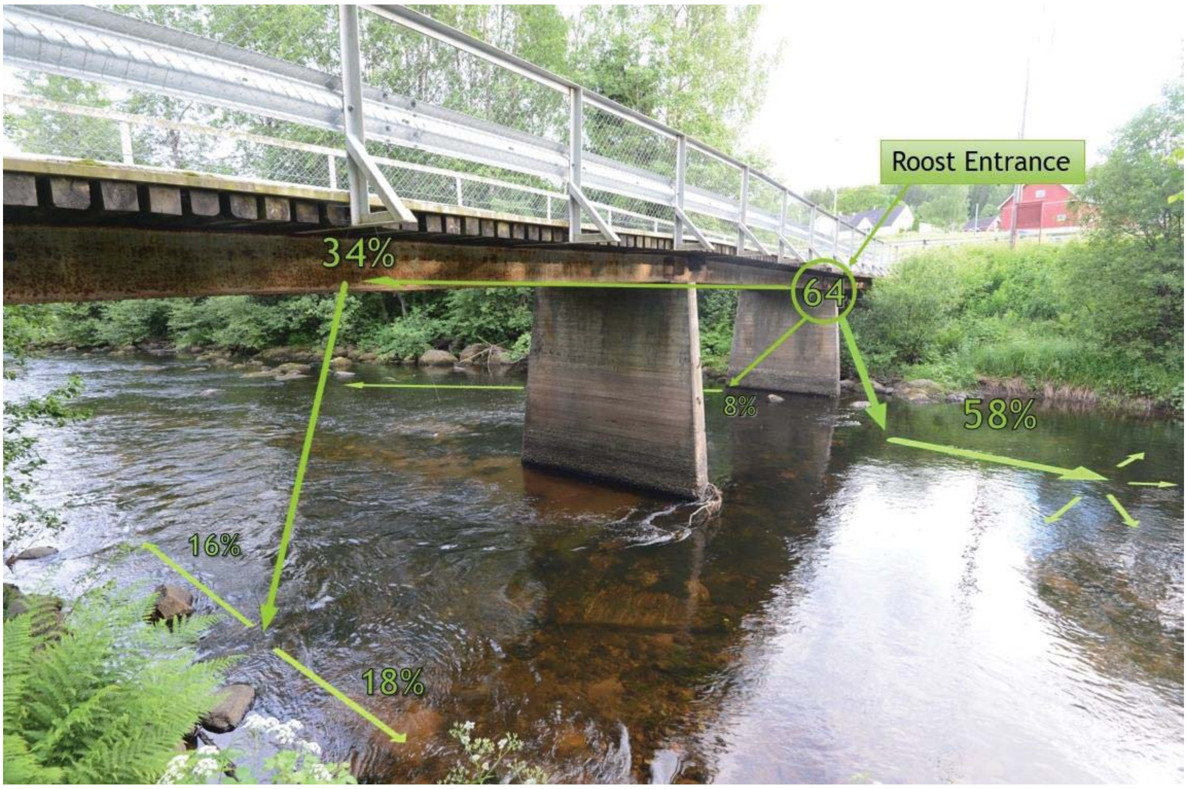

Figure 9: Strøm bridge colony. *M daubentonii* (presumed maternity colony). Chart of how bats used the immediate surroundings after exit. Based on spatial movement data from three days of observations. Detailed movements mapped for 64 bats over one day, 92 individuals total were counted at this colony and the maximum number of bats counted in one day was 64. Picture by Jeroen van der Kooij.

The Daubenton's bats (fig. 9) had their foraging ground right over the water surface below the colony. Foraging behavior could be immediately seen once the bats reached the water. Most of the bats went for the shortest path to the water, but a few went along the bridge to reach the other side of the river and some immediately started to forage. Once the bats reached the water surface however, it became impossible to tell how many went in which direction, how many started foraging on the site and how many travelled further to forage elsewhere. It was observed that some did travel further along the river, and even all the way up to a lake 3.5 km from the nearest Daubenton's bat colony (revealed by radio tracking), but all bats observed did fly to the river and then flew along the river. No bats were observed to fly away from the river.

Whiskered bats (*M. mystacinus*)

Gamleveien barn:

The whiskered bat colony (fig. 7 - colony 3) was the smallest colony found and for the most part the bats did not seem to be concentrated in one spot but seemed to use the eastern end of the barn more close to the ceiling and their main exit. On their way out they flew along the ridge of the barn bridge and used trees as 'stepping stones' before crossing the road. None were spotted flying across the open fields in other directions. The captured bat utilizing this colony was #131, which was a female, and thus this colony was presumed to be a maternity colony.

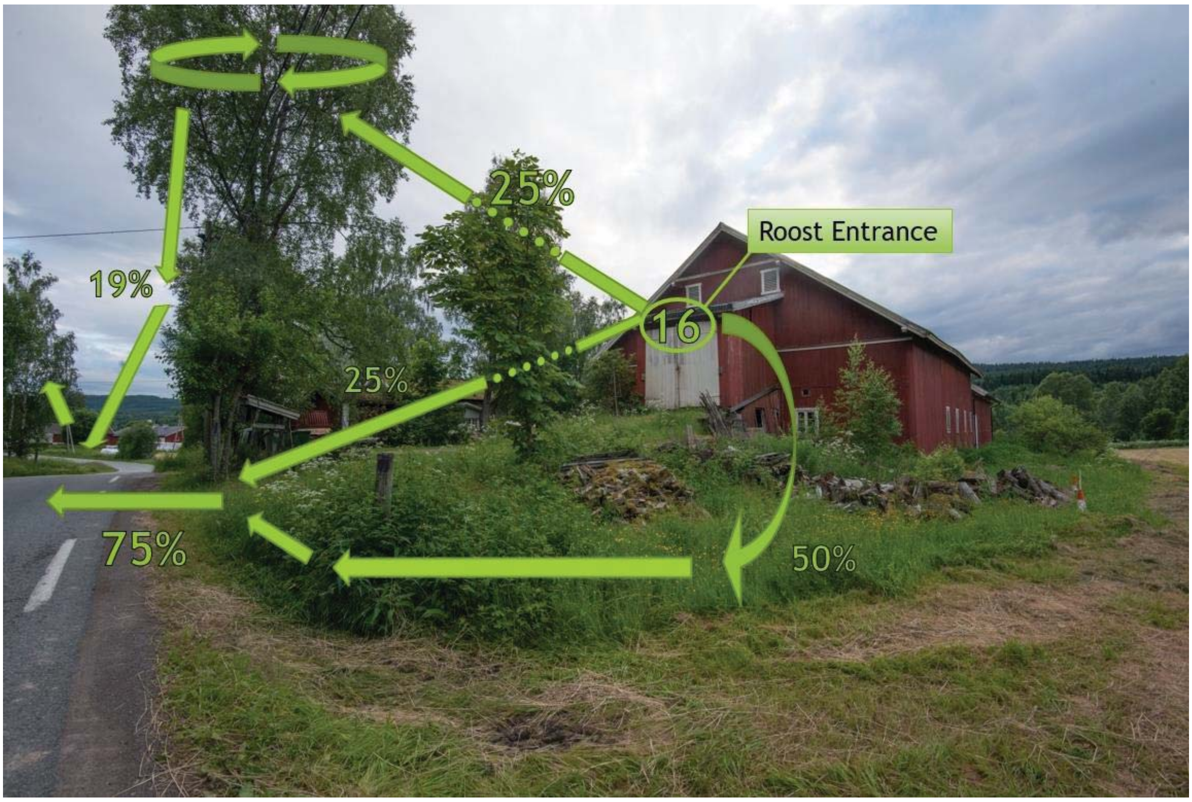

Figure 10: Gamleveien barn colony. *M. mystacinus* (presumed maternity colony). Chart of how bats used the immediate surroundings after exit. Based on spatial movement data from five days of observations. Detailed movements mapped for 16 bats over one day, additional observers were conferred with to determine if the chart matched their perception. 54 individuals total were counted at this colony and the maximum number of bats counted in one day was 16. Picture by Jeroen van der Kooij.

The whiskered bats (fig. 10) flew along objects or natural features providing cover and crossed the road at low height very close to the ground. The foraging ground identified by following the tagged bat of the colony was in the mixed forest across the road. A large open area of farmland surrounds the barn and gives very little cover on all sides except the forest across the road. A few bats also spent some time circling a tall birch before swooping down and making their way across the road. The exact crossing height was difficult to determine, but most likely not high enough to escape cars and avoid traffic mortality.

Nedre Hauger House

The whiskered bat colony (fig. 7 - colony 7) was located on the southeastern end of the house, between the ceiling and the roof on the first floor. The bats flew low across the open garden and then quickly dispersed as soon as they reached the shelter of the nearby trees. The captured bat using this colony was #131, which is a female, thus this colony was presumed to be a maternity colony.

Due to the roost exit being in a corner between an extension and the main house, facing east and south, and due to the immediate spread of the exit, mapping the exit routes take at least three persons and was thus not prioritized due to lack of personnel.

Brandt's bats (*M. brandtii*)

Askveien House:
The Brandt's bat colony (fig. 7 - colony 4) was located between the ceiling and the roof on the second floor, pointing northwest. All the bats exited along the northern wall and used a small stream surrounded by trees as cover to continue their path, which eventually led them going south through a forest road. The captured bats utilizing this colony were #203 (female) and #049 (female) and the colony was presumed to be a maternity colony.
The bats exited this colony in such a spread and difference of elevation that a chart could not be made in any congruent manner. The bats exited along the full length of the north wall, but the majority exited from eastern side of it.

Due to the roost exit being in a corner between an extension and the main house, facing east and south, and due to the immediate spread of the exit, any congruent chart would take at least 3 parts and was not prioritized.
Landscape types surrounding each colony and their percentages are given in table 3.

Landscape composition around the colonies

Most colonies seemed to be close to forests, most with at least 1/5 of their immediate surroundings filled with forest. Land cover types types surrounding each colony and their percentages are given in table 3. Both Hakadal (brown long-eared bat) and Ask (Brandt's bat) are surrounded by rural housing areas. Daubenton's bats are predictably very close to water, while whiskered bats seem to not be as heavily reliant on close sources of water. Many colonies have large amount of arable land nearby, but our study area's primary landscape types at lower altitudes (which all colonies were at) are agricultural fields and rural housing areas, as such that is to be expected.

Table 3: Percentages of land cover types within a 100m radius of each colony. All landscape cover types are named after suggested English counterparts to Norwegian AR5 landscape types. Forest = "skog", arable land = "dyrket mark", open land without significant vegetation = "fast mark med lav vegetasjon", urban fabric = "bebyggelse", road = "vei", closed pasture = "inngjerdet beiteområde", water bodies = "vann" (Schøning & Jonassen, 1997). Distance to water refers to the closest source of water.

Landcover type	Brown long-eared bats		Daubenton's bats			Whiskered bats		Brandt's bats
	Hakadal	Haugestad	Tennis	Rud	Strøm	Gamlevei	Nedre Hauger	Ask
Forest	21%	27%	40%	73%	21%	15%	34%	33%
Arable land	24%	28%	5%	18%	41%	62%	21%	4%
Open land	6%	5%	15%	0%	6%	18%	23%	0%
Urban fabric	45%	27%	20%	0%	11%	0%	18%	60%
Road	4%	4%	0%	0%	8%	5%	3%	3%
Closed pasture	0%	0%	10%	0%	0%	0%	1%	0%
Water	0%	9%	10%	9%	13%	0%	0%	0%
Distance to water	64 m	45m	6m	1m	1m	103m	114m	10m

Important landscape features

In addition with the colonies, one particular corridor was deemed to have a key role for many bats (fig. 11). It was used as a capture site on two occasions, and Brandt's bats, whiskered bats and northern bats utilized it. #203, #049 (female, Brandt's bats) and #131 (female, whiskered bat) were captured while using the corridor, and were all confirmed to use it after capture. The corridor consisted of a stream surrounding by trees running between to open agricultural fields. It connected the main river, Nitelva, and a large forested area to the east, which is likely the main reason for its importance. Table 5 shows an overview of the capture counts and other counts made within the corridor, as well as times when we detected #203 and #049 using the corridor over longer periods of time. Due to this expanded activity within the corridor it is possible that it was used for foraging as well, however in most cases the #203 and #049 would cross the corridor and spend some time on either side for a few minutes, then quickly cross over again to the other side.

Figure 11: 1:9224. The green line shows the important habitat corridor knowns as “Holterbekken”. Yellow pentagrams shows nearby colonies. “a” is the capture site location. “b” is a position where the road cross the river used on several occasions by observers counting bats. Bats crossed both above the bridge and underneath in an underpass.

Table 5: An overview of bat counts, captures and activity all measured the corridor “Holterbekken”. For the bat activity on 14.06, one tagged bat, #203 (female, *M. brandtii*), was followed closely via strong signals. For the bat activity on 15.06, two tagged bats, #203 (female, *M. brandtii*) and #049 (female, *M. brandtii*), were followed closely via strong signals. In addition activity was heard via bat detectors on several days other than those mentioned near or within the corridor.

Date	Count	Captures	Bat activity
12.06	-	8	23:30 – 24:00
13.06	10	-	23:30 – 24:00
14.06	-	-	02:00 – 03:00
15.06	-	-	01:00 – 02:00
16.06	12	-	00:00 – 00:30
18.06	-	2	23:00 – 24:00
19.06	-	8	00:00 – 03:00

COLONY COUNTS

The bats left their colonies earlier in August, than in June and July. An overview of counts, names, species, sex and name of the colonies can be found in table 5. No counts were carried out between July 10. and August 7. due to lack of personnel.

Table 5: Overview of: species, presumed sex (F = female, M = male) dominating the colony and bat counts for each colony.

ID	Type	Location	UTM32V_E	UTM32V_N	Species	Sex	Bats counted (max)	Days counted
1	Church	Hakadal	606265	6660041	*P.auritus*	M/F	17	3
2	Bridge	Strøm	605171	6658723	*M.daubentonii*	F	64	2
3	Barn	Gamlevei	605038	6658695	*M.mystacinus*	F	16	3
4	House	Ask	605020	6661475	*M.brandtii*	F	38	1
5	House	Haugestad	605291	6660307	*P.auritus*	F	28	2
6	Aspen	Tennis	604895	6658921	*M.daubentonii*	F	39	5
7	House	N. Haug	604355	6664663	*M.mystacinus*	F	43	2
8	Aspen	Rud	606992	6655569	*M.daubentonii*	M	36	6

A more in-depth view of the counts is given in table 6 for each exit that was counted during the summer study period, from mid-june to mid-august.

Table 6: An overview of all counts made during the summer field period. “Time started” refers to the time the observer was in place to begin the count. First sighing was when the first bat exiting the colony was seen. “Last sighting” means the last bat seen leaving the colony. “Time left” was when the count was stopped, either by no activity after 10-15 minutes or because the observer was needed elsewhere. “Max sighting” refers to the 5-minute interval that had the most bats counted. The total count refers to the total amount of bats counted. Sex and species refers to presumed sex of the bats of the colony, based off the sex of the tagged bat(s) belonging to it.

Date	Time started	First sighting	Last sighting	Time left	Max sighting	Total count	Species	Colony	Sex
14.06.17	22:25	23:00	23:35	23:50	23:00	38	*M. brandtii*	Ask	F
15.06.17	22:25	22:50	23:40	23:55	23:00	42	*M. brandtii*	Ask*	F
19.06.17	22:30	23:35	00:25	00:30	00:15	33	*M. brandtii*	Ask*	F
09.07.17	22:30	22:45	23:25	23:35	23:05	33	*M. brandtii*	Ask*	F
09.08.17	21:00	-	-	23:00	-	0	*M. brandtii*	Ask*	F
14.08.17	21:15	21:30	22:15	22:25	22:35	12	*M. brandtii*	Ask*	F
01.07.17	22:40	23:40	23:55	00:10	23:45	31	*M. daub.*	Rud	M
02.07.17	23:10	23:25	23:45	23:55	23:25	36	*M. daub.*	Rud	M
03.07.17	23:10	23:25	23:40	23:50	23:25	6	*M. daub.*	Rud	M
04.07.17	22:50	23:05	23:15	23:45	23:15	23	*M. daub.*	Rud	M
05.07.17	22:40	23:15	23:35	00:30	23:20	17	*M. daub.*	Rud	M
06.07.17	23:00	23:10	23:30	23:50	23:15	14	*M. daub.*	Rud	M
07.07.17	22:30	23:10	23:20	23:35	23:15	26	*M. daub.*	Rud	M
02.07.17	23:10	23:25	23:50	00:05	23:25	21	*M. daub.*	Rud*	M
02.07.17	23:10	23:25	23:50	00:05	23:25	21	*M. daub.*	Rud*	M
06.07.17	22:50	-	-	23:45	-	0	*M. daub.*	Rud*	M
26.06.17	22:30	23:05	00:05	00:05	23:10	64	*M. daub.*	Strøm	F
08.07.17	22:15	22:50	23:45	00:10	23:00	25	*M. daub.*	Strøm	F
15.08.17	21:10	21:30	21:40	22:00	21:30	3	*M. daub.*	Strøm	F
22.06.17	22:40	22:55	23:40	23:55	23:25	39	*M. daub.*	Tennis	F
23.06.17	22:40	-	-	23:25	-	0	*M. daub.*	Tennis	F
24.06.17	22:30	22:55	23:15	23:30	23:00	25	*M. daub.*	Tennis	F
25.06.17	22:35	22:45	23:05	23:35	22:50	15	*M. daub.*	Tennis	F
26.06.17	22:10	-	-	00:00	-	0	*M. daub.*	Tennis	F
08.08.17	21:20	21:25	22:00	22:15	21:40	53	*M. daub.*	Tennis	F
27.06.17	22:30	22:55	23:35	23:50	23:10	16	*M. myst.*	Gamlevei	F
28.06.17	22:40	22:55	23:20	23:35	22:55	7	*M. myst.*	Gamlevei	F
08.07.17	22:30	22:50	23:05	23:20	22:50	12	*M. myst.*	Gamlevei	F
14.08.17	21:20	21:25	21:35	22:00	21:30	10	*M. myst.*	Gamlevei	F
16.08.17	21:10	21:20	21:40	22:15	21:25	9	*M. myst.*	Gamlevei	F
20.06.17	22:30	23:00	23:35	23:45	23:05	43	*M. myst.*	N. Hauger	F
09.07.17	22:35	22:40	23:05	23:20	22:50	23	*M. myst.*	N. Hauger	F
14.08.17	21:15	21:50	22:05	22:40	21:50	5	*M. myst.*	N. Hauger	F
05.07.17	22:50	23:30	00:00	00:30	23:40	17	*P. auritus*	Hakadal	M/F
08.07.17	23:00	23:25	23:50	23:05	23:35	12	*P. auritus*	Hakadal	M/F
09.08.17	21:10	-	-	22:30	-	0	*P. auritus*	Hakadal	M/F
03.07.17	22:55	22:55	23:25	23:40	23:00	28	*P. auritus*	Haugestad	F*
07.07.17	22:40	22:40	23:05	23:15	22:50	27	*P. auritus*	Haugestad	F*

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*means the count was not made at the colony, but close by it.

As seen from table 6, most of the colonies we counted at irregular intervals. This is because the colony counts often had the lowest priority, since the colony was already discovered at that point, and so we would allocate our resources to finding additional colonies. Yet, some patterns can be extracted from our data:
We know #303 (female, Daubenton's bat) roosted together with #319 (female, Daubenton's bat) at the Strøm bridge colony. #303 had originally roosted in the Tenniscourt aspen colony. On 26.06.17 Strøm bridge had the all time highest number of individuals at 64, while the Tenniscourt had 0, which could suggest that not only #303 swapped colonies. On the days leading up to the 26.06 there was a lot of fluctuation of bat numbers within the Tenniscourt colony, going from 39 to 0, to 25, to 15. These fluctuations could be due bats changing roots. Our final Daubenton's bat colony at Rud could also have had a sister colony with which it exchanged bats, as we found #274 (male, Daubenton's bat) close by a cliffside around normal exit times coupled with general activity, but we could never locate a colony. The other colonies also had fluctuations, but the largest ones happened after the start of August. Figure 12 displays the changes between months for exit times. Unfortunately, our small sample size means that we cannot draw strong conclusions, but what we do see is as expected; with August having a much earlier exit time overall than June and July.

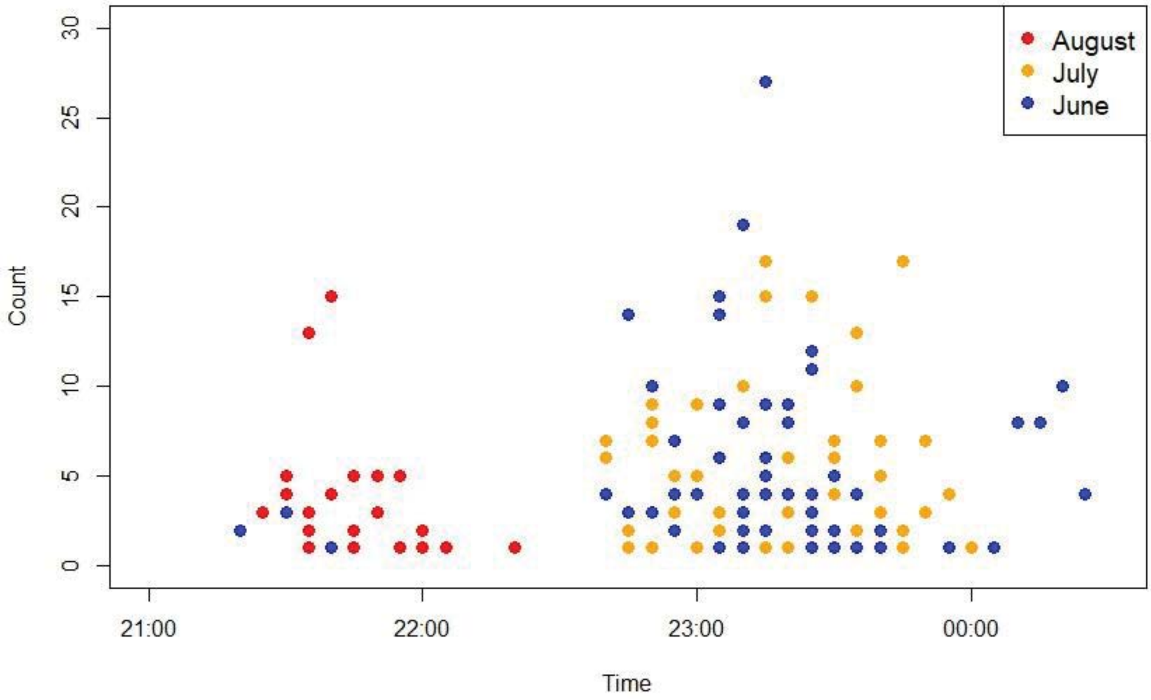


Figure 12: Shows the exit flight times of our bat counts. Bats were counted at 5-minute intervals and then tallied. Red dots were counts made in August, yellow dots for July and blue for June.

Due to the sporadic timing of our counts, the data did not allow for analyses of differences between colonies and species.

SPATIAL MOVEMENTS

Brandt's bat (*M. brandtii*)

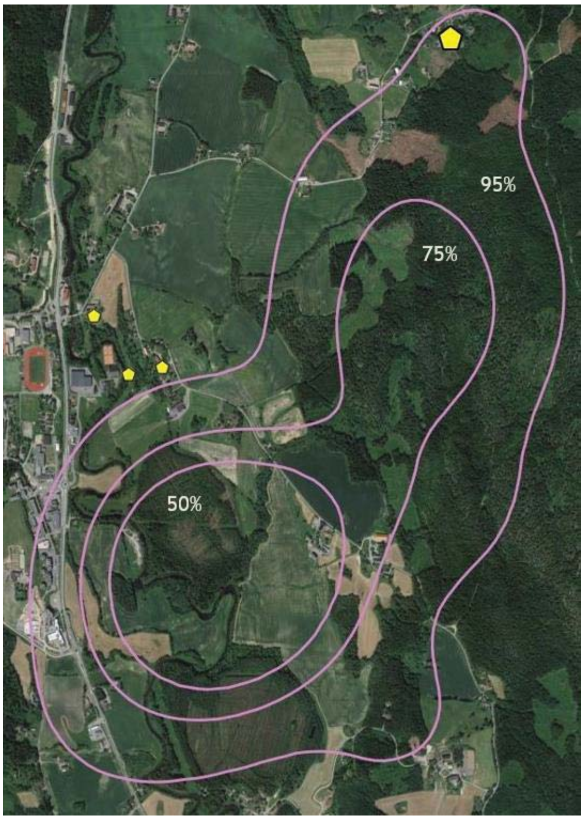


Figure 13: Scale: 1:36896. Kernel density plot of tagged bat #203(*M. brandtii*, female, Ask colony). Based on: on site plots, strong signal plots and triangulation plots. Yellow pentagrams are nearby colonies. The largest pentagram is the home of the tagged bat.

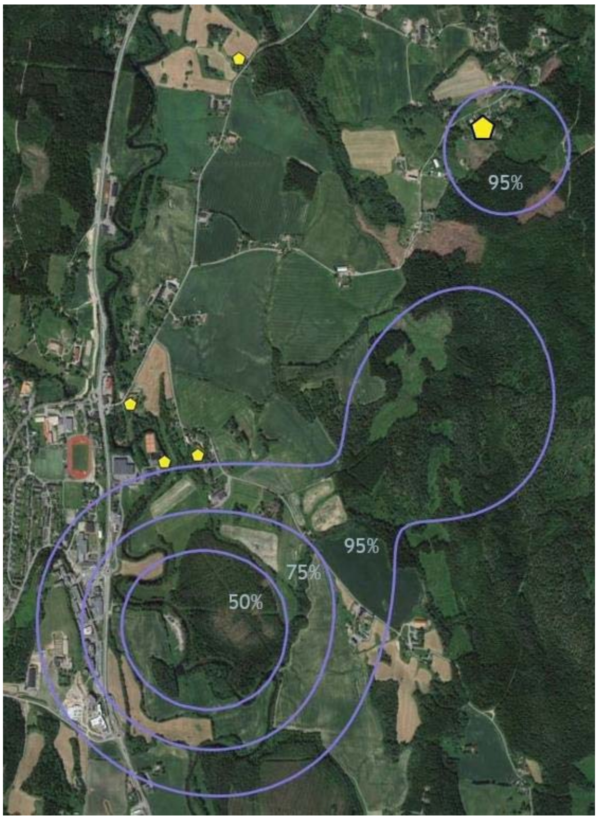


Figure 14: Scale: 1:36896. Kernel density plot of tagged bat #049 (*M. brandtii*, female, Ask colony). Based on: on site plots, strong signal plots and triangulation plots. Yellow pentagrams are nearby colonies. The largest pentagram is the home of the tagged bat.

Home range kernel plots for the two bats tagged from the Ask colony (figure 13 and 14). Both tagged bats were identified to take approximately the same route from to get to their main foraging ground (fig. 15 and fig. 16). The difference between the bats in the kernel plots are due to both having more plots of #203 (Brandt's bat, female, Ask colony), but also a slight difference in area use. The core 50% kernel area for both can be limited to the forested area, as the bats were never seen to hunt outside it. The home ranges are also a bit inflated due to the usage of plots that simply held strong signals and the coordinates of the observer was used for such plots. Still it gives a basic estimation of the landscape used by the bats, and used in conjunction with visual sightings, bat detector readings and our general observations of how the bats behaved, more accurate maps in figure 15 and 15 has been made. Figure 15 shows that all bats (same number or at least a closely comparable number was counted at an old forest road and the colony) used the same passage upon exit. Whereas it is uncertain exactly which path the bats took to get to the forest road, as is shown in figure 15 (solid green arrows), there are large open areas around the colony. We did observe a small number of bats flying around the eastern forest patch and crossing the road during August, and at the same time counted fewer bats at the forest road. So, it is possible other routes were utilized more as the nights grew darker. Once the bats reached the forest it was difficult to determine exactly what path was used. Most likely they funnelled out, as observers were placed at various points in the forest between the colony and capture site and detected at least a few *Myotis* bats passing. However, most of the route is based on locations off the two captured bats. We avoided counting at the colony itself and closely around to minimize conflict with the house owners.

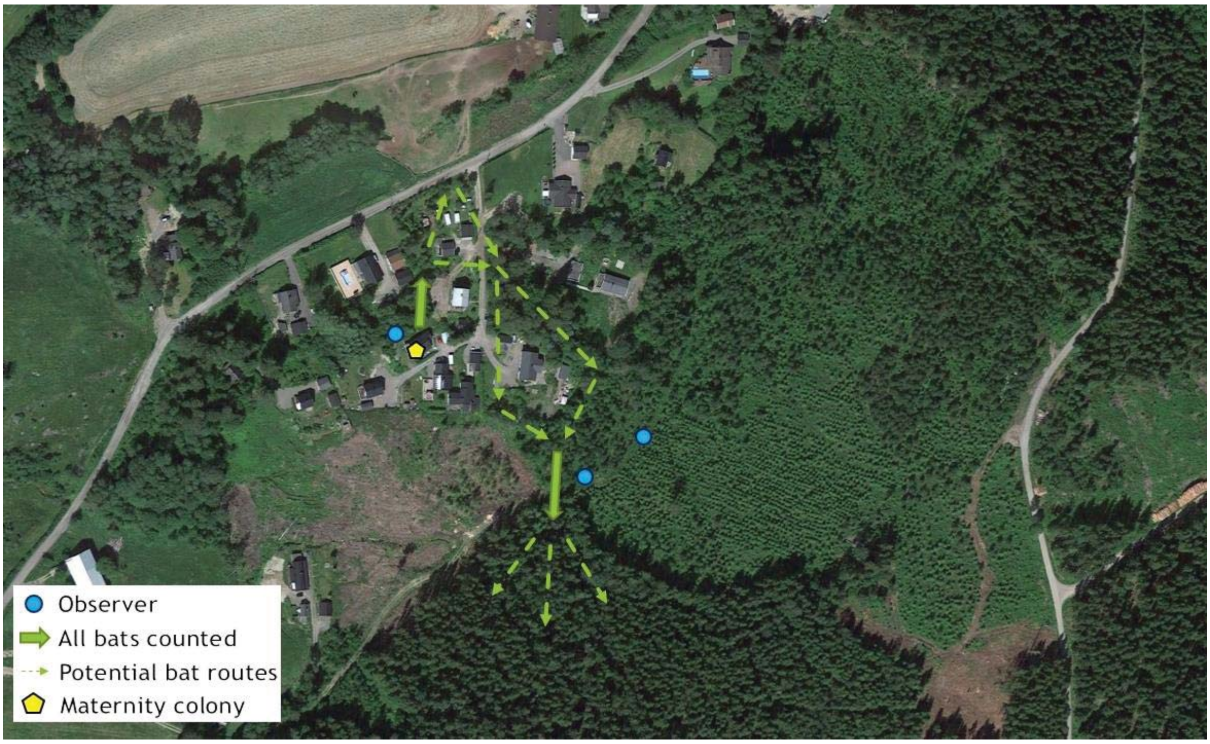


Figure 15: Scale.1:4162. Shows the perceived route that the bats (*M. brandtii,* female*)* of the Ask colony (presumed maternity colony) used. This is based of visual observations, counting, bat detector usage and signals from the tagged bats. The observer markers are used to highlight important positions that were used to either determine or exclude possible bat routes. The potential bat routes are suggestions based on what we see as the most likely path the bats took. They were not necessarily there on the same day and not necessarily the same observer. Tags lasted from 12.06 to 20.06 for #049 and 22.06 for #203.

It was also observed that #049 (Brandt's bat*,* female, Ask colony) had her foraging ground a little more south than #203 in the larger foraging area, while both were still within it. It is also possible the bats hunted on the way to their main foraging ground but based on their movement speed and the clear direction of the signals, it must have negligible compared to the time spent within the marked foraging areas (for our tagged individuals at least). It is also worth mentioning that the bats kept using the capture site as a corridor for several days after the capture. The capture site was on a small stream surrounded by bushes and trees between two large, open fields (fig. 11). Leaving very little cover to reach the foraging ground outside of the stream. #203 (Brandt's bat*,* female, Ask colony) was also observed to pass up and down the stream corridor several times, potentially using it for foraging. The tagged bats were not seen to expand their foraging ground, by for instance following the main river, Nitelva, or to swap foraging ground.

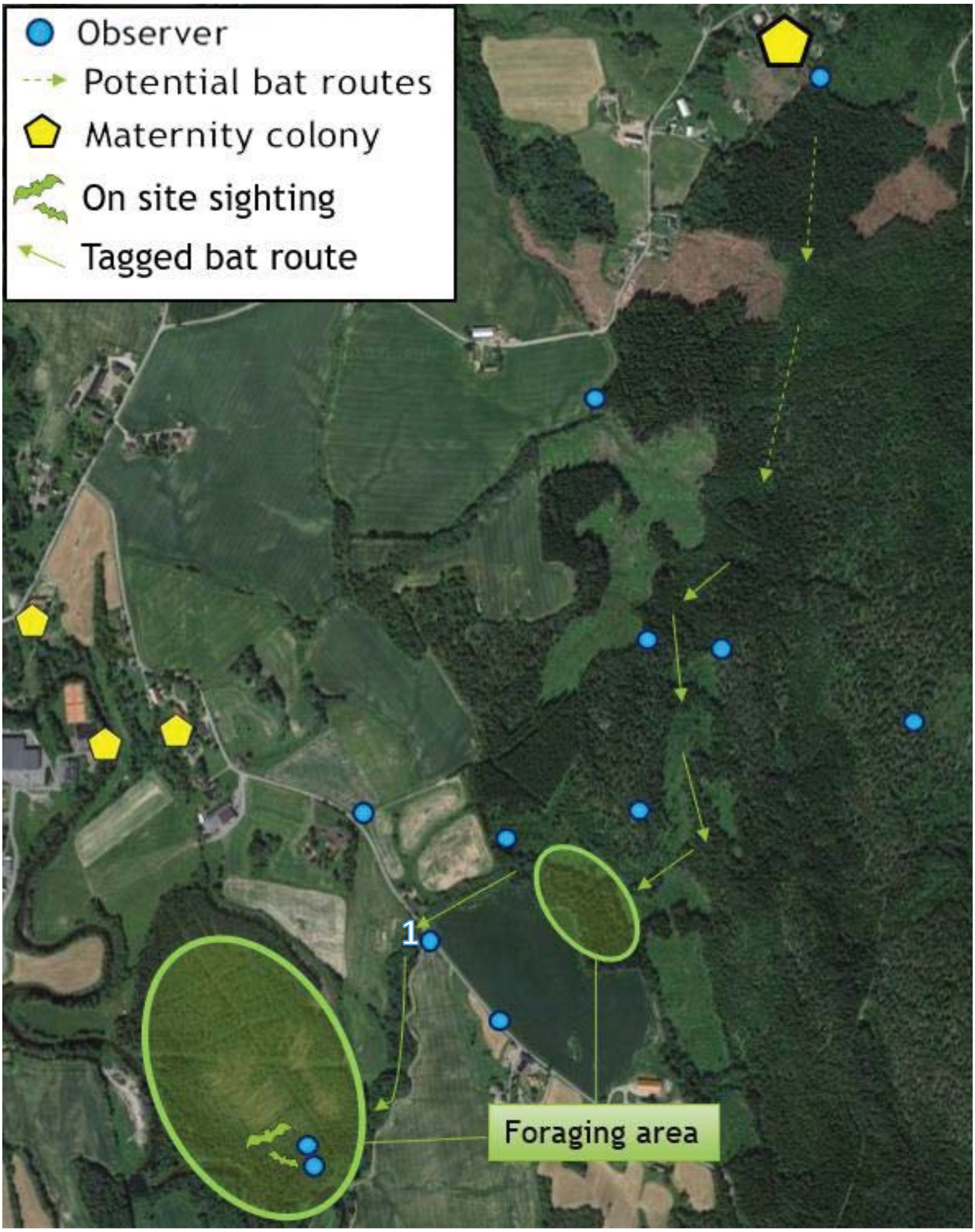


Figure 16: 1:36986. Shows the perceived route that the tagged bats (*M. brandtii,* female*)* of the Ask colony (presumed maternity colony, the large pentagon) used on a larger scale. “1” is the capture site of both bats. This is based of visual observations, counting, bat detector usage and signals from the tagged bats. The observer markers (blue circles) are used to highlight important positions that were used to either determine or exclude possible bat routes. The potential bat routes are suggestions based on what we see as the most likely path the bats took. They were not necessarily there on the same day and not necessarily the same observer. Tags lasted from 12.06 to 20.06 for #049 and 22.06 for #203.

Whiskered bat (*M. mystacinus*)

The tagged bat from the Nedre Hauger colony, #131 (whiskered bat, female), utilized a monoculture spruce forest as her main foraging ground. As previously the home ranges are shown in figure 17 while the perceived route taken is shown in figure 18. #131 also left towards the river at least once as shown in figure 18.

Figure 17: Scale: 1:18448. Kernel density plot of tagged bat #131 (*M. mystacinus*, female). from the Nedre Hauger colony. Based on site plots, strong signal plots and triangulation plots. Yellow pentagrams are nearby maternity colonies. The largest pentagram is the home of the tagged bat.

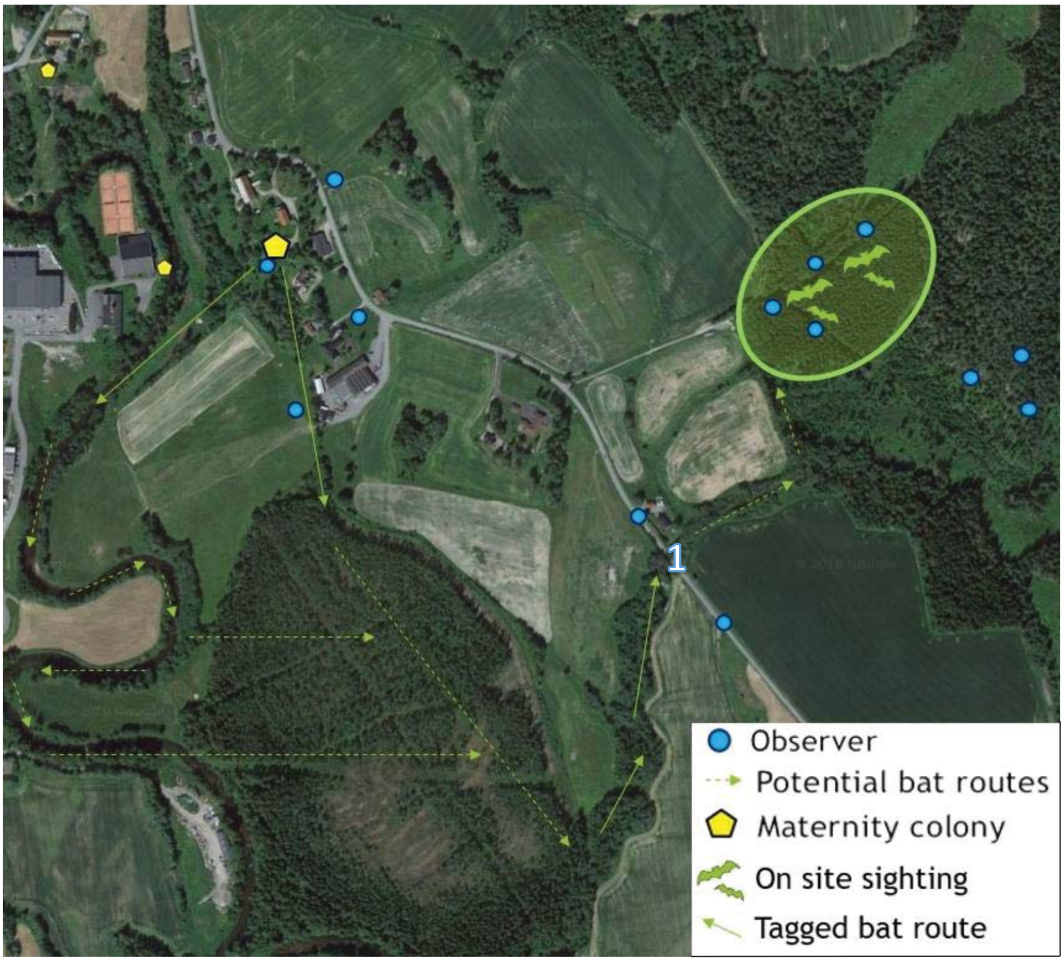


Figure 18: 1:9224. Shows the perceived route that the tagged bat of the Nedre Hauger colony used (#131, *M. mystacinus*, female). This is based of visual observations, counting, bat detector usage and signals from the tagged bats. “1” is the capture site for #131. The observer markers are used to highlight important positions that were used to either determine or exclude possible bat routes. The potential bat routes are suggestions based on what we see as the most likely path the bats took. They were not necessarily there on the same day and not necessarily the same observer. The green marked oval is the main foraging area used. Tag lasted from 18.06 to 25.06.

Other bats were also observed foraging in the same area alongside #131. The spruce monoculture was limited to the approximately the foraging ground as shown in figure 18, yielding to more mixed forests outside the green border. Bats leaving the Nedre Hauger colony could have used the river as their main foraging ground as many were seen leaving in the direction of it. Another possible foraging area is the closest forest patch directly south of the colony where a substantial of bats were also seen dispersing to.

Figure 19 is another example of how the homeranges get inflated. Signals of #086 never suggested she was ever outside the small forest patch right by her colony.

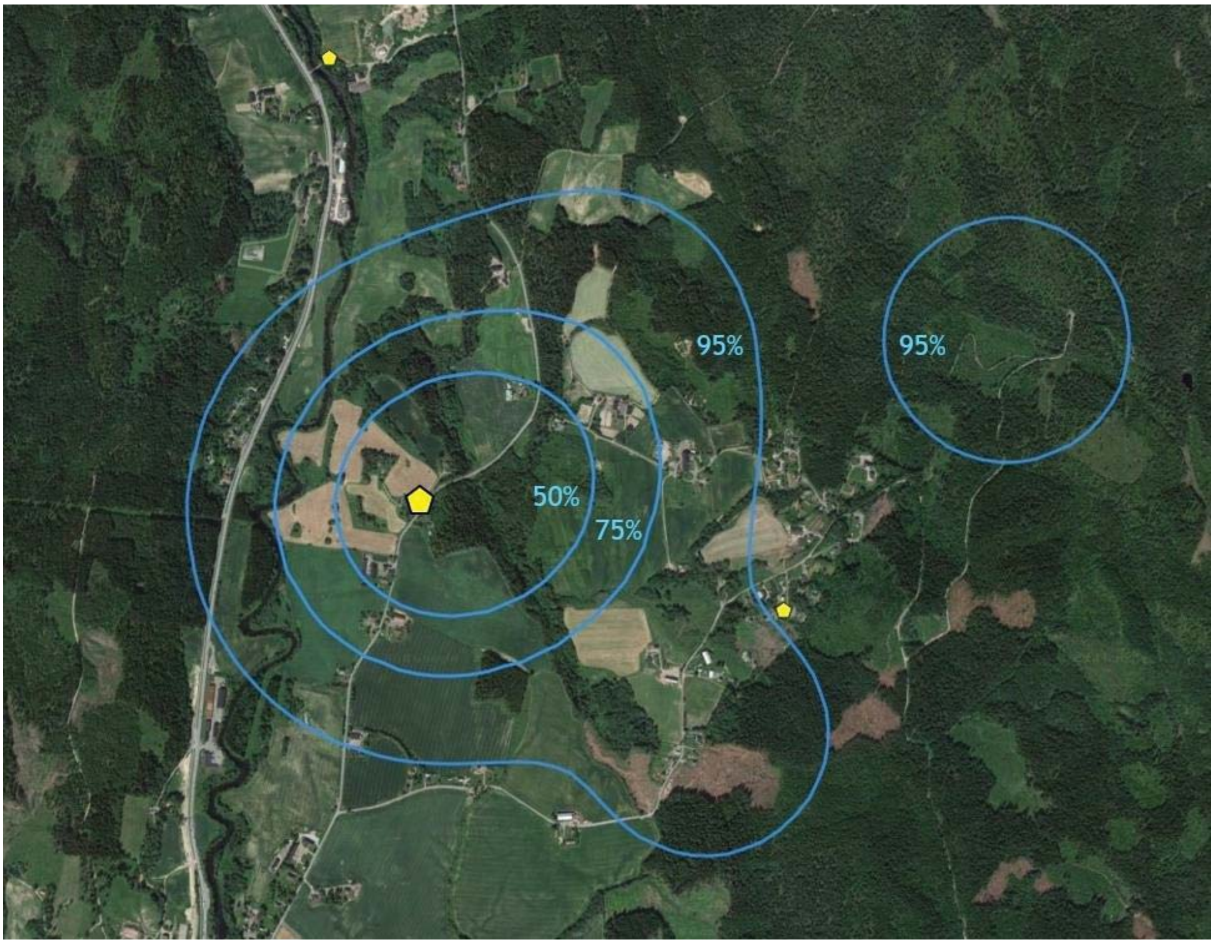


Figure 19. 1:30 000. Kernel density plot of tagged bat 086 (*M. mystacinus*, female, Gamlevei barn colony). Based on site plots, strong signal plots and triangulation plots.

As before, a map that more appropriately depicts reality according to our perception in the field along with visual and auditory sightings is shown in figure 20.

The foraging area of #086 constituted of a mixed forest with a small stream within the forest (fig. 19). All of the surrounding area of the colony were open agricultural fields. A stream that led through an underpass connected the foraging area to Nitelva. The stream had trees covering it the entire way and from the river the bats could spread further into other similar patches. It is likely that this was the case as we did not observe much prolonged bat activity in the foraging area of #086 other than herself.

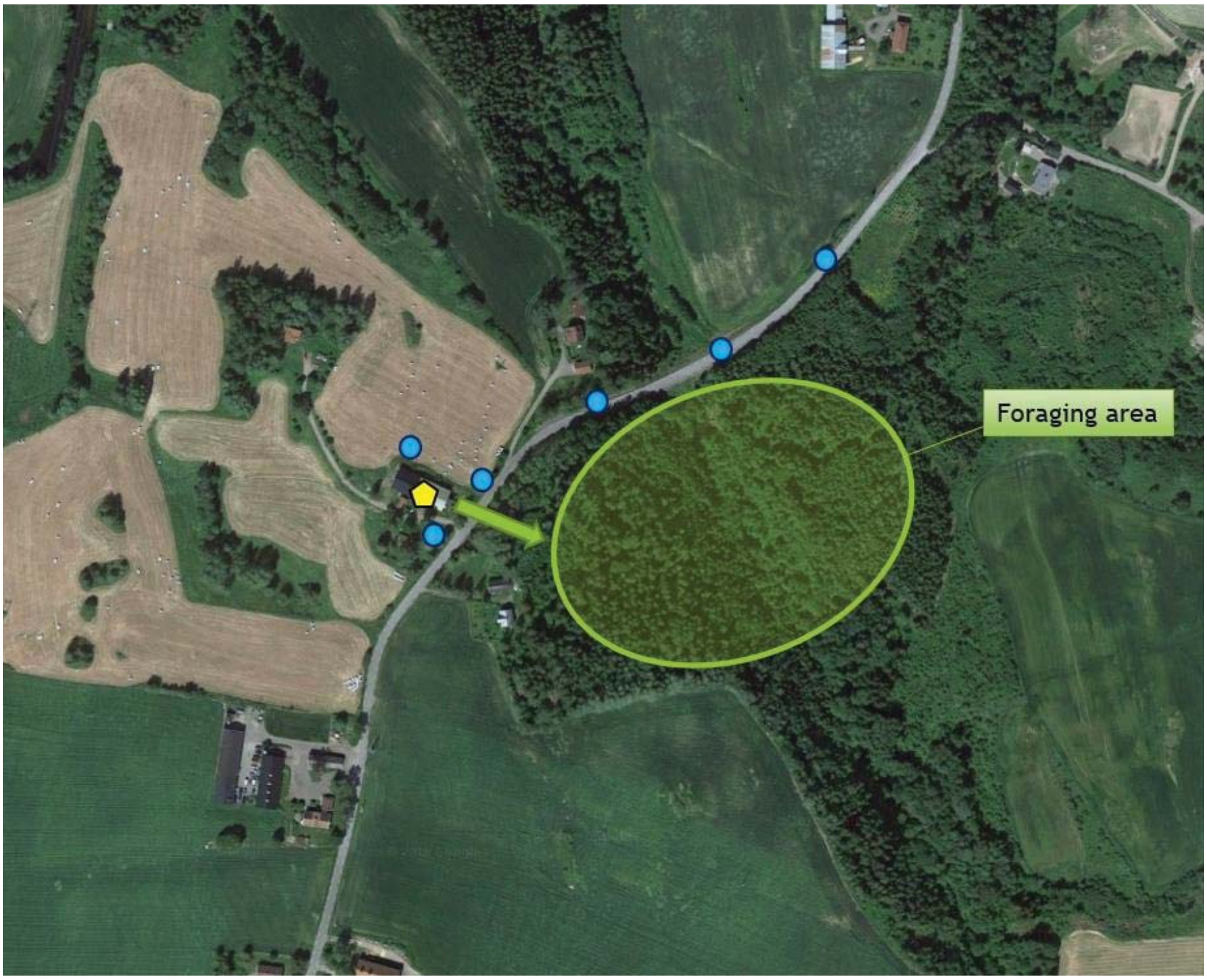
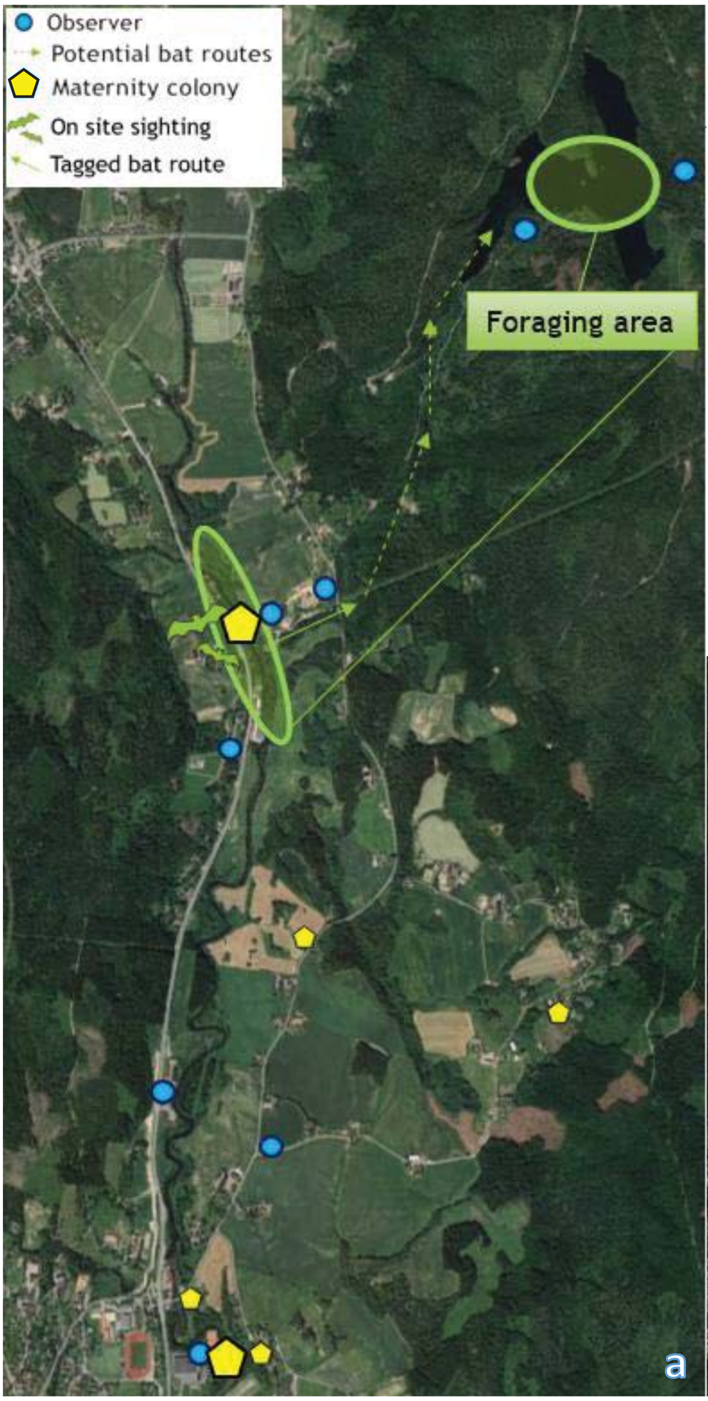


Figure 20. 1:7500. Shows the perceived route the tagged bat #086 (*M. mystacinusi*, female, Gamlevei barn colony) took. This is based of visual observations, counting, bat detector usage and signals from the tagged bats. The observer markers are used to highlight important positions that were used to either determine or exclude possible bat routes. They were not necessarily there on the same day and not necessarily the same observer. Tag lasted from 26.06 to 01.07.

Daubenton's bat (*M. daubentonii*)

Bat #319 (Daubenton's bat, female) roosted at the Strøm bridge colony (fig. 21a large pentagon, top), however another bat, #303 (Daubenton's bat, female) roosted at the Strøm bridge colony as well, even though she originally roosted at the Tenniscourt aspen colony (large pentagon, bottom). As such both colonies have been highlighted to signify their connection to one another as part of the same assumed population, even if #319 did not swap colonies. Homerange for #319 is shown in 20b.



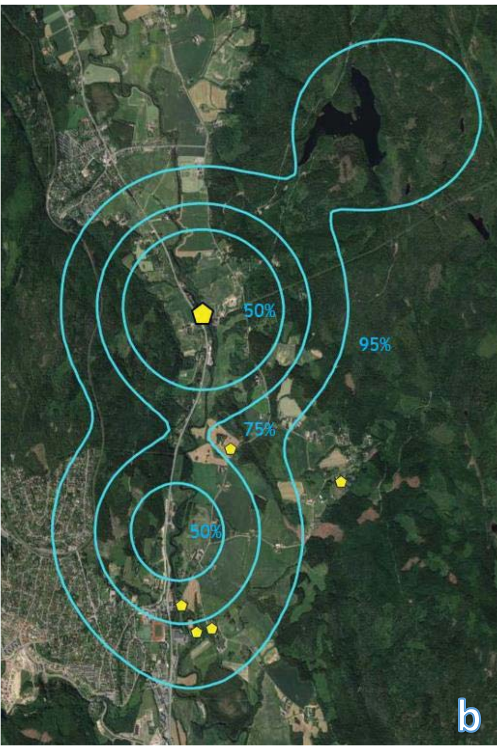
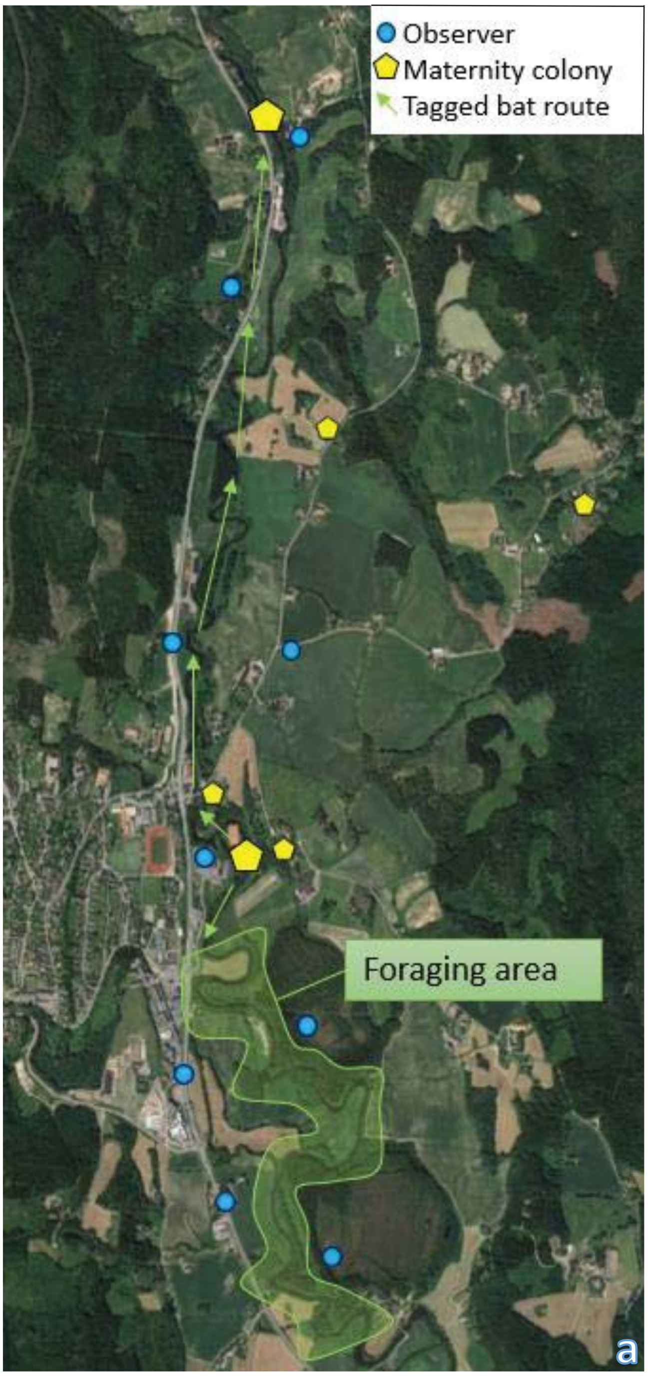


Figure 21a: 1:73792. Shows the perceived route the tagged bat #319 (*M. daubentonii*, female, Strøm bridge colony) took. It is likely more parts of the river were used for foraging. This is based of visual observations, counting, bat detector usage and signals from the tagged bats. The observer markers are used to highlight important positions that were used to either determine or exclude possible bat routes. The potential bat routes are suggestions based on what we see as the most likely path the bats took. They were not necessarily there on the same day and not necessarily the same observer. Tag lasted from 23.06 to 29.06.

Figure 21b: 1:73792. Kernel density plot of tagged bat #319 (*M. daubentonii*, female, Strøm bridge colony) from the Bridge colony. Based on site plots, strong signal plots and triangulation plots.

The foraging ground at the upper right in fig. 21a was likely a more important foraging ground than what it appears on the kernel in fig. 21b. This is because we found the foraging ground rather late and due to the difficulty of reaching it. Had it been found earlier and been easier to reach we would likely have more plots in the area. While the exact route to the foraging ground in the upper left is uncertain, a small stream connects the lake and the river approximately where the arrows lead (fig 20a). This is the most likely route taken based on (Kalko & Schnitzler 1989) and our observations.



Bat #303 (Daubenton's bat, female) roosted at the Tenniscourt aspen initially, but later roosted at the Strøm bridge colony (fig. 22a). The homerange could only be calculated for a 50% kernel successfully due to a lack of plots (fig. 22b). Since the observers could not stand in the river itself, the homerange is very inflated as the signals never suggested the bat was anywhere but at or close by the river.

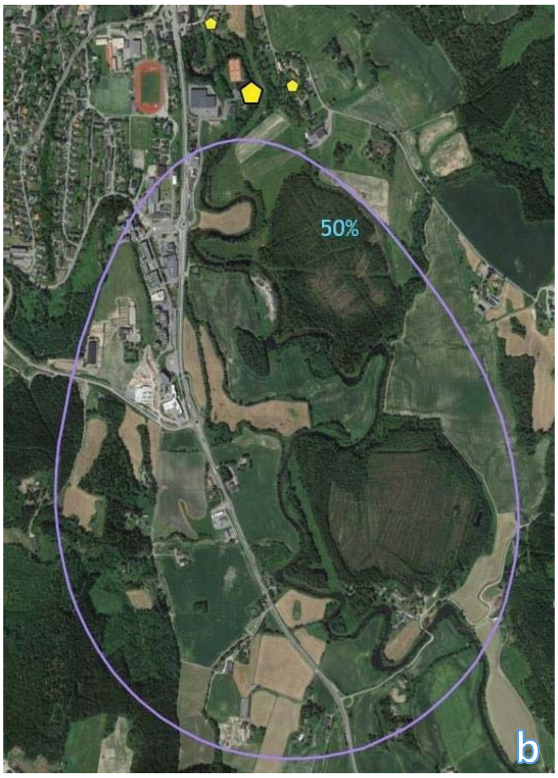


Figure 22a: 1:60 000. Shows the perceived route the tagged bat #303 (*M. daubentonii*, female, Tenniscourt aspen colony and Strøm bridge colony) took. It is likely more parts of the river were used for foraging. This is based of visual observations, counting, bat detector usage and signals from the tagged bats. The observer markers are used to highlight important positions that were used to either determine or exclude possible bat routes. They were not necessarily there on the same day and not necessarily the same observer. Tag lasted from 22.06 to 29.06.
Figure 22b: 1:47 000. Kernel density plot of tagged bat #303 (*M. daubentonii*, female, Tenniscourt aspen colony and Strøm bridge colony) from the Bridge colony. Based on site plots, strong signal plots and triangulation plots.

Out of our tagged bats, flight route maps have been made for #203, #049 (both Brandt’s bats, female), #131, #086 (both whiskered bats, female), #303 and #319 (both Daubenton’s bats, female). Flight routes were not made for any of our tagged brown long-eared bats. This is in part due to the our bat detectors having difficulties to pick up brown long-eared bats, which means we had fewer plots to work with. #284 (Brown long-eared bat, female) and #155 (Brown long-eared bat, male) lost their tags after zero and one day respectively. The two remaining Brown long-eared bats, #290 and #041 (both female) didn’t have enough plots to make homeranges for and also too few plots in general to have any proper certainty of any flight routes.

The two remaining tagged bats without flight route map, #168 and #274 (both Daubenton’s bats, male), also had too few plots for any homeranges, and due to the difficulty of moving in the terrain surrounding their colony, following them proved nearly impossible. Compared to the other bats the tags also had shorter lifespans, with #168 having two days and #274 with four days.

SIGNAL DETECTION TRIALS

Probability of detecting a signal

The tag positioned higher above the ground had a significantly higher chance of being detected than the tag at ground level (fig. 23, glm: z = 2.347, p = 0.019).

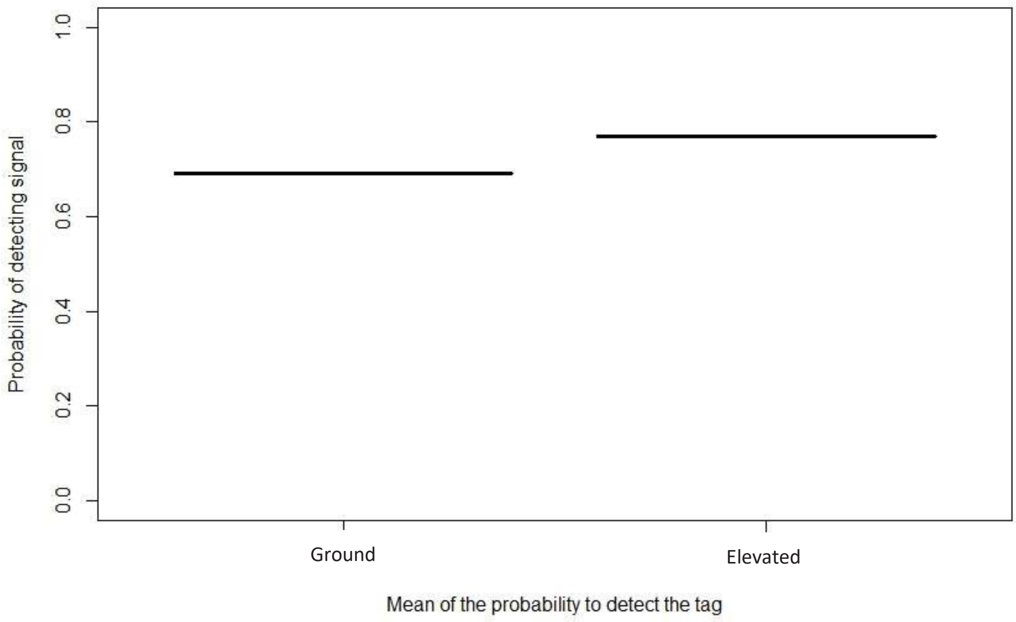


Figure 23: Mean probability of detecting the signal of the tag at ground level and the elevated tag, positioned approximately 1.70 meters above ground.

The observer Kristian had a significantly higher chance of detecting a signal than Joakim and Rune (fig. 24, glm; z = 5.39, p < 0.001).

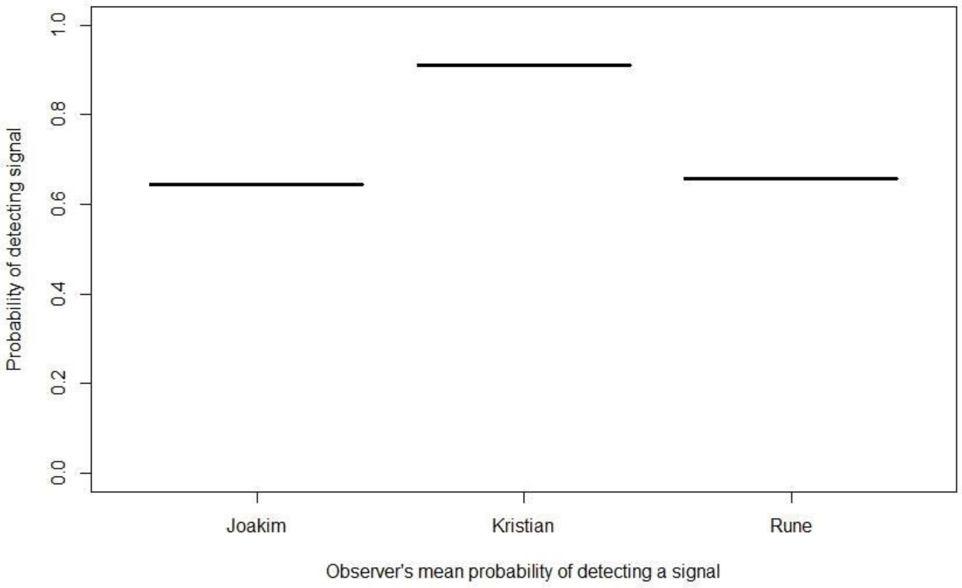


Figure 24: Mean probability of each observer detecting a signal.

Tag and observer as random effects were checked via ANOVA, the model with fixed effects had the lowest p value ($p < 0.001$).

The probability of hearing a signal decreased significantly with increasing distance from the tag (Fig. 25, glm: $z = -10.03$, $p < 0.001$).

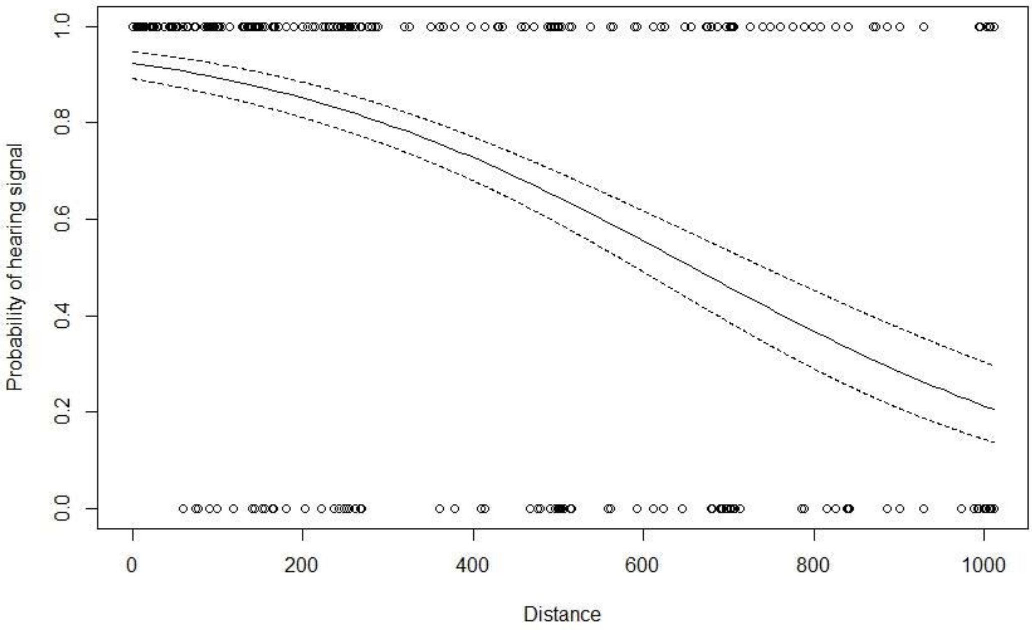


Figure 25: Estimated relationship between probability of detecting a signal and distance to the tag. Dashed lines indicate 95% confidence intervals.

The probability of hearing a signal decreased significantly with increasing PoLoSO (fig. 26, glm: $z = -3.172$, $p = 0.002$).

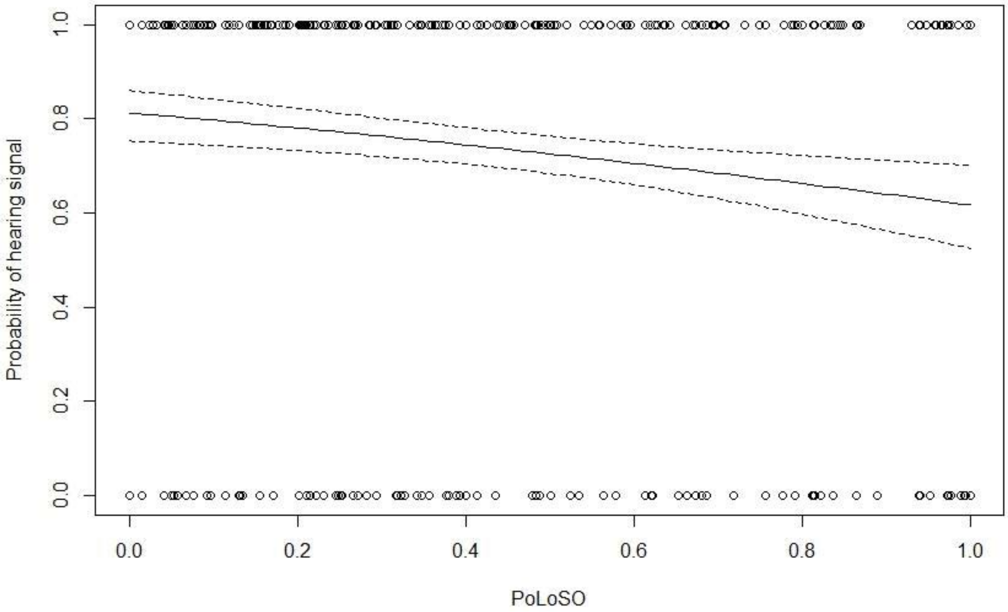


Figure 26: Estimated relationship between probability of detecting a signal and Proportion of Line of Sight Obstructed (PoLoSO). Dashed lines indicate 95% confidence intervals.

When line of sight is heavily obstructed (higher than 50%) there is a significantly lower chance to detect a signal than when there are minor obstructions (less than 50%), glmm, $z = -4.260$ and $p < 0.001$ (fig. 27). Distance as before also had a significant effect: $z = -9.91$ and $p < 0.001$.

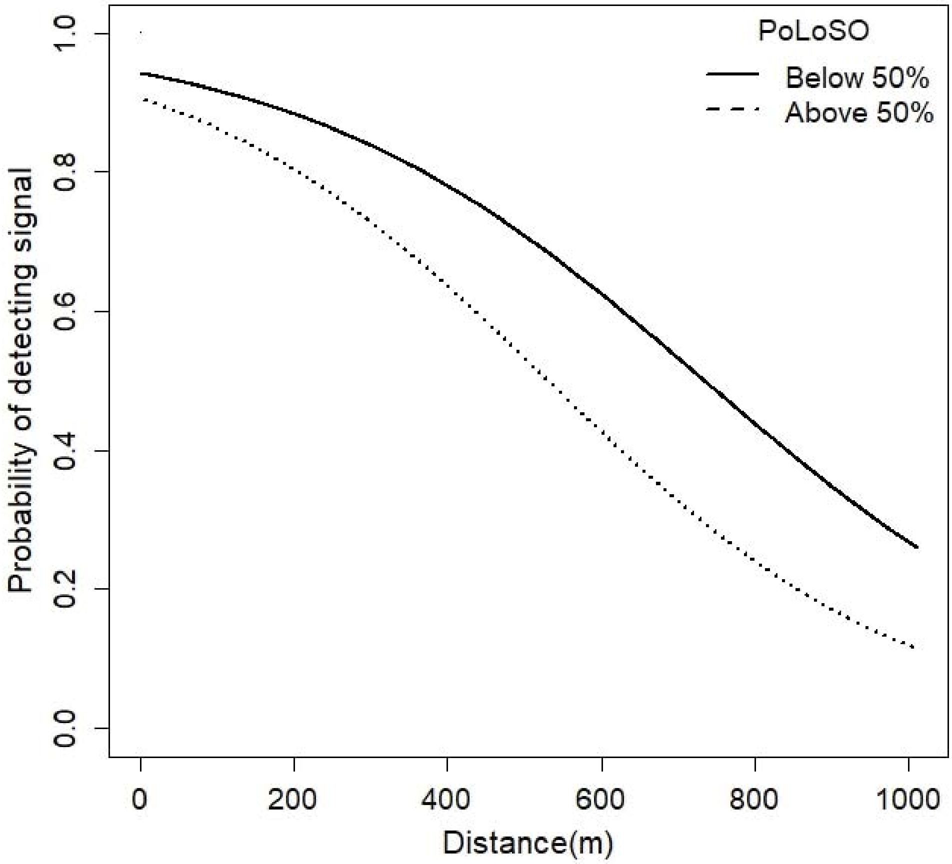


Figure 27: Estimated probability of detecting a signal as a function of distance to the tag, when PoLoSO is above or below 50% at varying distances.

Signal strength

For all plots where a signal was heard the top tag had a significantly higher signal strength than the tag at ground level (fig. 28, glm, t = 3.935, $p < 0.001$).

For all plots where a signal was heard the top tag had a significantly higher signal strength than the tag at ground level (fig. 28, glm, t = 3.935, $p < 0.001$).

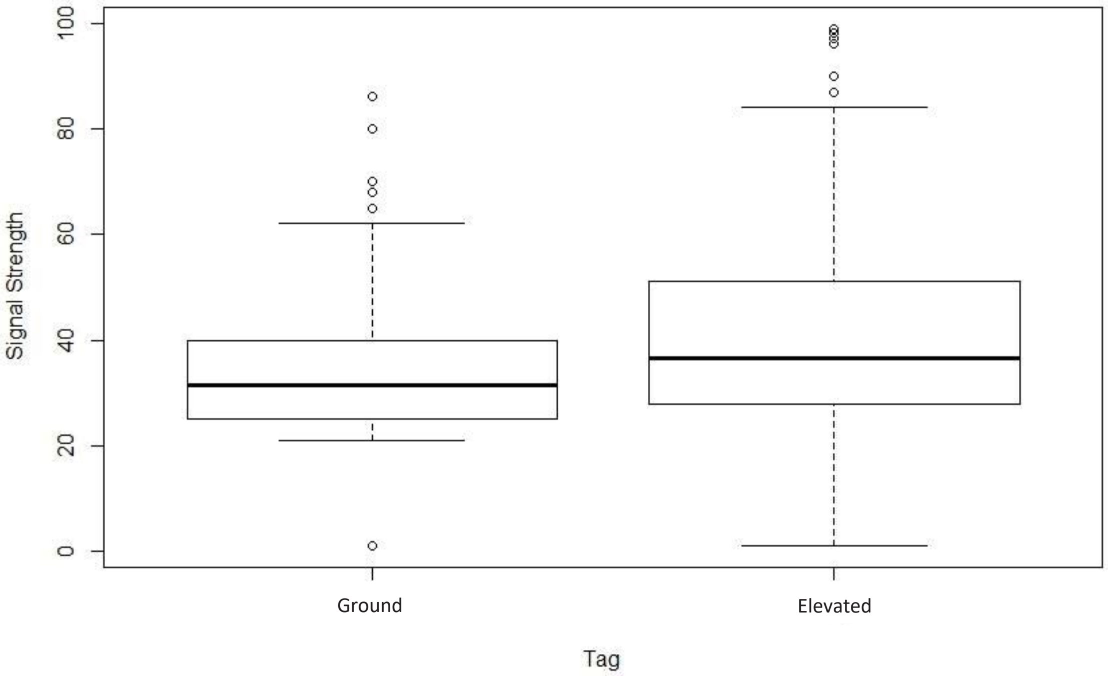


Figure 28: Boxplots for signal strength for the tag at ground level and the tag positioned 1.70 m above ground.

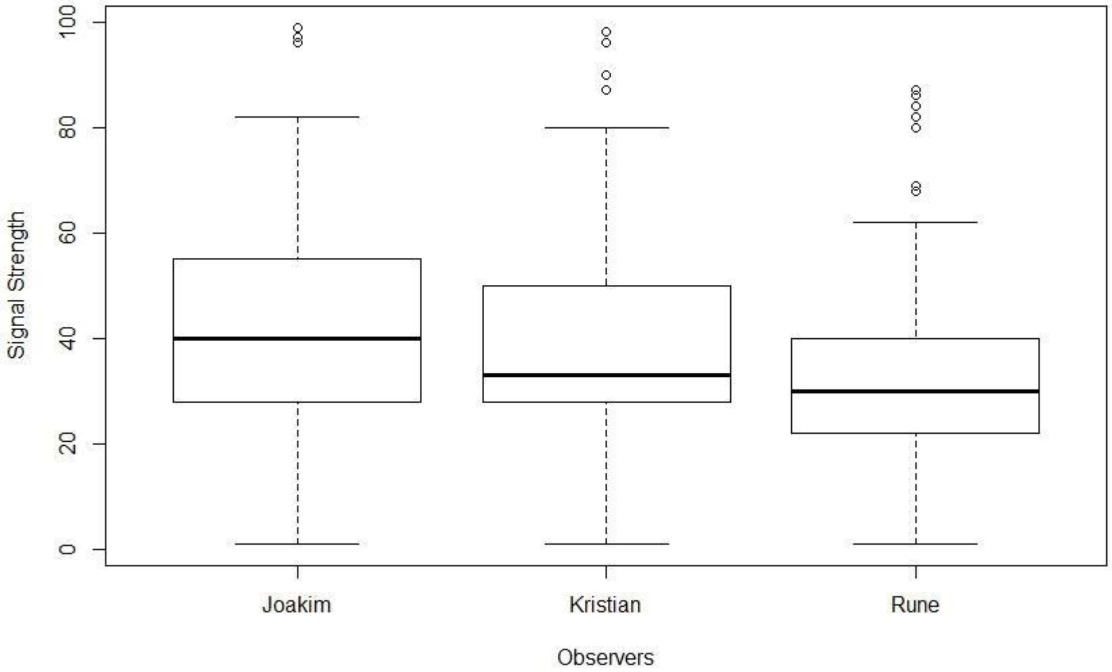


Figure 29: Boxplot of signal strength for each observer.

For all plots where a signal was heard signal strength decreased significantly with increasing distance, glm, $t = -6.207$ and $p < 0.001$ (fig. 30).

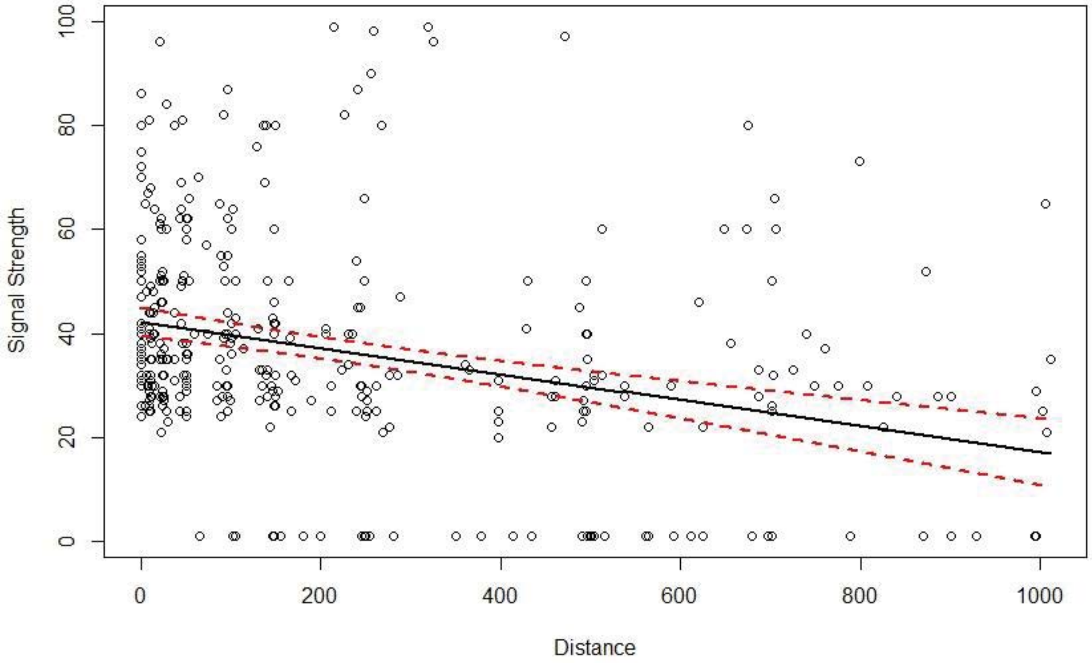


Figure 30: Estimated relationship between signal strength and distance to tag. Dashed red lines show 95% confidence intervals.

The model shows some issues with heteroscedasticity, most likely caused by the few positions at the farthest distance. However, as the project advances and more plots added on with further transmitter tests, this is the expected trend and so I chose to include it. A box-cox transformation did not solve the issue on its own, and other models like an additive model (GAM) also had the problem of heteroscedasticity. Thus, any conclusions from this plot should be drawn with caution.

For all plots where a signal was heard signal strength decreased significantly with increasing PoLoSO, glm, t = -4.588 and $p < 0.001$ (fig. 31).

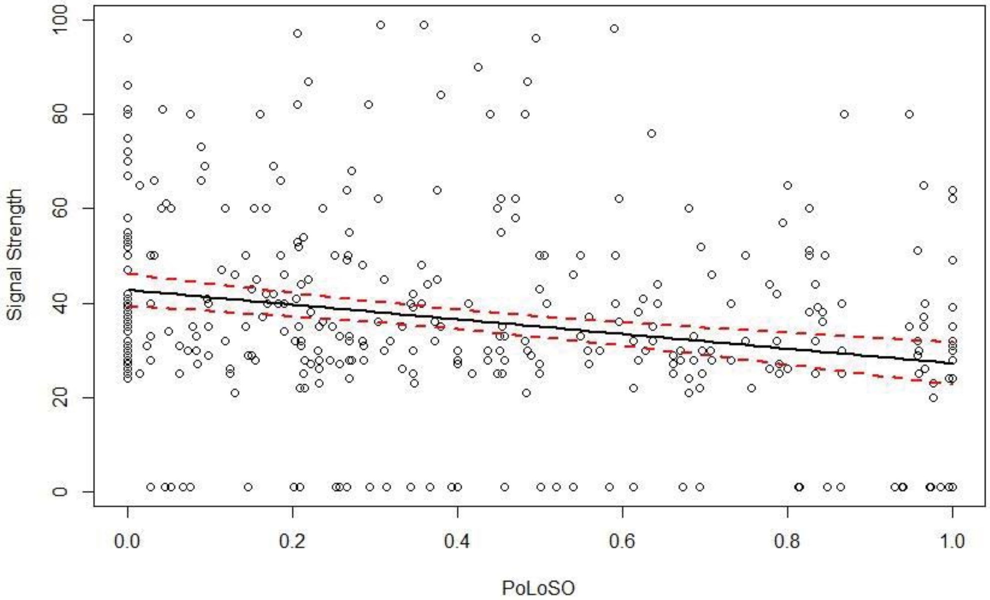


Figure 31: Estimated relationship between ignal strength and Proportion of Line of Sight Obstructed (PoLoSO). Dashed red lines show 95% confidence intervals.

When line of sight is heavily obstructed (higher than 50%) signal strength is significantly lower than when there are minor obstructions (less than 50%), glmm, t = -5.053 and p < 0.001. Distance also had a significant effect: z = -7.244 and p < 0.001 (fig. 32).

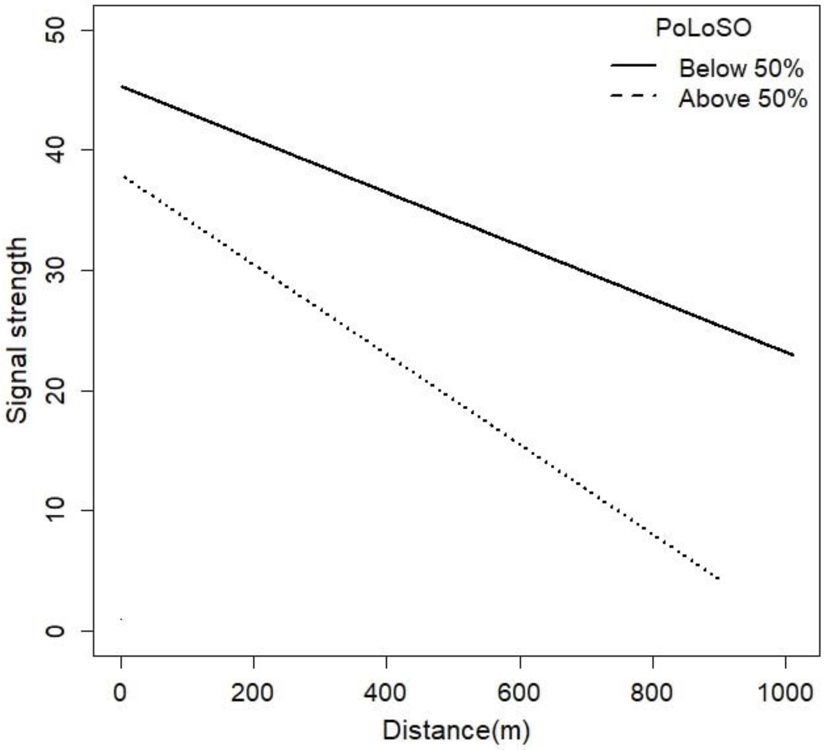


Figure 32: Estimated probability of detecting a signal as a function of distance to the tag, when PoLoSO is above or below 50% at varying distances.

This plot also suffers the same problems with heteroscedasticity and as figure 28. However, this only impacted the decline in signal strength with increasing distance and not the significant difference in PoLoSO I have determined to include the plot as with more transmitter tests and more data, these issues will most likely be solved and the pattern (or something similar to it) will probably persist.

DISCUSSION

MATERNITY COLONIES

We found seven colonies during the summer of 2017 via VHF telemetry; one brown-long eared bat colony in a house (another one previously known about in a church), three Daubenton's bat colonies, two in aspen trees and one in a bridge above water, two whiskered bat colonies, one in a barn and one in a house and finally one Brandt's bat colony in a house. For all colonies the closest source of water was within 120 meters or closer.

We found our Brandt's bats in a house. Houses as colonies for Brandt's bats has been observed prior to this study as well in Norway (Bögelsack, 2011). Our colony size of 32 (average) is also within expectations of between 20 and 120 individuals as noted by Häussler (2003) in Germany. However, the relative importance of buildings as colony sites may have been overestimated, because detecting the bats in trees often requires telemetry, whereas the inhabitants will often detect the bats in their own home. Studies from the rest of Scandinavia suggest that tree colonies for Brandt's bats aren't uncommon, at least not in Sweden (de Jong, 2006; Baagøe & Jensen 2007a). Therefore, with more studies it is likely that more tree-based colonies for Brandt's bats will be found in Norway as well. Fortunately, the owners of the buildings in which we found colonies were positive or least not negative towards the colonies. An important conservation concern is often the negative perception bats have in the in the public (Mickleburgh *et al.* 2002) which can lead to the illegal termination of colonies (Stone *et al.* 2013). The best way to safeguard our bat species when so many roost in homes and other man-made structures and properties must be education (Stone *et al*. 2013) and evidence based conservation (Sutherland *et al.* 2004).

Our two whiskered bat colonies were found in a house and a barn. The house colony (Nedre Hauger, nr. 7 fig. 7) had perhaps a larger number of bats than expected at its largest, with 42 bats (Isaksen *et al*. 2009). The barn colony (Gamlevei, nr. 3, fig. 7) conversely had fewer than what has been reported in previous studies (Isaksen *et al*. 2009). This is likely due to the sub-optimal conditions of the barn. Although it was heated, the large gaps in the doors and walls likely made it colder than a regular inhabited house. Furthermore, heavy machinery was often used within the colony, caused observer inside (and likely also the bats) a certain amount of distress. Whiskered bats have been observed to roost in trees in Denmark (Baagøe & Jensen 2007b), but rarer than in buildings. These numbers could be inflated due to the ease of detecting a bat colony within a house compared to a tree. Whiskered bat populations have been in decline in Sweden for the past 20 years (Ahlén, 2006). This may be due to increased pressure from forestry, agriculture and urbanization within Sweden, which is a major threat to bat abundance and activity (Ahlén, 2006; Kurta & Teramino, 1992; Mickleburgh, Hutson, & Racey, 2002). This gives us an incentive to further focus on finding the maternity colonies of whiskered bats especially, so that we can find out if it is happening here as well.

Brown long-eared bats in our study was found within a church and a large house currently undergoing refurbishing. In our study area, brown long-eared bats are a known church-goer and has used this colony for many years (van der Kooij, 2012), it has also been found in churches other places in Norway and Sweden (Ahlén 2004; Isaksen *et al*. 2009), while in Scotland brown long-eared bats have been found to the prefer older wooden houses (Entwistle, 1994; Entwistle *et al*., 1997). Van der Kooij's counts previously numbered above 30 individuals in the same day, whilst our counts never exceeded 17 in one day. This decrease could be related to the recent decrease in big deciduous trees near the church. We observed all bats flying toward a small forest surrounding a nearby stream. Many of those trees are gone due a planned extension of the graveyard, which may have impacted the colony size. Furthermore, we saw additional decline in trees as the project went along. Now, most of the main corridor used by these bats have been reduced to open land. Most of the surrounding area to the church is open due to the cemetery and there are bright lights pointed at the church on the opposite side of the colony, which may dissuade the bats from taking any routes there (Rydell et al. 2017; Stone *et al.* 2009). Thus, we expect to see a further decline in this colony, or perhaps complete abandonment.

We found Daubenton's bats roosting in aspen trees close by a river as well within a bridge overhanging the same river. Daubenton's bats often roost close by rivers and lakes (Russ & Montgomery, 2002). Bridges as colonies for Daubenton's bats, while they are on the rarer side, has been observed in central Europe (Ceľuch & Ševčík, 2008). Bridges often have considerable traffic and noise disturbance. Bats tend to avoid foraging in areas with heavy noise pollution (Jones, 2008; Schaub, 2009), and it is possible bats would prefer to avoid roosting near heavy noise as well. Our bridge is close to the most trafficked road in the municipality, but it is a pedestrian bridge so the colony itself does not suffer direct contact with the road. Unfortunately, Daubenton's bats are one of the species most prone to traffic casualty, probably due to their low-flying foraging strategy (Lesiński, 2007; Lesiński *et al*., 2011). Furthermore; Medinas *et al.* (2013), found that higher quality foraging grounds for bats like woodland, water courses and water reservoirs close by roads yielded more casualties. Fortunately we did not observe any Daubenton's bats crossing the road, and due to the light and noise it is rather unlikely (Jones, 2008; Schaub, 2009; Stone *et al.* 2009) that they will attempt to cross it, however it is something to keep in mind for conservation purposes.

We also found that one of our Daubenton's bats 303 (female), switched roosts, which has been found before (Lucan & Radil, 2010). The Daubenton's bat colonies also had the greatest fluctuation in colony exit counts, from 3 to 64 in the Strøm bridge colony and from 0 to 53 in the Tennis aspen colony. The aspen incidentally had 0 bats exit during the same date that the bridge had 64 bats exit. There is a possibility the bats belonged to the same population and swapped roosts. Unfortunately, due to personnel and time constraints this was not further investigated. What would have been preferable would be if the colonies suspected of swapping individuals were to be counted at the same day for several consecutive days. Another option would be to radio ta individuals to investigate with telemetry if the bats swap between the specific colonies in question.

Water too has a precedent of having a significant tie to roost location and foraging habitats for our study species (Ahlén, 2006; Baagøe & Jensen 2007a and 2007b; Isaksen *et al*. 2009). In our study area, agriculture and rural housing (urban fabric) are the most abundant land cover types, and the Hakadal church colony was not discovered with telemetry. Thus, making any correlation between these land cover types and colonies should be done with caution. Forest on the other hand had the highest average land cover percentage (33%) within 100m of the colonies, and it is not the among the most abundant land cover types on lower altitudes. Other studies also support the importance of forests for bats, mainly as foraging habitats (Baagøe & Jensen, 2007a and 2007b, Jung *et al.* 2012, Wermundsen & Silvonen, 2008). The brown long-eared bat colonies had a bit less forest surrounding them (24% average), than the average for all colonies, which could be due to both colonies being in buildings. In addition, one of the brown long-eared bat colonies (Hakadal) recently had trees close to the colony removed, which would lower the percentage further. The locations of our capture sites also most likely limited the location of colonies we could find. Since our capture sites were all at lower altitudes, our colonies were also at lower altitudes. Had we captured bats further up on either side of the valley were forests are the most predominant land cover type, urban fabric and agricultural fields would likely be much less represented.

COLONY EXITS

We observed a tendency for the bats to exit colonies at earlier times later in summer, likely due to the longer nights (Catto *et al*., 1995; Erkert, 1978; Frafjord, 2013, Newson *et al.* 2015). Most bats seemed to fly along natural obstructions, potentially for cover, before reaching a more sheltered place like a forest. Furthermore, a type of behaviour was often seen when bats were faced with crossing a relatively large open space: they had a "tentative" period of circling the point before the open space, as if gathering courage before making the crossing. Every species except for northern bats showed this behaviour. It could be that these "tentative" periods occurred because of hunting. This is unlikely due to the often abundance of bats circling together, competition would be fierce in the small circling spaces observed. Furthermore, no sharp turns or other classical hawking behaviour was observed. There is a possibility that this circling could be a social activity, but it was also observed even when solitary bats were about to cross an open space. What is more likely is that this circling was due to a perceived risk of open space, related to predators such as the tawny owl (*Strix aluco*) (Speakman, 1991). In general, the perceived behaviour in the field was that our study species, with the exception of northern bats, kept close to linear elements when faced with an open field, like the edge of a forest or the wall of a building. This behaviour has been seen before by Frey-Ehrenbold *et al.* (2013) for instance, however they also suggest northern bats adhere to flying close to linear elements. The reason we did not see this, could be because we had no tagged northern bats to follow, and as such we only have anecdotal evidence for our perception in the field. Only while within areas of relative cover, like forests, did the bats seem to fly freely.

Some of the fluctuations in bat activity or numbers seen exiting a colony could be explained by rainfall. Berková & Zukal (2010), found that increasing temperatures during the summer period increased bat activity, but that it was suppressed by rainfall the day before. Increased activity could be explained by a short break in precipitation granting a window to allow the bats to forage. Likewise, rainfall probably has the potential to decrease temperature enough to significantly influence bats (Voigt, *et al.* 2011). As suggested by Berková & Zukal (2010), due to this decrease in temperature the bats' activity could be reduced.

The use of cover or "edge" structures has been documented for many bat species (Frey-Ehrenbold *et al*., 2013; Schaub & Schnitzler, 2007; Verboom & Huitema, 1997), and there is likely there is a trade-off effect with the choice of flight routes. A shorter distance to the destination requires less energy, whilst a longer route in cover could decrease the risk of being prey. There are also other disturbances to take into account, like noise and light, as many species are known to avoid them (Schaub *et al.* 2009). This could influence flight patterns, as bats could prefer cover and shelter over a shorter path to their foraging ground. This is supported by the majority of the bats counted not choosing the most direct route to reach their destination.

There seems to be a link with how the bats move in relation to their immediate surroundings when exiting a colony. Often choosing cover over the shortest and most direct route. However, there is likely a trade-off between saving energy by taking shorter routes and safety by taking longer routes with more cover. As we have seen many bats still chose the shortest and most direct route to their destination, at least in the short term. Whether the bat takes a short energy-saving route, or a longer and safer route is likely influenced by bat experience, the amount of noise and light disturbance in the vicinity and the presence of predators. In areas where there are not much disturbance or predators, it is likely the bats would always pick the shortest route.

SPATIAL MOVEMENTS

We found that one of the two whiskered bats we most thoroughly studied, #131 (female) foraged almost exclusively in a monoculture spruce forest. #086 (female), our other whiskered bat*,* foraged in a mixed forest by a pond and a stream. Both foraging grounds of our tagged whiskered bats were a lot closer to their respective colonies than with our tagged bats of a very similar species: Brandt's bat*.* Both tagged Brandt's bats travelled further than our whiskered bats and hunted in approximately the same area (fig. 13 and 14), which was a mixed forest. Though after the tagging of more bats, following #049 and #203's (both Brandt's bats*,* female, Ask colony) movements had reduced priority since their colony was already discovered and it was very early in the study period, thus they could have changed their behaviour later.

The literature report contrasting findings with respect to foraging use for Brandt's bats and whiskered bats*:*
In Norway, *M. brandtii* is mostly found in forests, regardless of type (Isaksen *et al*. 2009). In Sweden De Jong (2006) found that Brandt's bats primarily use coniferous forests and distance to water from foraging area seems to matter little*.* Berge (2007) found that Brandt's bats in England primarily use coniferous forests, like in De Jong (2007) in Sweden. This seems to contrast what we found, however with only two tagged individuals it is difficult to draw general conclusions. Whiskered bats in Norway forage mainly in mixed- or deciduous forests often close to lakes (Isaksen *et al*., 2009). De Jong (2006) found that whiskered bats are found in mixed, coniferous, and deciduous forests. In contrast, Berge (2007) found that whiskered bats seem to primarily use grassland over forests. Forests in England are smaller and there are less of them when compared with Norway (Hansen *et al*., 2013). Thus, this grassland choice may be a forced choice caused by a lack of forests, or heavy competition within the remaining preferred patches. Our results suggest somewhat of a mix

Our tagged Daubenton's bats foraged a lot around and over the main river, Nitelva, running through our study area. This is in line with findings from previous studies (Kalko & Schnitzler, 1989; Isaksen *et al*. 2009; Encarnação *et al.* 2010). One of our Daubenton's bats*;* #319 (female) travelled 3.5 km to reach her foraging ground, these far-travelling outliers have been documented before and according to (Encarnação *et al*., 2010) this behaviour can be explained by the ideal distribution theory. The bats simply have to spread out when the population size demands it. The choice of foraging ground is likely influenced by the fluctuations in the colonies, but this was not investigated further.

Brown long-eared bats seemed to choose to hunt near water, and in mixed- or deciduous forests. According to Isaksen *et al*. (2009) brown long-eared bats often hunt in mixed-, deciduous- and coniferous forests, which coincides with our perception of the species in the field. However, we have the smallest amount of data regarding foraging choices. Many of the tags fell off early before we could follow them to their foraging ground, or we prioritized other targets.

It would seem most of our species behave similar to what we would expect from other studies. The clearest exceptions we have are our contrasting findings for whiskered bats and Brandt's bats, to other studies. There still seem to be differences from country to country (and within countries). This could suggest generalist adaptations, or just changes due to local factors. Further studies are needed to reveal their preferred habitat for the purposes of conservation, especially for whiskered bats, considering the recent decline in Swedish populations. Studies like this one, where bats are captured and tagged, then tracked with telemetry, have worthwhile applicability to finding their preferred habitat, provided there is enough personnel.

SIGNAL DETECTION TRIALS

We found that the chance of detecting a signal from a radio depended on the distance to the tag and PoLoSO (Proportion of Line of Sight Obstructed) between the tag and the observer. Furthermore, there was a significantly lower chance to detect a signal if the tag was at ground level than if it was elevated to 1.7 m. We also found that tree density had no significant impact on the chance of detecting a signal.

Our results concur with the information from Biotrack's own homepages (http://www.biotrack.co.uk/faqs.php). That tree density was not significant is interesting, which suggests in relatively flat areas, even if densely forested, this method of telemetry should still work well, i.e. the detection range is not much reduced. This is a considerable benefit, because the probability of detection by visual observation is very much reduced in forested terrain, especially for elusive nocturnal species. The real challenge begins in areas with heavy topography with few to no roads within the study area. Finding roost sites, i.e. bats that are not moving around, should be possible through clever use of terrain and a few days of narrowing in on the tags. Following movements and hunting real time in such an area however can be very challenging.

According to our results, one of our observers (Kristian) had a significantly higher chance of detecting a signal than the others (Joakim and Rune). This could be due to Joakim using a rigid antenna as opposed to a flexible antenna which the two others used. In the field it seemed to have a lesser range than its counterparts and seemed to receive weaker signals at the same distances. Observers Joakim and Kristian also changed between going the southeast and southwest routes for the transmitter tests, as such the routes should not have an impact. Rune went north for every test and the main valley within our study area go mainly north-south, this means that any change terrain could significantly change the proportion of obstruction. Kristian went either south-west or south-east. South-east would usually increase his elevation compared to the tag, which probably meant less obstructions, at least until going over the peak and down the other side. Obstruction would probably be increased when going downhill from the tag (i.e. south-west), however the distance would be relatively small, thus the chance to hear a signal would likely remain high. When reaching the bottom of the valley the line of sight would have less and less obstruction which would keep the chance to hear a signal relatively high even as distance increases. Further studies should randomize directions, or the directions the observers take further.

We found that signal strength significantly decreased with increasing distance and solid ground obstruction. It also significantly decreased when the tag was at ground level rather than elevated. Tree density was almost significant, and I expect to be significant with further studies. It might have been easier to detect if not for the very varied topography within the study area.

If further studies continue with this for the purposes of making a correlation between distance and the bat, there could be made indexes for certain terrain-types where each signal strength corresponds to a range of distance to tag. It might be impossible to practically implement, but given the results of this study there is a chance it could be useful. As such I believe it is worthwhile to investigate this further. Because if such an index can be, it will help to more accurately pin-point a tagged bat's movement and location, especially for solitary observers.

CONCLUSION

The maternity colonies remain a vital point of interest for conservation but is a challenge as bats often roost in private homes, which can lead to conflicts of interest (Stone *et al*., 2013). There is still a need for public education about bats' role in the ecosystem and how they are not dangerous, and for evidence-based conservation in order to safeguard the future of our bat populations (Sutherland *et al*., 2004).

Based on our results, VHF telemetry is indeed a valid method to find maternity colonies in a topographically challenging area. With some experience and clever use of the terrain it can be done effectively and with little manpower.

Tree density, according to our results, did not significantly impact the likelihood of detecting a signal, which was surprising. However, both distance and hills (PoLoSO) did significantly impact the chance to detect a signal and the signal strength.

Following tagged bats in real time however is challenging and require several people over a large area at the ready to track the bats. This process often requires a few days at least to find the bats' preferred foraging ground(s). There are still many gaps in our knowledge, but this study begins to fill in a few holes, and as it built upon further as this project continue, we might reach some of the answers we are looking for.

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http://www.eurobats.org/official_documents/agreement_text#ARTICLEIII
Agreement on the Conservation of Populations of European Bats, EUROBATS, 1991. © 2015 UNEP/EUROBATS. Downloaded 03.17.2017

Map data from NIBIO (https://www.nibio.no/), and Geovekst/Nittedal.

APPENDIX

Table 7: *Myotis*, *Plectotus* and *Eptesicu*s bats captured during the summer field work period in 2017, N = number of bats captured of each species at each date and location. If more than one individual was captured, body mass and forearm measures are average values for the individuals captured. (*) value is missing on one individual.

Date	Location	UTM32 V E	UTM32 V N	Species	N	Mass (g)	Forearm (mm)
12.06.2017	Holterbekken	605622	6658349	*M. brandtii* *M. mystacinus*	4 4	5.4 ± 0.38 4.9 ± 0.47	34.3 ± 0.83 34.0 ± 0.48
18.06.2017	Holterbekken	605616	6658342	*M. brandtii* *M. mystacinus*	1 9	5.2 5.6 ± 1.93*	34.5 33.4 ± 0.80
21.06.2017	Nedre Haug	605133	6658694	*M. mystacinus*	1	5.7	NA*
22.06.2017	Nitelva (S)	605191	6657520	*M. mystacinus* *M. daubentonii*	1 1	4.8 12.1	32.0 38.1
23.06.2017	Strøm bridge	604962	6661576	*M. daubentonii*	5	10.5 ± 2.36	38.3 ± 0.61
25.06.2017	Kasbekken	605473	6660340	*M. brandtii* *M. mystacinus*	2 5	5.5 ± 1.63 5.6 ± 5.8	34.6 ± 2.12 34.2 ± 1.09
27.06.2017	Solvang	604461	6664297	*M. brandtii*	1	7.3	35.2
28.06.2017	Hakadal church	604384	6664671	*P. auritus*	2	9.6 ± 2.62	39.3 ± 0.14
29.06.2017	Nedre Haug	605089	6658743	*P. auritus*	3	10.4 ± 1.41	39.2 ± 0.80
30.06.2017	Rud bridge	606741	6655694	*M. daubentonii*	3	9.5 ± 0.56	37.7 ± 1.23

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