Norwegian University
of Life Sciences

Master's Thesis 2024 60 ECTS
Faculty of Environmental Sciences and Natural Resource Management

Long-Term Effects of Clear-Cutting on the Threatened Bat Species *Eptesicus nilssonii*

Emma Helen Berg
Master of Science in Population and Landscape Ecology

Acknowledgements

This thesis marks the conclusion of my master's degree at the Faculty of Environmental Science and Natural Resource Management (MINA) and five-year study period at the Norwegian University of Life Sciences (NMBU). As a part of the Ecoforest project, I have been able to meet and work with a great deal of competent researchers which have furthered my own knowledge and interest in ecology and forest management. I am proud to be a part of such an engaging research project.

I would like to express my gratitude towards my supervisors, Katrine Eldegard and Reed McKay for their continuous support, trust, and dedication throughout my thesis project. I have gained a lot of confidence and knowledge from them both, in addition to respect for their enthusiasm and commitment to bat conservation.

I wish to thank Jackson Michael Charles Helling for a great field season and continued moral and academic support that I greatly appreciate. I cannot imagine a more competent or positive companion through this journey.

My friends Kåre-Jørgen Ingerø Bøe and Ole Eivind Ovnan Fjeldstad have supplied me with invaluable feedback and guidance throughout the last year, which I sincerely appreciate. Finally, my friends, sister, and parents have always been my biggest supporters, whereas my thesis is no exception. Thank you.

Emma Helen Berg

14.05.2024

Ås, Norway

Abstract

Clear-cutting is the most common method utilized in modern Fennoscandian forestry. As a large-scale disturbance, it completely transforms the forest ecosystem. It results in even aged monocultures which lack heterogeneity and critical biotic structures for forest dwelling organisms. In this study, we wished to investigate the long-term effects of clear-cutting on threatened bat species, as they are insufficiently examined in boreal forest ecosystems.

Ten sites across southeastern Norway were examined through acoustic monitoring and forest habitat measurements. Each site consisted of a pair of forest stands; one near-natural area (NN) which had never undergone clear-cutting, and one mature, previously clear-cut area (CC). The sites utilized are a part of the Ecoforest project (https://ecoforest.no/), which is a broader study of long-term ecological impacts of clear-cutting. The northern bat (*Eptesicus nilssonii*) was selected as the focal species in this study, due to its threatened status following a recent population decline and its distinction as the most common bat species in Norway.

Higher levels of bat activity in general were observed in the near-natural forest habitat. The northern bat displayed less commuting and foraging activity in the clear-cut sites, implying negative long-term effects of the logging technique. Northern bat activity was highest in high temperatures and low levels of precipitation, and the effects of weather conditions seemed dependent on forest type. Lighting conditions and forest composition such as dead wood volume had no significant effect on northern bat activity, though significant differences in forest composition between clear-cut and near-natural sites were found.

This study highlights the importance of researching the impact of forest management on a large time scale and how stand-replacing forestry negatively influences the activity of the northern bat in boreal forests. As the near-natural forest areas of Norway are continuously shrinking, the opportunity to research these habitat types and the effects of forest management are limited and urgent.

Contents

1 Introduction

Out of the 44 000 species registered in Norway, about 60 percent are present in the forest ecosystems (Miljødirektoratet, 2023) and about half (1330 species, 48%) are considered threatened species (Artsdatabanken, 2021). Since 44 percent of Norway's land is covered in forests, its importance as a habitat cannot be overstated (Sundling, 2023). Common intensive forestry, characterized by even-aged monocultures, have a significant detrimental effect on forest-dwelling species like bats. These intensively managed forests have a lower density of dead wood and old trees, in addition to limited amounts of heterogeneity of species and reduced diversity in lighting condition (Asplund et al., 2024; Miljødirektoratet, 2023). In most cases a mixed forest has greater biodiversity than a single species stand (Sundling, 2023), and the forest ecosystem benefits from biodiversity through increasing the efficiency of ecosystem services such as carbon storage, supporting the growth of trees and plants, and providing goods and services to humans and animals alike (Huuskonen et al., 2021; Viljur et al., 2022).

Clear-cutting is one of the most effective and economically sustainable forest cutting techniques dominating North America and Europe (Kuuluvainen et al., 2012; Rosenvald & Lõhmus, 2008). The practice removes and reestablishes whole forest stands of at least 4-5 acres with silvicultural treatments such as planting seeds or saplings (Kelvin et al., 2015; Larsen, 2022). Up to 60% of all harvested forest areas in Norway are planted with Norway spruce (*Picea abies*), which has caused most Norwegian forests to consist of purely Norway spruce since the 1950s (Allen II et al., 2020). Although the timber production and consequent economic value is great, the ecological impacts are mostly negative (Kelvin et al., 2015). The massive disturbance leads to an increase in carbon emissions and complete conversion of the forest habitat (Piirainen et al., 2002). After felling, the light and moisture conditions change from an initial increase, and later reduction as the forest stand grows denser than natural, which in turn affects the species composition of understory vegetation (Esseen et al., 1997; Ilintsev et al., 2020; Majasalmi & Rautiainen, 2020). The effect of eradicating such a large forest area is comparable to natural disturbances such as forest fires or windstorms, but dissimilarly to clear-cutting, these natural disturbances leave remnants that are vital to rebuild and support the biodiversity. These remnants include live and dead trees of varying structure (Rosenvald & Lõhmus, 2008). Additionally, the scale in which clear-cutting is currently occurring is typically larger than that of natural disturbances and stand-replacing disturbances are generally uncommon in natural forest dynamics in Norway (Kuuluvainen et al., 2012; Piirainen et al., 2002).

The forest ecosystem provides an essential habitat for several wildlife species. Due to a variety of foraging and roosting sites, the highest number of bat species across Europe are found in forests (Dietz & Kiefer, 2016; Meschede & Thorson, 2001). All Norwegian bat species depend on forests during all or part of their life cycle (Dietz & Kiefer, 2016). Roost sites are the locations where bats reside for protection, mating, hibernation, food digestion and raising offspring. Roosting ecology, such as type preference, fidelity, and size of colonies, can vary greatly between bat species and seasons (Barclay & Kurta, 2007; Bat Conservation Trust, 2023). As clear-cutting changes the entire forest composition, it fragments the forest habitat and can force bats to relocate in order to roost and forage successfully (Bat Conservation Trust, 2023). While displacement is one of the indirect effects of clear-cutting, bats may be directly harmed if roost sites are felled with individuals residing in them (Russo et al., 2016). A forest without clear-cutting consists of trees of varying age and diameter, which in time develop holes and cracks in their trunks. An array of animal species, including bats, utilize these trunk structures as roost sites in addition to cavities created by other animals (such as wood-pecker holes) (Kunz, 2003; Vonhof, 1996). As trees are logged before roost sites are formed, the amount of available habitat for many forest dwelling species is reduced (Meschede & Thorson, 2001).

The amount of dead wood, both standing and downed, in Scandinavian forests has decreased greatly with the introduction of intensive forestry, which is especially negatively impacting saproxylic (species living in decaying wood) arthropod species (Allison et al., 2023; Sugar, 2000). All Norwegian bat species are insectivores, therefore their distribution in Norway can be closely linked to the invertebrate accessibility (Frafjord, 2022). Bat foraging strategies vary based on the habitat composition. Different approaches are necessary for bats to capture stationary than flying insects, therefore a change in habitat could constitute a change in foraging tactic (Denzinger & Schnitzler, 2013; Jones, 2005).

Echolocation, or biosonar, is a tool utilized by bats to forage, orient themselves, and avoid flying into obstacles, even in the dark (Griffin, 1946). Acoustic detectors record the ultrasonic auditory activity of bats, which include echolocation, social calls, and feeding buzzes. Acoustic detectors are used in a number of bat studies since it is a non-invasive, cost effective, and more manageable approach than capture methods, direct observation, or telemetry (Adams et al., 2012; Stahlschmidt & Brühl, 2012). Insectivorous bat species seldom fly inside the range of ground-based traps, such as mist nets, and are therefore more easily observed with acoustic sampling (Furey et al., 2009), although rainfall can impair the quality of recordings and the activity of bats is depressed under wet and cold conditions (LaVal & Lawton, 2021; Wildlife Acoustics, 2024a).

Norway currently has 11 registered species of bats (Artsdatabanken, 2021). Despite their adaptability and robust nature, bat populations have been found to significantly decrease across the world (Altringham, 2011; Russo et al., 2016). According to the "IUCN Red List categories and criteria" the species have been graded and evaluated on their risk of extinction from the Norwegian fauna (Artsdatabanken, 2021; Vié et al., 2009). The categories are as follows: Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT) and Least Concern (LC) (Vie et al., 2009). Six of the bats found in Norway are categorized as threatened or near threatened, while all Norwegian bats are protected. Additionally, more species are listed as NA due to lack of sufficient data (Artsdatabanken, 2021). Since 2007 the northern bat (*Eptesicus nilssonii*) has had a documented population decline in Norway, which has led to a change of category from least concern to vulnerable (Artsdatabanken, 2021; Eldegard et al., 2021; Henriksen & Hilmo, 2015). The northern bat is the most common bat species in Norway (Frafjord, 2023), causing its population decline to raise concern and need for further investigation. The data collection and identification in this study allowed for the vulnerable northern bat to be studied.

The distribution of the northern bat overlap largely with Fennoscandian boreal forests, which have been changed under modern forest management. Since the source of the northern bat population decline is unknown, we wished to examine the possible long-term effects of clear-cut forestry in Norway. Therefore, the following questions were asked:

I) How do near natural and clear-cut forest patches differ in respect to habitat attributes that are important to bats?
II) In what ways does the activity of *Eptesicus nilssonii* differ between near natural and clear-cut habitats?
III) How is bat activity influenced by amount of dead wood, light conditions, and weather conditions in clear-cut and near-natural forest sites?

2 Material and methods

2.1 Study area

The study was conducted over a large area across southeast Norway (Figure 1). The Ecoforest project investigates the long-term effects of clear-cut forestry on biodiversity, in addition to carbon storage and differences in ecosystem functions. Sites used in this study are part of the Ecoforest project (https://ecoforest.no/) (for specific locations see appendix table A1). The project includes 12 sites which were further narrowed down to 10 sites (excluding sites 1 and 10) to match the amount of resources available. Near-natural forest patches have no history of clear-cut forestry but might have undergone other forms of management in the past. The age of the clear-cut forest patches varied slightly between sites. Other varying factors include elevation, distance from roads and other human-made structures and distance to waterbodies.

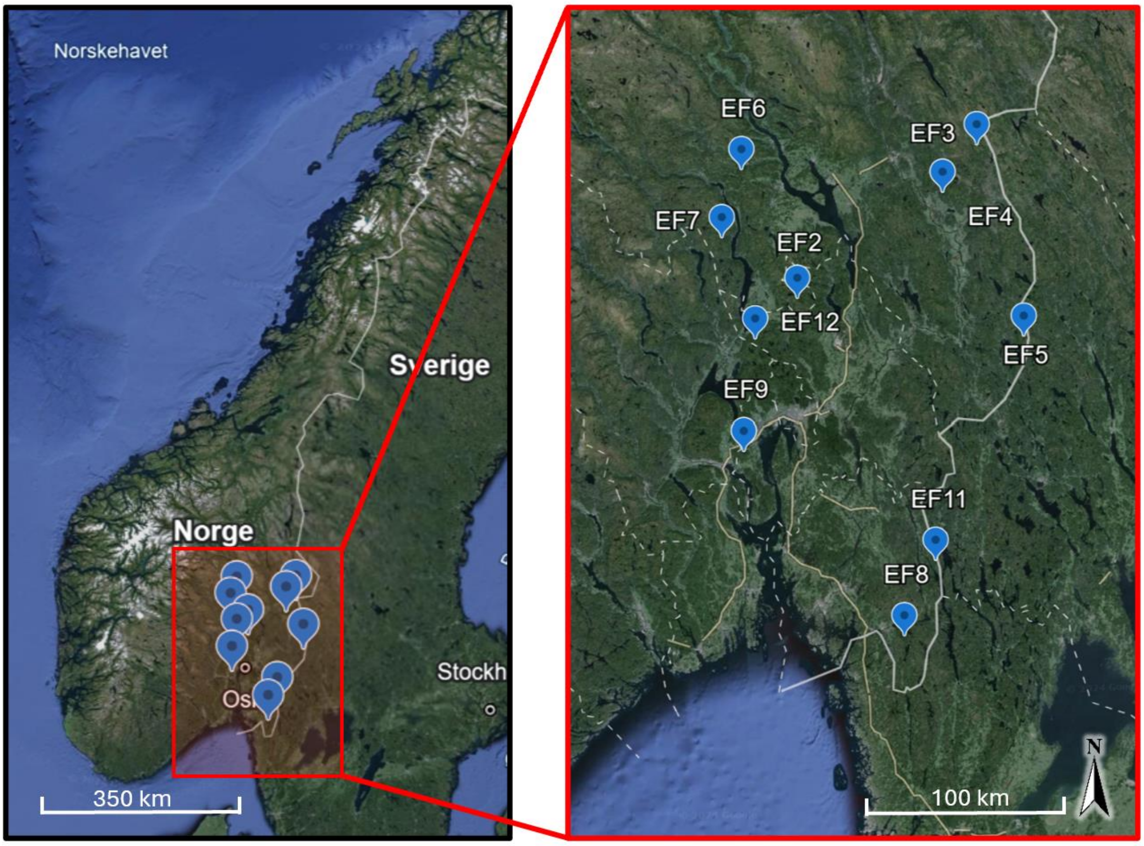

Figure 1: Location of the study area represented by the Ecoforest tag (EF) and corresponding numbers. Each point includes two study sites; one near-natural forest patch and one previously clear-cut patch. To the left the study area is shown in red rectangle in relation to Norway. To the right, study sites marked by number. Maps are generated in Google Earth.

2.2 Study species

In this study the aim was to examine the threatened bat species that reside in Norway: *Barbastella barbastellus, Eptesicus nilssonii, Nyctalus noctula, Pipistrellus nathusii, Vespertilio murinus* and *Myotis nattereri* (Table 1). However, no recordings of *B. barbastellus* and *P. nathusii* were identified, therefore these are not present in this study. Additionally, due to difficulty in identifying the different species of *Myotis*, these were lumped together by species group, which in turn makes it impossible to accurately identify the activity of the endangered *M. nattereri* in this study. Finally, *E. nilssonii* was selected as the focal species of this study, as it constituted close to half the identified bat passes identified.

Table 1: List of bat species currently registered in Norway. Data from the Norwegian national red list (Artsdatabanken, 2021).

Latin name	**English name**	**Status**	
Barbastella barbastellus	Western barbastelle	Critically endangered	CR
Myotis nattereri	Natterer's bat	Critically endangered	CR
Nyctalus noctula	Common noctule	Endangered	EN
Eptesicus nilssonii	Northern bat	Vulnerable	VU
Pipistrellus nathusii	Nathusius' pipistrelle	Near threatened	NT
Vespertilio murinus	Parti-colored bat	Near threatened	NT
Myotis brandtii	Brandt's bat	Least concern	LC
Myotis daubentonii	Daubenton's bat	Least concern	LC
Myotis mystacinus	Whiskered bat	Least concern	LC
Plecotus auritus	Brown long-eared bat	Least concern	LC
Pipistrellus pygmaeus	Soprano pipistrelle	Least concern	LC

Eptesicus nilssonii, or northern bats, are a member of the Vespertilionidae family and one of the most common bats in Scandinavia. The northern bat distribution extends from southern Europe to the northern reaches of Fennoscandia, making it the sole bat species to reproduce north of the Arctic Circle (Dietz & Kiefer, 2016). Due to its northern distribution, it has been found to be partly diurnal during the summer months. The foraging habitat varies between seasons, from forests, farmland, and wetlands. Northern bats have also been known to forage frequently above lakes and fresh water bodies (Wermundsen & Siivonen, 2008). When they forage in forests, they hunt airborne insects, preferably in open spaces at relatively high altitudes of up to 100 meters above the ground, and about 8 meters from surrounding vegetation or along forest edges (Dietz & Kiefer, 2016; Rydell, 1986; Rydell, 1993).

2.3 Data collection

The data collected in this study includes acoustic recordings of bat calls and habitat descriptions. The field work was conducted over the summer of 2023. Detectors were deployed between June 5th and June 12th, maintenance and habitat recordings were done from June 25th to July 7th, and lastly the equipment was retrieved between July 18th and July 24th. Additionally, weather data, in the form of precipitation and temperature logs, was gathered for each site from the SeNorge.no database. Data from the relevant dates was extracted. Light availability and forest composition data was collected by collaborators in the Ecoforest project (Asplund et al., 2024).

2.3.1 Acoustic monitoring

One ultrasonic bat detector (SM4-BATFS Wildlife Acoustics) was deployed at each site (see appendix table A2 for detector settings) to record from early June to late July. Since deployment and retrieval of equipment was conducted across several days, recording start and end dates varied across sites, yet all detectors were deployed in the field for an equal duration of 41-43 nights. Ultrasonic, omnidirectional microphones (SMM-U2 microphone, Wildlife Acoustics) were calibrated before use and deployed with each detector. Detectors were fastened to wooden poles that were struck into the ground (Figure 2A). To obtain high quality recordings the detectors were placed a minimum of 5 meters from trees and other tall vegetation when possible, but some sites were too cluttered to adhere to this rule. Tall grass and bushes were also avoided. Placement under large canopy openings were favored as bats have been found to prefer open canopy forest patches while foraging (Rydell, 1986). Detectors were checked for maintenance once during the field season. Maintenance included checking the detectors and microphones for damage, changing the batteries, exporting diagnostics from SD-cards, collecting SD-cards with data and replacing them with new ones, formatting new SD-cards, and checking the microphone.

2.3.2 Habitat survey

Habitat structure descriptions were acquired within a 15-meter radius plot (Figure 2B). In each plot, data was collected on trees and snags, including their distance from the centroid, decay stage, presence of broken tops, and diameter at breast height (see appendix table A3). Additionally, cavities, loose bark, dead branches, and bird evidence were recorded. The decay stages range from 1 to 7 where 1 is a live tree and 7 is decomposed (see appendix figure A1). Broken snags were included if they exceeded breast height.

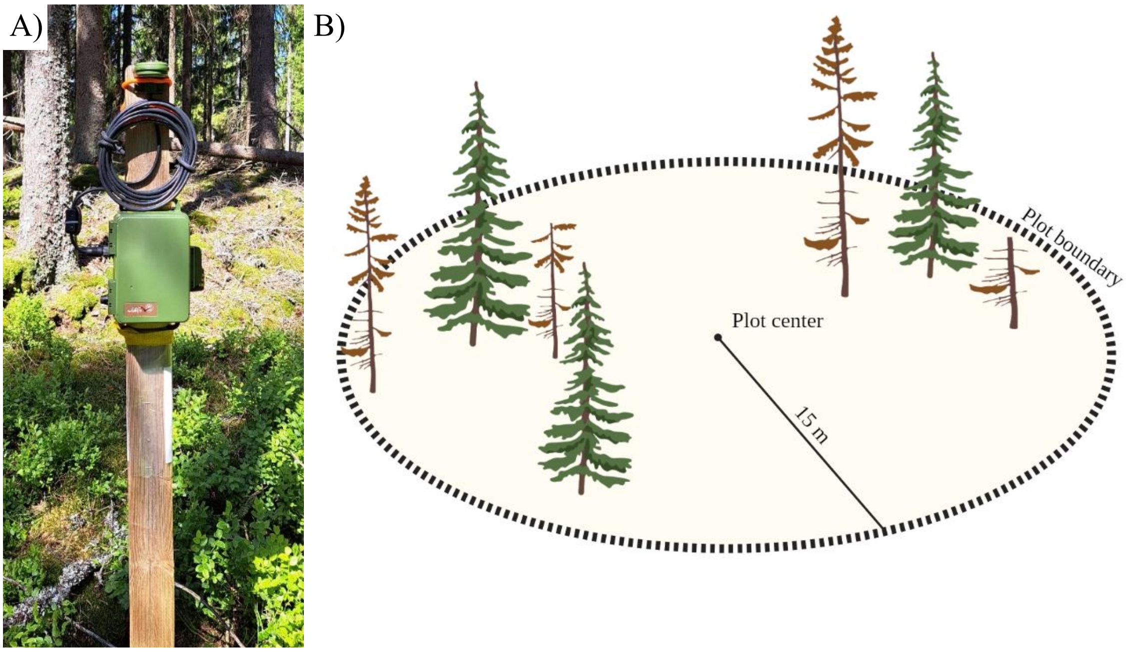

Figure 2: A) Field setup of SM4-BATFS acoustic bat detector (Wildlife Acoustics). B) Setup of habitat survey radius plot, created in Biorender.com.

2.4 Acoustic data analysis

The acoustic data collected by the detectors was processed through Kaleidoscope Pro (Wildlife Acoustics, 2024b) and quantified from the raw file format to the form of 2-5 second recordings of bat calls, which include a minimum of two consecutive pulses of high frequency sound produced by a bat. Therefore, in this study, a single “bat call” comprises a 2-5 second recording of sounds emitted by a bat. All recordings were subjected to noise filtering with the following parameters: a frequency range of 8-120 kHz, a maximum pulse length of 2-500 ms, a maximum inter-syllable gap of 500 ms, and a minimum of 2 pulses. Initial classification was done automatically to species level through the “Bats of Europe” classifier using the Kaleidoscope Pro software (Wildlife Acoustics, 2024b). The classifier settings were modified to exclusively account for species identified in Norway and Sweden.

All passes were categorized as a species or NoID. NoIDs include non-bat produced sounds and/or sounds the program was unable to identify to species level due to noise or unclear recordings. Passes that were identified as one of the target species of the study and a subset of NoIDs were included in manual analysis.

2.4.1 Manual species identification

To verify the automatic classification each recording was viewed and examined manually. Identification of species was done following "Bat calls of Britain and Europe" by Russ (2021), "Social calls of the bats of Britain and Ireland" by Middleton et al. (2020) and Reed Mckay. The *Myotis* bats have a similar frequency modulated structure in their calls which is challenging to distinguish, therefore all *Myotis* bats were identified to their genus and not to species level. Recordings with poor quality or insufficient clarity for classification were put in the NoID category. High frequency sounds other than bat calls that were recorded were filtered out. All bat passes were further classified as commuting (no label), feeding buzz (B) and social calls (S). In recordings where more than one activity is present, both were recorded. Recordings with more than one type of bat were marked with both species, while two or more bats of the same species were marked only once per recording.

2.4.2 Data preparation

After identification of bat passes was concluded, the acoustic data was prepared for statistical analysis using R (R Core Team, 2024). Due to the processing error which excluded the data EF7-CC, all data from EF7 was omitted from further analysis. Equipment failure caused a shorter survey period at sites EF2-CC and EF12-CC (see appendix figure A2), these were still included in the analysis. Nights where the detectors were operational, but no activity detected were manually accounted for as "zero-activity nights". Using the statistical program R studio, the data was aggregated to night, per behavior and species. Environmental factors were merged with the acoustic dataset.

2.5 Statistical analysis

All statistical analyses were conducted in the Rstudio Statistical Software (R Core Team, 2024). Using the R package "DHARMa" (Florian Hartig, 2022) the data was checked for zero inflation and scored very high (92.3%). This is caused by the aggregation of observations by night, which returns a high number of zero recorded bat passes for each species and/or behavior each night. Due to the small sample size, most analyses were done without interactions between multiple variables. Models were selected through a combination of AIC and model validation using the DHARMa package in R. In all models the count of northern bat passes is the response variable.

2.5.1 Bat behavior

To investigate the differences in bat behavior between forest types a negative binomial generalized linear mixed model (NB-GLMM) was applied, with behavior and site type as the predictor variables. Only feeding and commuting behavior was included in the analysis due to low numbers of social calls detected. No zero-inflation component was included, and the random effects were location and site.

Sum of bat passes ~ Site type + Behavior + (1 | Location/Site)

2.5.2 Site type

A Poisson generalized linear mixed model (GP-GLMM) was used to examine the effect of site type (clear-cut vs. near-natural) on bat activity. The predictor variable was site type. The model included a zero-inflation component, and location and site as random effects.

Sum of bat passes ~ Site type + (1|Location/Site)

2.5.3 Abiotic factors

Abiotic factors were included in analyses to investigate if they affect bat activity differently in the two habitat types. The abiotic factors included in statistical analysis were temperature, precipitation, and diffuse light index (DLI). All three continuous explanatory variables were scaled to avoid statistical issues and summarized for each site and site type.

To examine the influence of temperature and precipitation on northern bat activity a GP-GLMM with zero inflation was applied. Temperature and precipitation were the predictor variables in the first and second model respectively, and location and site were applied as random effects.

Sum of bat passes ~ Site type + Temperature + (1|Location/Site)

Sum of bat passes ~ Site type + Precipitation + (1|Location/Site)

The impact of DLI on bat activity was investigated with a NB-GLMM with site type and DLI as the predictor variables. Location and site were random effects, and the model did not include a zero-inflation component.

Sum of bat passes ~ Site type + DLI + (1 | Location/Site)

2.5.4 Forest composition

To examine the effect of dead wood on bat activity a GP-GLMM with zero inflation was applied. Total volume, standing volume, and downed volume of dead wood were all included as predictor variables in separate models with the same configuration.

Sum of bat passes ~ Site type + Total dead wood volume + (1 | Location/Site)

The effect of total number of snags was included in its own GP-GLMM, with zero inflation and both site type and sum of snags as predictor variables.

Sum of bat passes ~ Site type + Snag + (1|Location/Site)

3 Results

3.1 Bat activity

Across the 20 sampling sites and 49 active sampling nights a total of 8930 bat calls were identified. Out of the manually identified samples 4215 (47.2%) were *E. nilssonii*, 4481 (50.2%) *Myotis*, 15 (0.17%) *N. noctula*, 8 (0.09%) *V. murinus*, 2 (0.02%) *P. pygmeus*, and 205 (2.23%) unidentified species (Figure 3). In general, more bat activity was recorded at near-natural sites, but the activity varied greatly between site types across the site locations (figure 4 & 5). The majority of bat passes were identified as commuting or feeding, only 23 passes included social calls (see appendix figure A3).

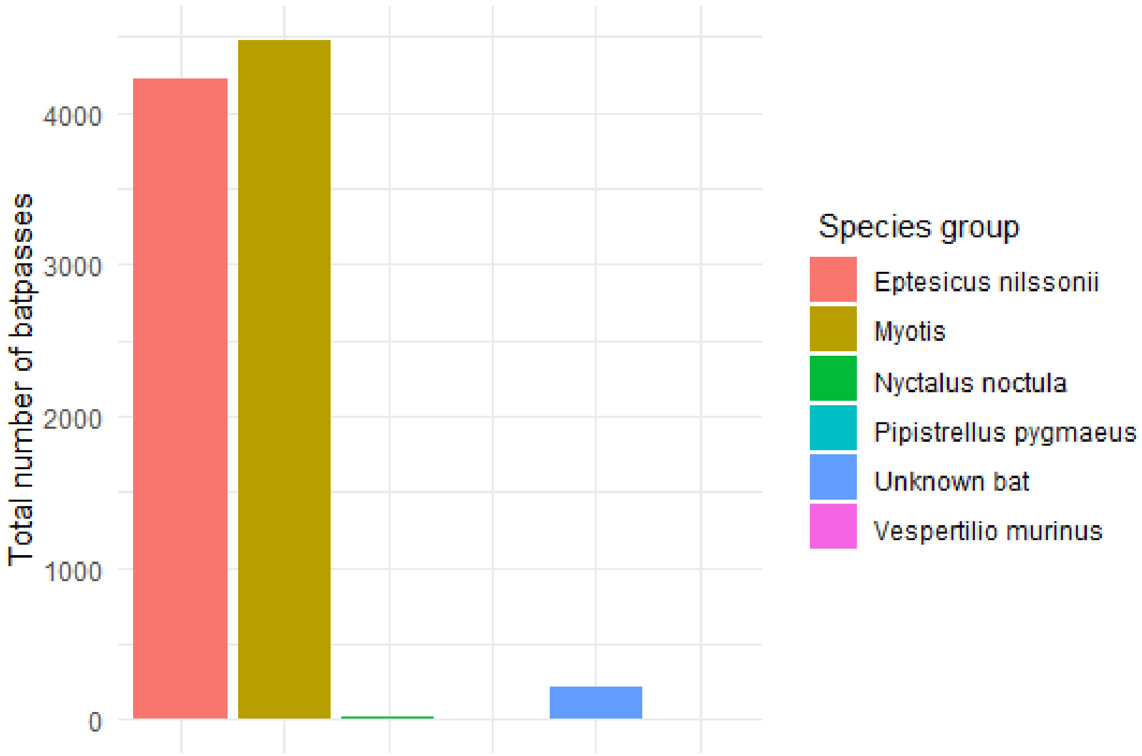

Figure 3: Total number of bat passes in each species group after manual identification.

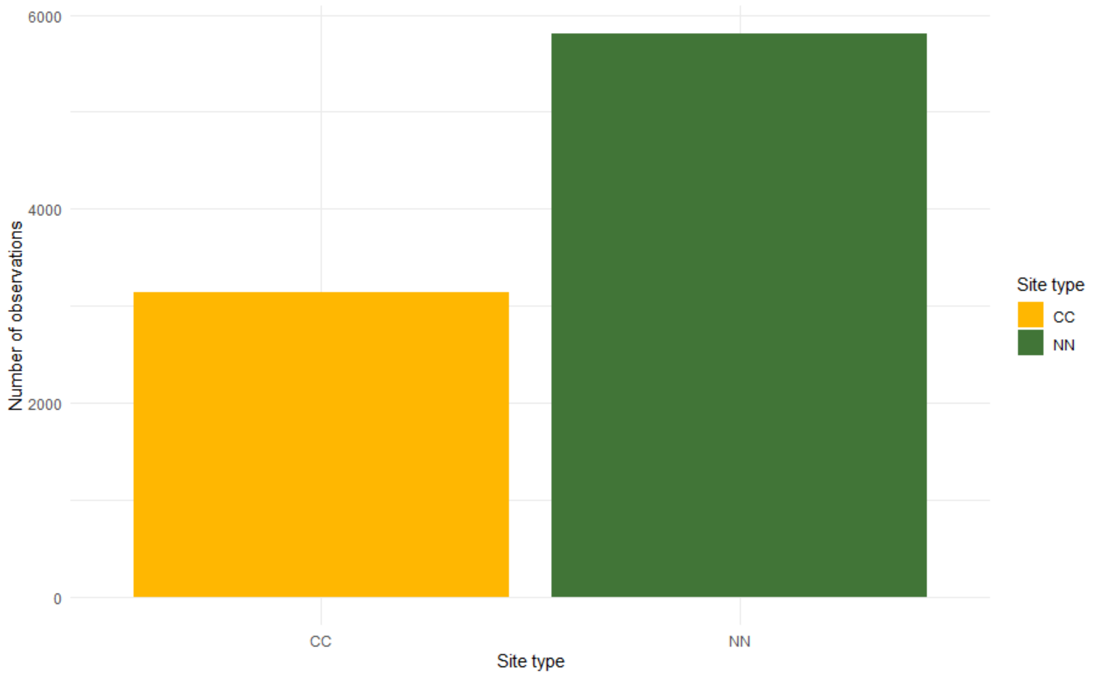

Figure 4: Total number of manually identified bat passes in each site type (clear-cut and near-natural).

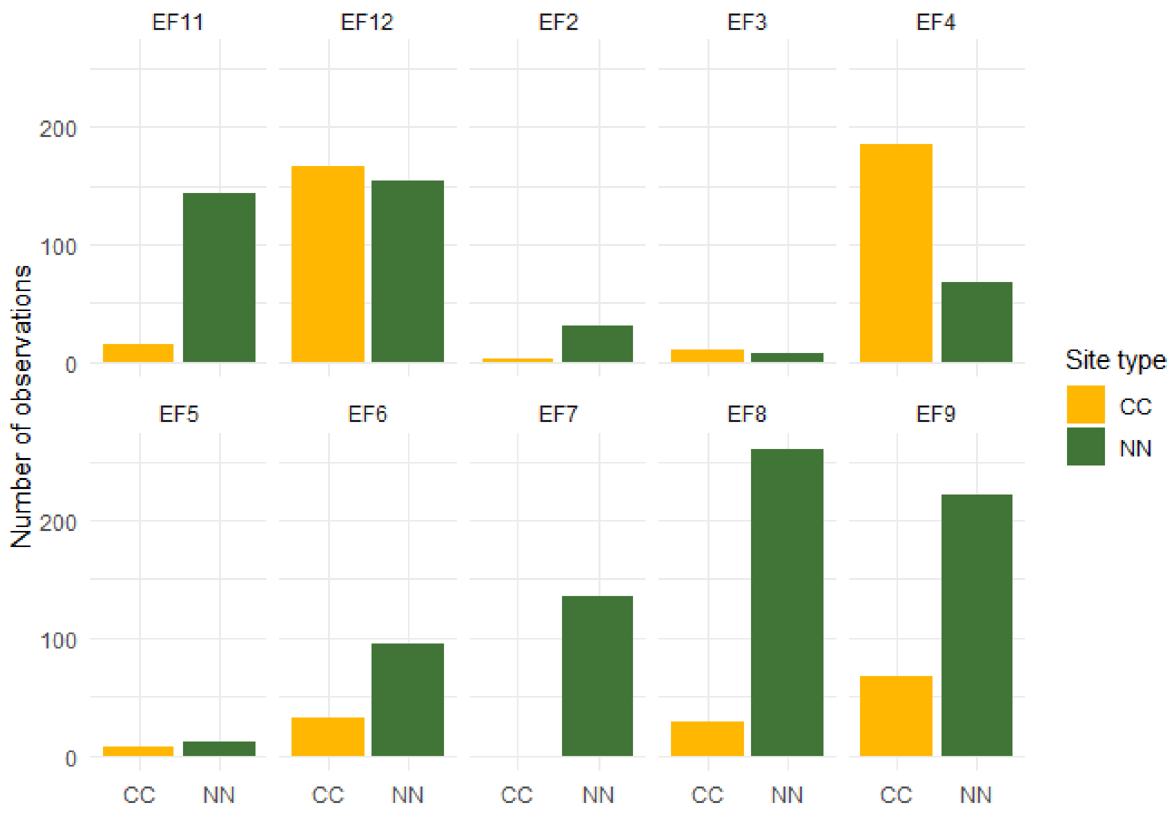

Figure 5: Total number of manually identified bat passes in each site type (clear-cut and near-natural) at all site locations.

3.2 Forest composition

The sum of the different habitat characteristics showed varied distributions across the site locations (See appendix figure A4). Broken tops and broadleaf trees were more prevalent in clear-cut forest patches, while dead branches, snags and cavities were more abundant in near-natural sites. The total number of trees in decay stage 1 and 2 (living and decreasing) was 56% higher in clear-cut sites, but 30% more trees of decay stages 3-4 (dead and loose bark) and 80% of decay stages 5-7 (without bark, broken, and decayed) were observed in the near-natural habitat than the clear-cut (Figure 6).

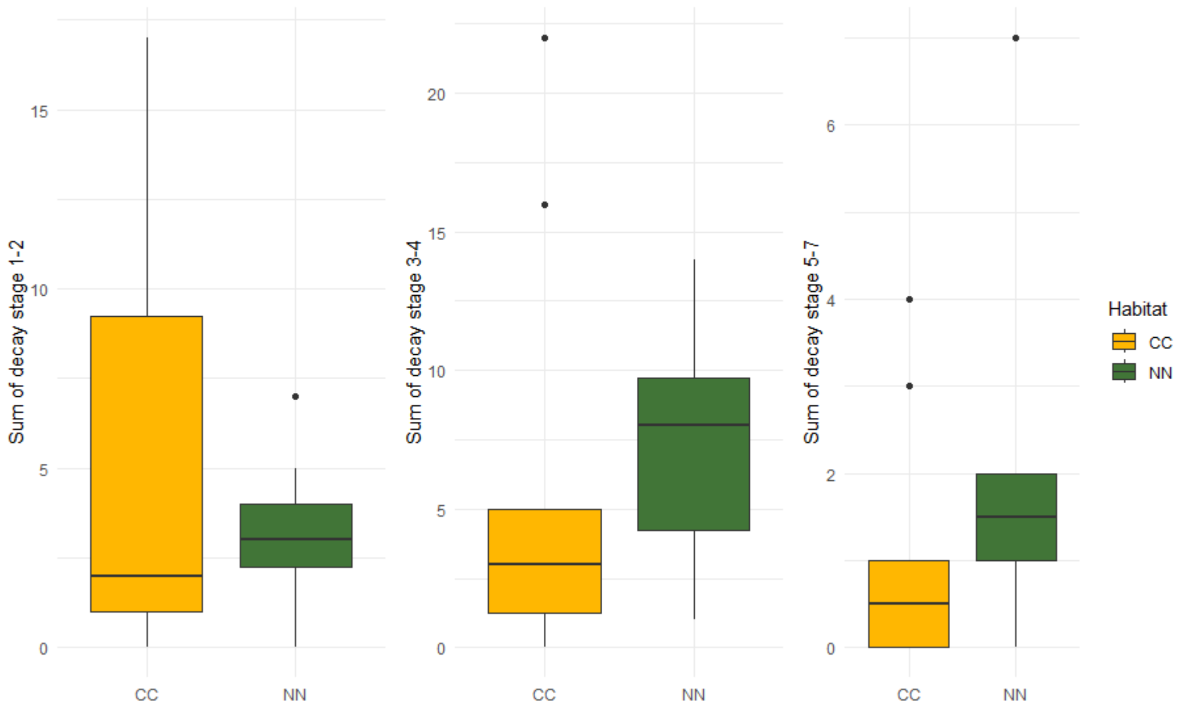

Figure 6: Total number of trees in decay stages 1-2 (living and decreasing), 3-4 (dead and loose bark) and 5-7 (without bark, broken, and decayed) in each site type (clear-cut and near-natural).

3.3 Statistical analysis

3.3.1 Covariate selection

A Wilcoxon test was conducted to check for significant differences within the covariates acquired from the Ecoforest project collaborators (Table 2). The site types differ greatly in age, with little to no overlap, therefore age was not included as a covariate in an analysis of factors influencing bat activity. Substantial overlap was found in the amount of dead wood, both standing and downed, therefore these were included in further analyses. The diffuse light index (DLI) showed large variation in both forest types, hence an overlap between site types was found. DLI was therefore included as a possible influencing factor on bat activity (Figure 7).

Table 2: Wilcoxon test p-value output for covariate variables.

Variables	p
Age	0.0020
Age max	0.0020
DLI yearly	0.85
Total volume of downed dead wood	0.0020
Total volume of standing dead wood	0.064
Total volume of dead wood	0.0059

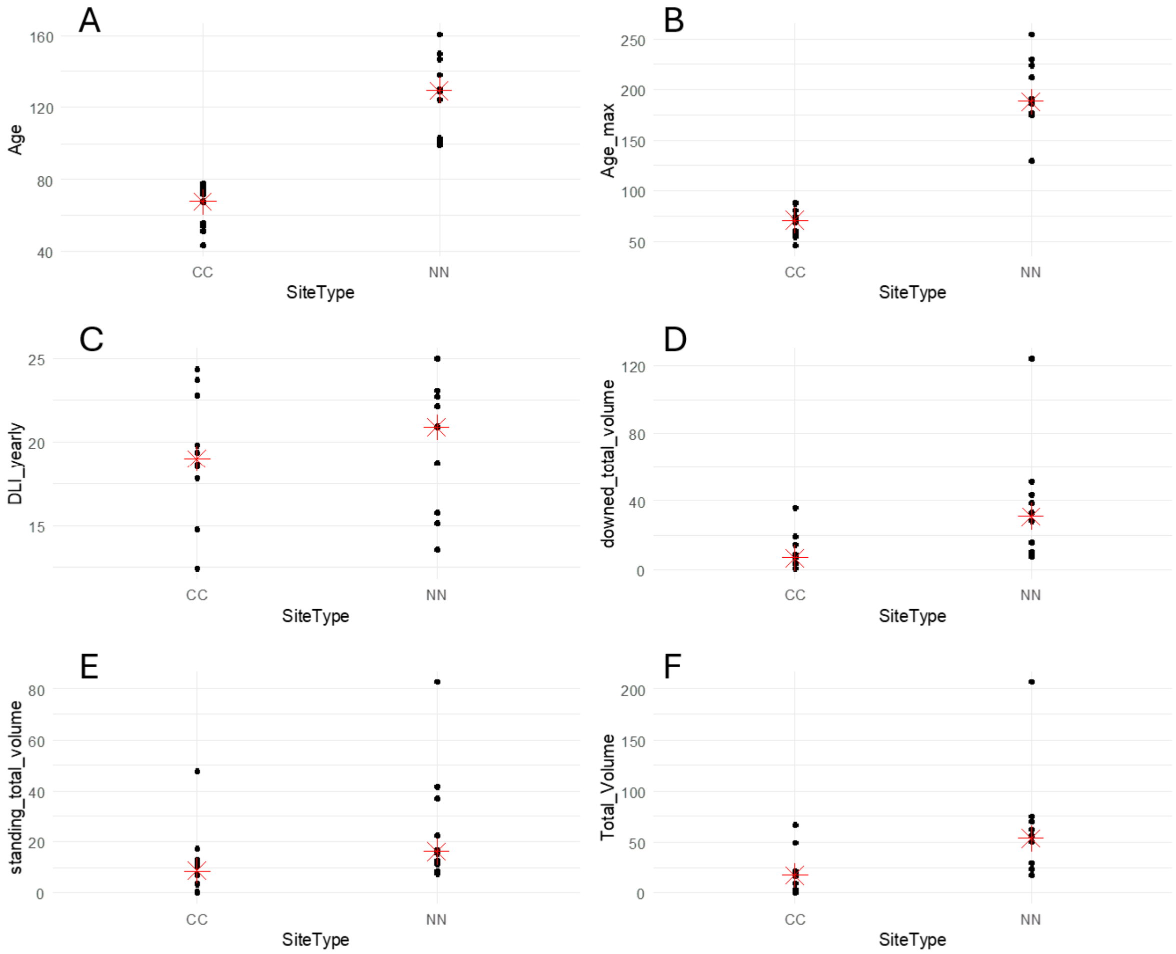

Figure 7: Variables measured by the Ecoforest project including A) forest age, B) maximum age of trees in the forest type, C) diffuse light index (DLI), D) total volume of downed dead wood, E) total volume of standing dead wood, and F) total volume of dead wood in both site types; clear-cut (CC) and near-natural (NN).

3.3.2 Bat behavior

A significant interaction between bat activity and behavior (commuting or feeding) (p = < 0.001) was found within the sample (Table 3), and a significant difference was detected in behavior between site types (p = 0.047). The feeding activity of the northern bat was significantly higher in the near-natural forest type (p = 0.037). There is a higher number of commuting passes than feeding buzzes, but the variation in data is larger in commuting (Figure 8).

Table 3: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes, site type, and behavior. Sum of bat passes is the response variable, while behavior (commuting and feeding) and site type (clear-cut and near-natural) are the predictor variables.

Variables	**$\chi 2$**	**Df**	**p**
Intercept	0.16	1	0.69
Site type	3.95	1	0.047
Behavior	121.39	1	< 0.001

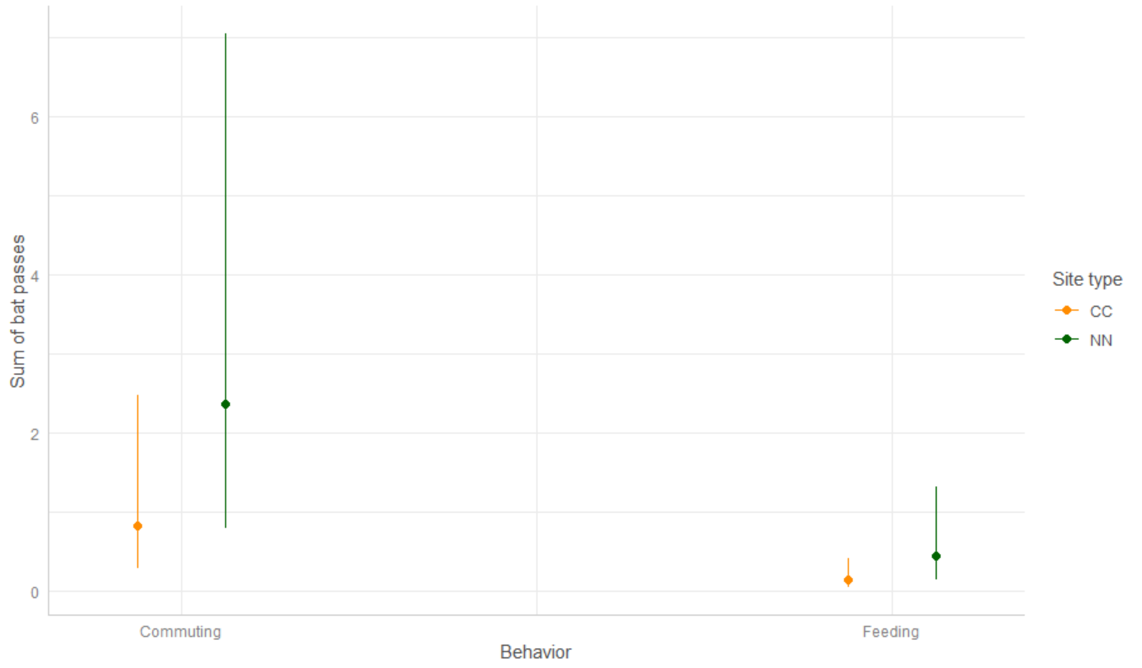

Figure 8: Predicted number of total northern bat passes per behavior (commuting and feeding) and site type (clear-cut and near-natural).

3.3.3 Site type

Approximately double the amount of northern bat passes were registered in the near-natural as in the clear-cut habitat, but the difference was not statistically significant on the $\alpha = 0.05$ level ($p = 0.063$) (Figure 9).

Table 4: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes and site type. Sum of bat passes is the response variable and site type (clear-cut and near-natural) is the predictor variable.

Variables	**$\chi 2$**	**Df**	**p**
Intercept	9.23	1	0.0024
Site type	3.45	1	0.063

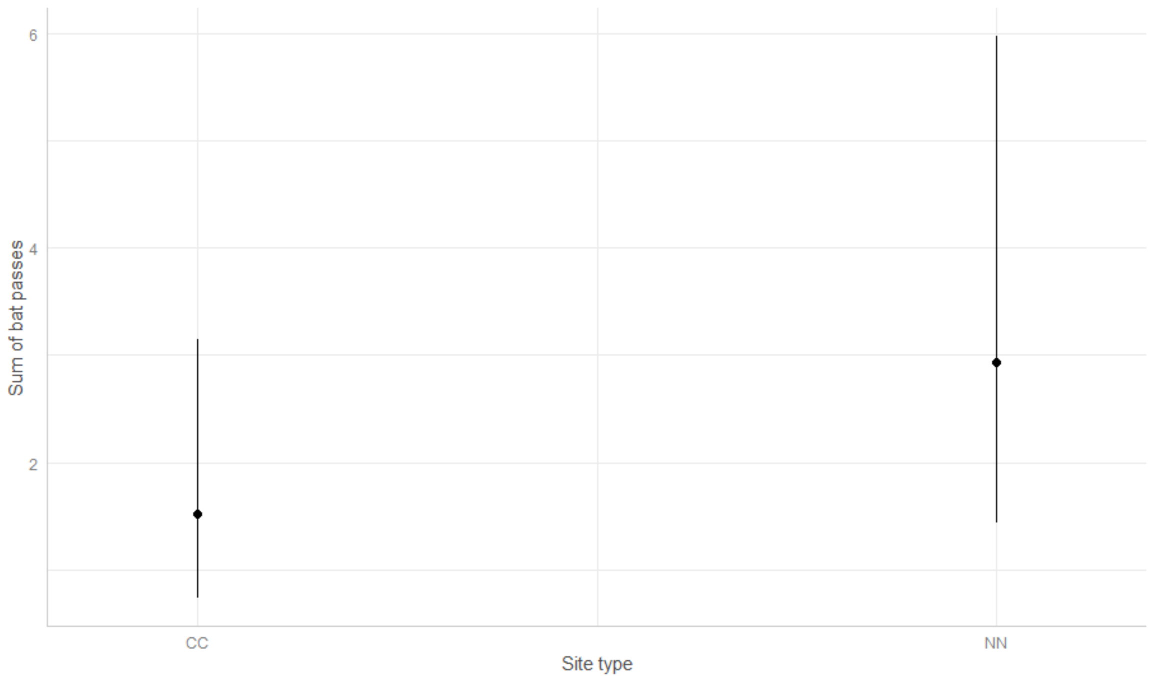

Figure 9: Predicted number of total northern bat passes per site type (clear-cut and near natural).

3.3.4 Abiotic factors

The interaction between total sum of northern bat passes per night and mean daily temperature was significant ($p = < 0.001$) (Table 5). As the relationship is positive, it indicates an increase in activity with increased average temperature (Figure 10). A significant interaction between bat activity and average precipitation was found ($p = 0.013$) (Table 6), and the effect is negative, meaning that bat activity is reduced with an increase in precipitation (Figure 11. A difference in northern bat activity between site types depending on temperature ($p = 0.051$) and precipitation ($p = 0.061$) was found, just barely not statistically significant on the $\alpha = 0.05$ level. No interaction between activity and temperature ($p = 1.0$) or precipitation ($p = 0.95$) was detected.

Table 5: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes, site type, and temperature. Sum of bat passes is the response variable, while temperature (Celsius) and site type (clear-cut and near-natural) are the predictor variables.

Variables	**$\chi 2$**	**Df**	**p**
Intercept	7.45	1	0.0063
Site type	3.82	1	0.051
Temperature	13.73	1	< 0.001

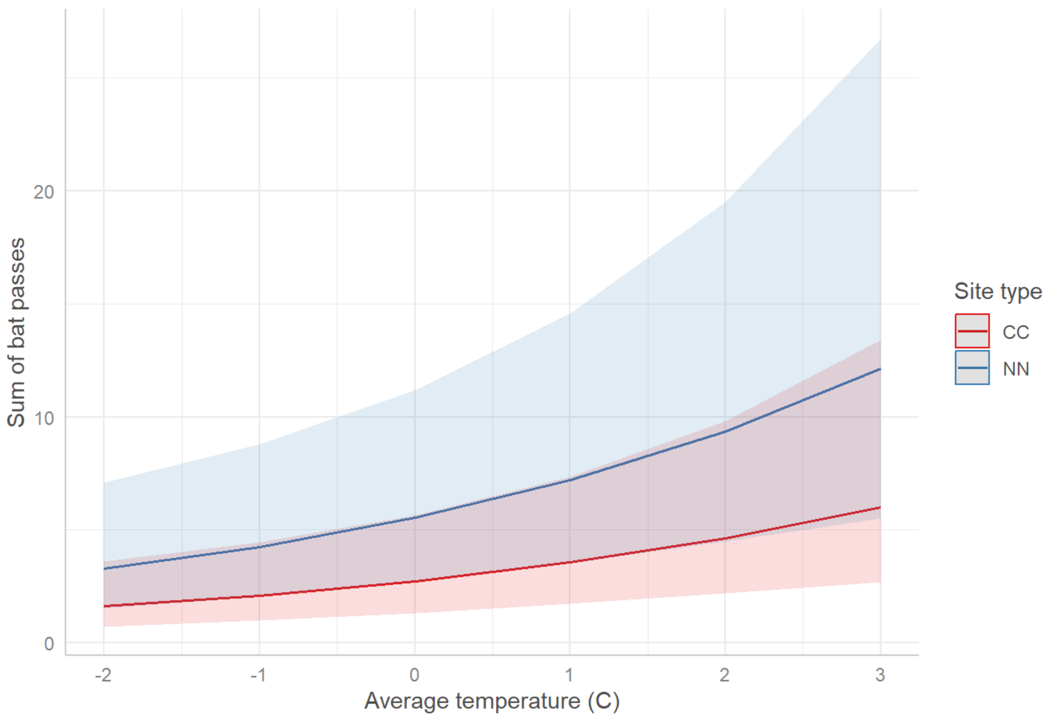

Figure 10: Predicted sum of northern bat passes per scaled average temperature (C) and site type (clear-cut and near natural).

Table 6: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes, site type, and precipitation. Sum of bat passes is the response variable, while precipitation (in millimeters) and site type (clear-cut and near-natural) are the predictor variables.

Variables	**$\chi 2$**	**Df**	**p**
Intercept	8.35	1	0.0039
Site type	2.52	1	0.061
Precipitation	6.26	1	0.012

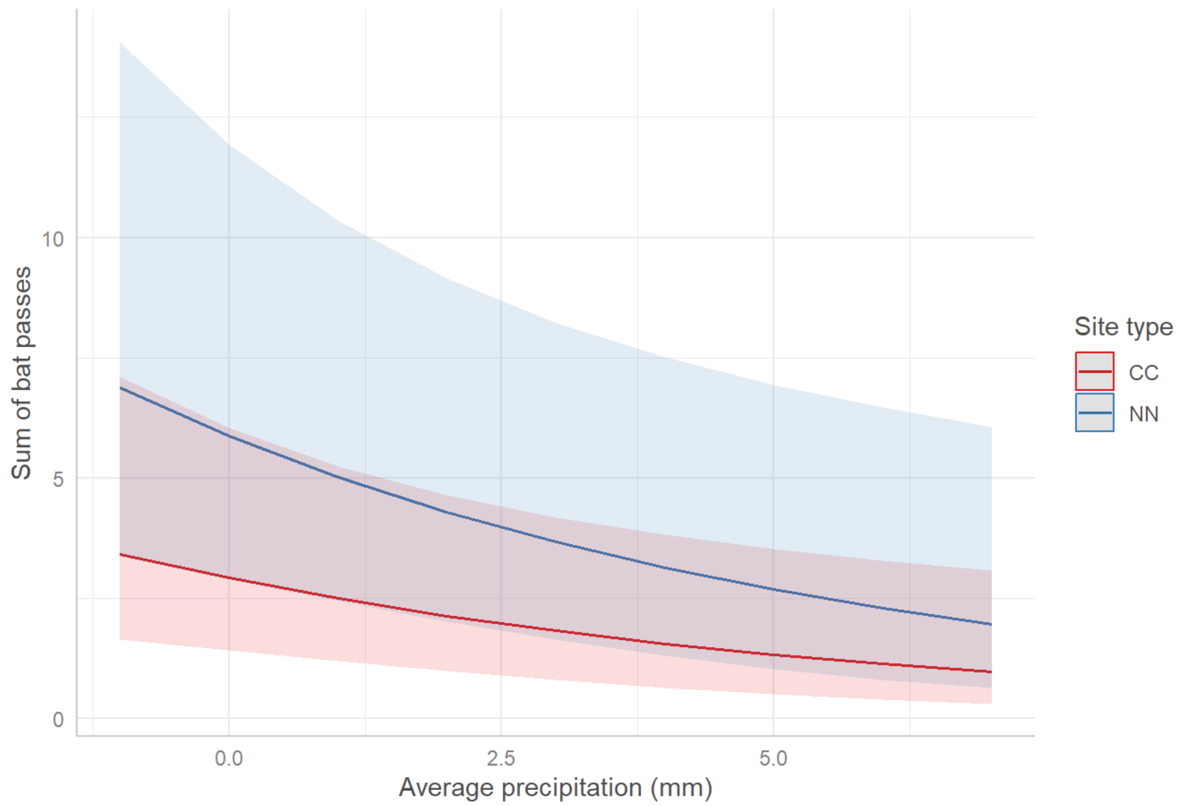

Figure 11: Predicted sum of northern bat passes per scaled average precipitation (mm) and site type (clear-cut and near natural).

No significant interaction between bat activity and light influx (measured as DLI) was observed (p = 0.45) (Table 7). The very slight positive effects of increased diffuse light can be seen in visualization, but more prominent is the large uncertainty in the near-natural data (Figure 12).

Table 7: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes, diffuse light index (DLI), and site type. Sum of bat passes is the response variable, while DLI and site type (clear-cut and near natural) are predictor variables.

Variables	χ2	Df	p
Intercept	10.41	1	0.0013
Site type	3.045	1	0.081
DLI	0.57	1	0.45

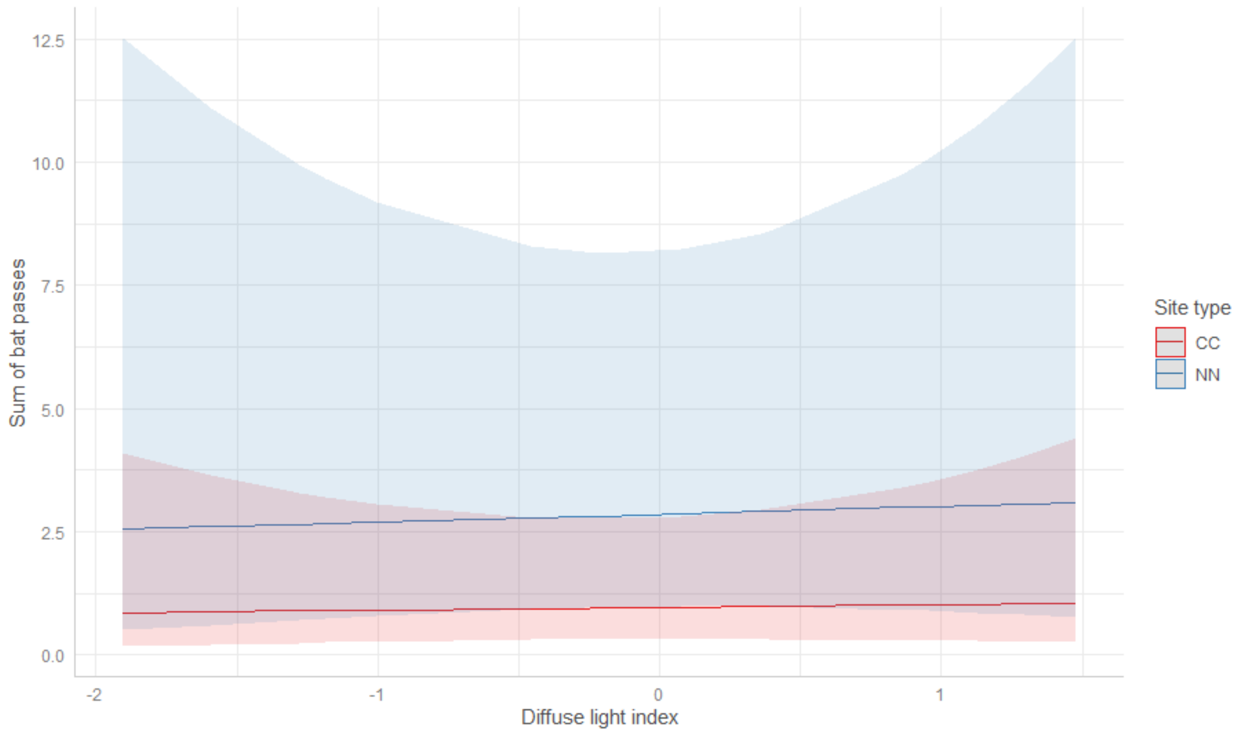

Figure 12: Predicted sum of northern bat passes per DLI and site type.

3.3.5 Forest composition

Tests of dead wood influence showed no significant relationship with bat activity (Table 8) (For standing and downed dead wood see appendix tables A5 & A6). A large amount of uncertainty is present in higher quantities of dead wood (Figure 13). Total number of snags had no significant effect on number of northern bat passes ($p = 0.40$) (Table 9), although a slight positive correlation is visible (Figure 14).

Table 8: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes and total volume of deadwood, both downed and standing. Sum of bat passes is the response variable, while total volume of dead wood and site type (clear-cut and near-natural) are predictor variables.

Variables	**$\chi 2$**	**Df**	**p**
Intercept	9.07	1	0.0024
Site type	1.74	1	0.19
Total volume of dead wood	0.11	1	0.74

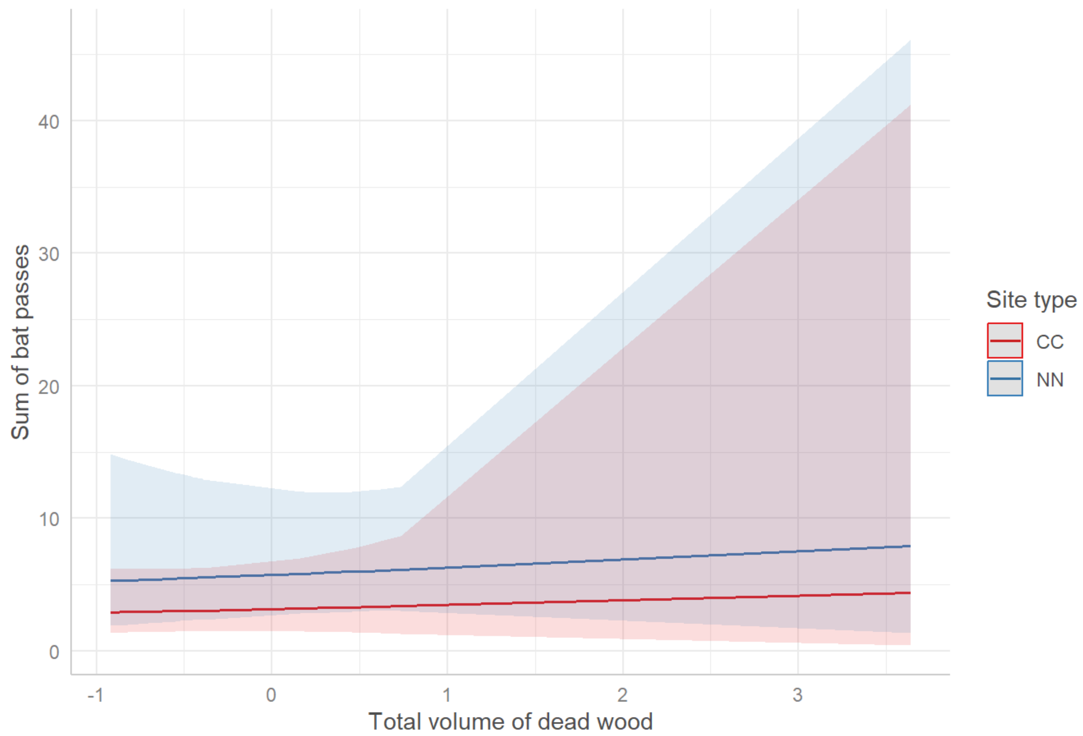

Figure 13: Predicted distribution of total volume of dead wood per sum of northern bat passes.

Table 9: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes and total number of snags. Sum of bat passes is the response variable, while total number of snags and site type (clear-cut and near-natural) are predictor variables.

Variables	**$\chi 2$**	**Df**	**p**
Intercept	9.96	1	0.0016
Site type	3.13	1	0.077
Snag	0.70	1	0.40

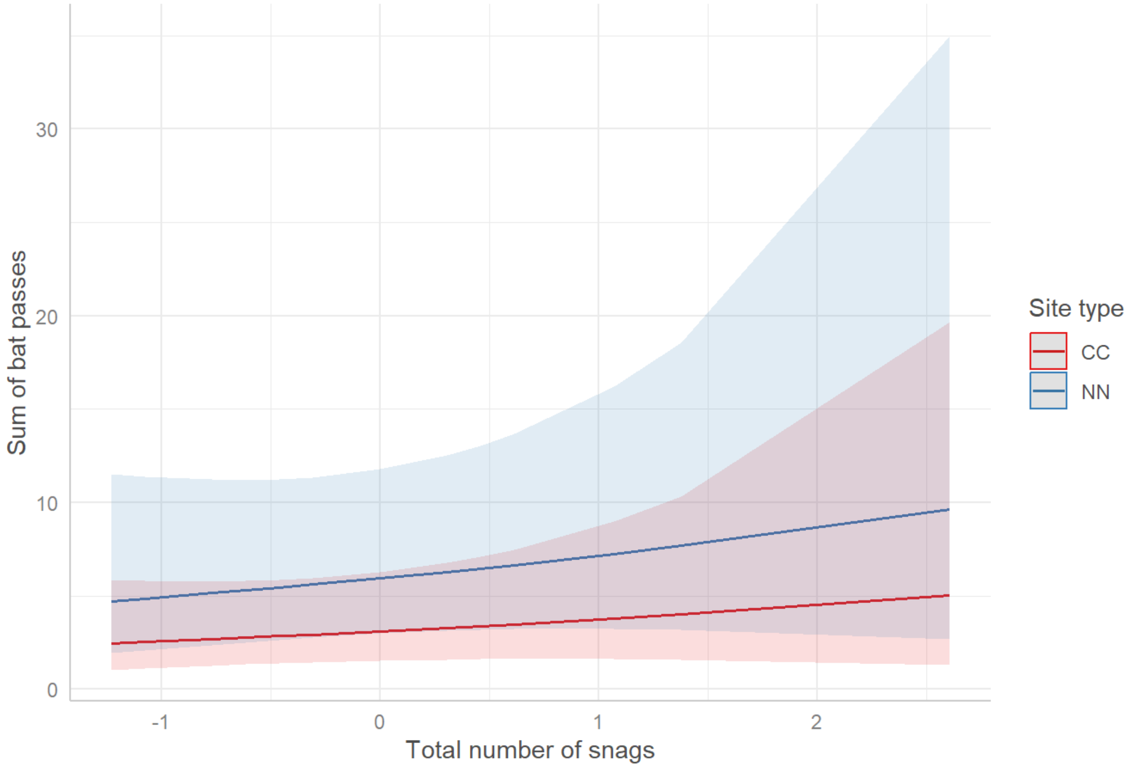

Figure 14: Predicted sum of northern bat passes per total number of snags.

4 Discussion

The findings in this study indicate that the northern bat is more active in near-natural forest patches than the previously clear-cut areas, which corresponds with theories that bat activity is reduced in clear-cut forest patches (Caldwell et al., 2019; de Jong, 1994; Law & Law, 2011). Although no significant effect of site type on bat activity was observed in this study ($p = 0.063$), the small effect size of only ten site pairs (nine when excluding EF7) can be responsible for the lack of strong results. Additionally, equipment failure at two of the clear-cut sites skews the amount of active sampling nights in favor of the near-natural habitat type, creating more uncertainty in the results. Contradictory, some studies have found that clear-cutting either has no effect or actually stimulates more bat activity post felling, most likely caused by creating more edge space, which is the preferred foraging habitat of a variety of bat species (Denzinger & Schnitzler, 2013; Kirkpatrick et al., 2017; Patriquin & Barclay, 2003). A common finding in studies involving multiple focal species is that the responses to silvicultural treatments such as clear-cutting are species specific (Hogberg et al., 2002; Kirkpatrick et al., 2017; Patriquin & Barclay, 2003; Russo et al., 2016). Therefore, when investigating the impacts of clear-cut forestry it is crucial to consider a diverse array of species and potential consequences.

The effects of forestry on bats' foraging activity have also been found to vary among species and across spatial scales (Grindal & Brigham, 1999; Patriquin & Barclay, 2003). In this study, the majority of recordings in both site types were commuting calls, but the feeding activity of the northern bat was significantly higher in the near-natural forest habitat ($p = 0.037$), possibly suggesting a more suitable or abundant foraging habitat. As an insectivorous species, the decline in the northern bat population may indicate long-term negative impacts on insect communities (Jones et al., 2009) after a felling event, which has been documented within the Ecoforest project (Lish et al., 2022). As northern bats mainly forage in open spaces (Rydell, 1986), an increase in feeding activity could be expected after clear-cutting in the short term. However, as this study demonstrates, more feeding activity is present in near-natural patches in the long term.

Abiotic factors

Given that abiotic factors such as light levels and temperature variability are among the most prominent consequences of clear-cutting (Brunet et al., 2010), it is reasonable to expect an impact on bat activity. Results of the diffuse light index comparison between habitat types showed no significant differences, but this can be due to the large variation between sites. Previous studies have found that the light conditions of forests are most altered shortly after felling (Shorohova et al., 2008), which in turn create higher temperatures and dryer soil conditions which affect the composition of understory vegetation (Esseen et al., 1997; Majasalmi & Rautiainen, 2020). Therefore, it is possible to assume that the lack of strong correlation between bat activity and light conditions in this study, is because measurements of light are taken at a point where the forest structure creates similar lighting conditions in both site types. This removes the possibility of studying the long-term effects of the light influx increase immediately following a clear-cutting event. Additionally, the more heterogeneous forest structure of near-natural forest sites creates a larger variety of light levels, which does not translate in the average measurements used in this study. Since the northern bat prefers open spaces for foraging (Rydell, 1986), the varied light conditions in the near-natural forests could indicate more suitable foraging habitats.

Both temperature and precipitation are known to affect bat commuting and feeding activity (Kaufman & Willig, 1998; Ulrich et al., 2007), but the extent of impact in the northern hemisphere is less studied. As the northern bat has the northernmost dispersal of any bat species (Dietz & Kiefer, 2016), it is safe to assume that the species has a resilience to both lower temperatures and high amounts of rainfall. On the other hand, a species that is utilizing the edges of its habitat ranges, is likely vulnerable to shifts in their environment. The summer of 2023 in southeastern Norway had large weather variations in both temperature and precipitation between the summer months. June was exceptionally dry and warm with 45% less precipitation than normal (Sanna, 2023), while large amounts of rainfall in July and August caused floods (Sanna & Holte, 2023). In this study a clear decrease in bat activity was found in July compared to June. Temperature and precipitation had a significant relationship with sum of bat passes, where higher temperatures and lower precipitation increased their activity levels, which correlates with previous studies (Erickson & West, 2002; Gorman et al., 2021).

Forest composition

The composition of the forest habitats differed between the previously clear-cut and near natural sites (See appendix table A3). Similarly to other studies (Fridman & Walheim, 2000; Lõhmus et al., 2013), more snags and cavities were observed in the near-natural habitat, which indicates more suitable conditions for saproxylic insects. Although no significant effect of dead wood presence was detected, large uncertainty in model outputs leads to the conclusion that more data is needed to accurately describe the relationship between northern bat activity and dead wood. Downed dead wood was significantly more prevalent in the near-natural forest type, which might be explained by the fact that forestry machinery used during felling reduces lying dead wood to small particles which increases the speed of wood decay (Brunet et al., 2010). Surprisingly, a higher number of broadleaf trees were observed in the clear-cut sites, which are commonly known to be spruce dominated (Gustafsson et al., 2010). Generally, the forest composition examined in this study is too limited to give a proper comparison of the two site types.

Evaluation of methodology

Acoustic monitoring of bat populations has its limitations. Most importantly, the method only allows one to measure the activity of bats producing calls within reach of detecting the bat call, with no way of identifying individuals. High intensity calls at a lower frequency are more frequently detected than high frequency, low intensity calls (Lawrence & Simmons, 1982). The northern bat has been found to forage above the tree canopy, as far as 100 meters above ground (Rydell, 1986), possibly out of reach of acoustic detectors. Therefore, it is impossible to accurately estimate the population size, and/or dispersal rates solely based on acoustic recordings. Quality and accuracy of recordings was affected by a number of factors. A notable decrease in activity was measured in the second half of the field season, when the weather changed to be especially wet. Although no significant effect of precipitation was found in this study, bats are known to be less active during rainfall (Erickson & West, 2002). Additionally water buildup on top of the SMM-U2 microphones utilized in this study can lead to a temporary block of the microphone element (Wildlife Acoustics, 2024a). Therefore, the additive effect can cause an underestimation of bat activity during periods with heavy rain. Recording quality is also affected by proximity to clutter in the surrounding area (Frick, 2013), hence why the detectors were placed at least 5 meters from vegetation when possible, but amount of clutter between sites varied. Similarly, large openings in the canopy were favored when possible, to ensure quality of recordings was maximized (Frick, 2013). To summarize, dense forest patches had little to no clearings with optimal recording environments, which in turn could account for variation between sites in recording quality, and possibly quantity of registered bat passes.

5 Conclusions and management implications

Sound management is dependent on further applied research and a broader perspective on the long-term effects of forestry on biodiversity. Although the negative impacts of modern logging techniques are impossible to fully mitigate, the goal should be to minimize the effects, both on a global and local scale. The northern bat, although still the most prevalent bat species in Norway, has had a prominent population decline in previous years (Eldegard et al., 2021). This study indicates a possible negative influence of clear-cutting, as the number of northern bat passes recorded and feeding activity are higher in the near-natural sites. Most importantly, this study highlights the need for further bat research in boreal forests to better understand the dynamics of forest structure, climate, and biotic interactions with Norwegian threatened bat species.

6 References

Adams, A. M., Jantzen, M. K., Hamilton, R. M. & Fenton, M. B. (2012). Do you hear what I hear? Implications of detector selection for acoustic monitoring of bats. *Methods in Ecology and Evolution*, 3 (6): 992-998.

Allen II, M. G., Antón-Fernández, C. & Astrup, R. (2020). A stand-level growth and yield model for thinned and unthinned managed Norway spruce forests in Norway. *Scandinavian Journal of Forest Research*, 35 (5-6): 238-251.

Allison, J. D., Paine, T. D., Slippers, B. & Wingfield, M. J. (2023). *Forest Entomology and Pathology: Volume 1: Entomology*: Springer Nature.

Altringham, J. D. (2011). *Bats: from evolution to conservation*: Oxford University Press.

Artsdatabanken. (2021). Norsk rødliste for arter 2021. *Artsdatabanken.no*. Available at: https://www.artsdatabanken.no/lister/rodlisteforarter/2021 (accessed: 25.04.23).

Asplund, J., Nordén, J., Kjønaas, O. J., Madsen, R. L., Lunde, L. F., Birkemoe, T., Ronold, E. K., Norkute, M., Jansson, K. U. & Karlsen, D. (2024). Long Term Effects of Forest Management on Forest Structure and Dead Wood in Mature Boreal Forests. *SSRN*.

Barclay, R. M. & Kurta, A. (2007). Ecology and behavior of bats roosting in tree cavities and under bark. *Bats in forests: conservation and management (MJ LACKI, JP HAYES, and A. KURTA, eds.). Johns Hopkins University Press, Baltimore, Maryland*, 352: 17-59.

Bat Conservation Trust. (2023). *Bat roosts*. bats.org.uk: Bat Conservation Trust. Available at: https://www.bats.org.uk/about-bats/where-do-bats-live/bat-roosts/what-is-a-roost (accessed: 17.10).

Brunet, J., Fritz, Ö. & Richnau, G. (2010). Biodiversity in European beech forests-a review with recommendations for sustainable forest management. *Ecological bulletins*: 77-94.

Caldwell, K. L., Carter, T. C. & Doll, J. C. (2019). A comparison of bat activity in a managed central hardwood forest. *The American midland naturalist*, 181 (2): 225-244.

de Jong, J. (1994). Habitat use, home-range and activity pattern of the northern bat, Eptesicus nilssoni, in a hemiboreal coniferous forest.

Denzinger, A. & Schnitzler, H.-U. (2013). Bat guilds, a concept to classify the highly diverse foraging and echolocation behaviors of microchiropteran bats. *Frontiers in physiology*, 4: 164.

Dietz, C. & Kiefer, A. (2016). *Bats of Britain and Europe*: Bloomsbury publishing.

Eldegard, K., Syvertsen, P., Bjørge, A., Kovacs, K., Støen, O.-G. & van der Kooij, J. (2021). Pattedyr: Vurdering av nordflaggermus Eptesicus nilssonii for Norge. Available at: http://www.artsdatabanken.no/lister/rodlisteforarter/2021/31779 (accessed: 15.04.24).

Erickson, J. L. & West, S. D. (2002). The influence of regional climate and nightly weather conditions on activity patterns of insectivorous bats. *Acta Chiropterologica*, 4 (1): 17-24.

Esseen, P.-A., Ehnström, B., Ericson, L. & Sjöberg, K. (1997). Boreal forests. *Ecological bulletins*: 16-47.

Florian Hartig. (2022). *DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models* (Version R package version 0.4.6). Available at: https://CRAN.R-project.org/package=DHARMa.

Frafjord, K. (2022). Flaggermus. *Store norske leksikon*. Available at: https://snl.no/flaggermus (accessed: 28.04.2023).

Frafjord, K. (2023). *nordflaggermus*. snl.no: Store norske leksikon. Available at: https://snl.no/nordflaggermus (accessed: 14/05).

Frick, W. F. (2013). Acoustic monitoring of bats, considerations of options for long-term monitoring. *Therya*, 4 (1): 69-70.

Fridman, J. & Walheim, M. (2000). Amount, structure, and dynamics of dead wood on managed forestland in Sweden. *Forest ecology and management*, 131 (1-3): 23-36.

Furey, N. M., Mackie, I. J. & Racey, P. A. (2009). The role of ultrasonic bat detectors in improving inventory and monitoring surveys in Vietnamese karst bat assemblages. *Current Zoology*, 55 (5): 327-341.

Gorman, K. M., Barr, E. L., Ries, L., Nocera, T. & Ford, W. M. (2021). Bat activity patterns relative to temporal and weather effects in a temperate coastal environment. *Global Ecology and Conservation*, 30: e01769.

Griffin, D. R. (1946). Supersonic cries of bats. *Nature*, 158 (4002): 46-48.

Grindal, S. D. & Brigham, R. M. (1999). Impacts of forest harvesting on habitat use by foraging insectivorous bats at different spatial scales. *Ecoscience*, 6 (1): 25-34.

Gustafsson, L., Kouki, J. & Sverdrup-Thygeson, A. (2010). Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. *Scandinavian Journal of Forest Research*, 25 (4): 295-308. doi: 10.1080/02827581.2010.497495.

Henriksen, S. & Hilmo, O. (2015). Norsk rødliste for arter 2015. (accessed: 15.04.24).

Hogberg, L. K., Patriquin, K. J. & Barclay, R. M. (2002). Use by bats of patches of residual trees in logged areas of the boreal forest. *The American Midland Naturalist*, 148 (2): 282-288.

Huuskonen, S., Domisch, T., Finér, L., Hantula, J., Hynynen, J., Matala, J., Miina, J., Neuvonen, S., Nevalainen, S. & Niemistö, P. (2021). What is the potential for replacing monocultures with mixed-species stands to enhance ecosystem services in boreal forests in Fennoscandia? *Forest ecology and management*, 479: 118558.

Ilintsev, A., Bogdanov, A., Nakvasina, E., Amosova, I., Koptev, S. & Tretyakov, S. (2020). The natural recovery of disturbed soil, plant cover and trees after clear-cutting in the boreal forests, Russia. *iForest-Biogeosciences and Forestry*, 13 (6): 531.

Jones, G. (2005). Echolocation. *Current Biology*, 15 (13): R484-R488.

Jones, G., Jacobs, D. S., Kunz, T. H., Willig, M. R. & Racey, P. A. (2009). Carpe noctem: the importance of bats as bioindicators. *Endangered species research*, 8 (1-2): 93-115.

Kaufman, D. M. & Willig, M. R. (1998). Latitudinal patterns of mammalian species richness in the New World: the effects of sampling method and faunal group. *Journal of Biogeography*, 25 (4): 795-805.

Kelvin, S.-H. P., Richard, T. & Yves, B. (2015). *Routledge handbook of forest ecology*: London: Routledge Press.

Kirkpatrick, L., Oldfield, I. F. & Park, K. (2017). Responses of bats to clear fell harvesting in Sitka Spruce plantations, and implications for wind turbine installation. *Forest Ecology and Management*, 395: 1-8.

Kunz, T. H., Lumsden, L. F. (2003). "Ecology of cavity and foliage roosting bats," in Bat Ecology, eds T. H. Kunz and M. B. Fenton (Chicago, IL: University of Chicago Press), 3–89. (2003). *Bat Ecology*. Chicago, IL: University of Chicago Press.

Kuuluvainen, T., Tahvonen, O. & Aakala, T. (2012). Even-aged and uneven-aged forest management in boreal Fennoscandia: a review. *Ambio*, 41: 720-737.

Larsen, Ø. S. (2022). Flatehogst. *Store norske leksikon*. Available at: http://snl.no/flatehogst.

LaVal, R. K. & Lawton, R. O. (2021). The effect of environmental variables on nightly activity patterns of insectivorous bats monitored over ten years in a tropical premontane forest, Costa Rica. *Neotropical Biodiversity*, 7 (1): 476-490.

Law, B. S. & Law, P. R. (2011). Early responses of bats to alternative silvicultural treatments in wet eucalypt forests of Tasmania. *Pacific Conservation Biology*, 17 (1): 36-47.

Lawrence, B. & Simmons, J. (1982). Echolocation in bats: the external ear and perception of the vertical positions of targets. *Science*, 218 (4571): 481-483.

Lish, G. N., Birkemoe, T. & Sverdrup-Thygeson, A. (2022). *Long-term effects of clear-cut forestry on beetle community diversity in boreal forests of southeastern Norway*: Norwegian University of Life Sciences, Ås.

Lõhmus, A., Kraut, A. & Rosenvald, R. (2013). Dead wood in clearcuts of semi-natural forests in Estonia: site-type variation, degradation, and the influences of tree retention and slash harvest. *European Journal of Forest Research*, 132: 335-349.

Majasalmi, T. & Rautiainen, M. (2020). The impact of tree canopy structure on understory variation in a boreal forest. *Forest ecology and management*, 466: 118100.

Meschede, A. & Thorson, A. (2001). *Bats in forests: information and recommendations for forest managers*: German Association for Landcare.

Middleton, N., Froud, A. & French, K. (2020). *Social Calls of the Bats of Britain and Ireland*: Pelagic Publishing Ltd.

Miljødirektoratet. (2023). *Antall nær truede og truede arter og naturtyper i skog*. miljostatus.no: Miljødirektoratet (accessed: 17.10.2023).

Patriquin, K. J. & Barclay, R. M. (2003). Foraging by bats in cleared, thinned and unharvested boreal forest. *Journal of Applied Ecology*, 40 (4): 646-657.

Piirainen, S., Finér, L., Mannerkoski, H. & Starr, M. (2002). Effects of forest clear-cutting on the carbon and nitrogen fluxes through podzolic soil horizons. *Plant and Soil*, 239 (2): 301-311. doi: 10.1023/A:1015031718162.

R Core Team. (2024). *R: A Language and Environment for Statistical Computing* (Version v. 4.3.3): R Foundation for Statistical Computing. Available at: https://www.R-project.org/.

Rosenvald, R. & Lõhmus, A. (2008). For what, when, and where is green-tree retention better than clear-cutting? A review of the biodiversity aspects. *Forest Ecology and Management*, 255 (1): 1-15.

Russ, J. (2021). *Bat calls of Britain and Europe: A guide to species identification*: Pelagic Publishing Ltd.

Russo, D., Billington, G., Bontadina, F., Dekker, J., Dietz, M., Gazaryan, S., Jones, G., Meschede, A., Rebelo, H. & Reiter, G. (2016). Identifying key research objectives to make European forests greener for bats. *Frontiers in Ecology and Evolution*, 4: 87.

Rydell, J. (1986). Foraging and diet of the northern bat Eptesicus nilssoni in Sweden. *Ecography*, 9 (4): 272-276.

Rydell, J. (1993). Eptesicus nilssonii. *Mammalian species* (430): 1-7.

Sanna, A. (2023). *Juni startet kaldt, men endre som den 4. varmeste*. met.no: Meteorologisk institutt. Available at: https://www.met.no/nyhetsarkiv/juni-startet-kaldt-men-endte-som-den-4.varmeste (accessed: 12/05).

Sanna, A. & Holte, K. R. (2023). *August 2023 vil bli husket for ekstremværet som rammet Sør-Norge*. met.no: Meteorologisk institutt. Available at: https://www.met.no/nyhetsarkiv/august-2023-vil-bli-husket-for-ekstremvaeret-som-rammet-sor-norge (accessed: 12/05).

Shorohova, E., Kapitsa, E. & Vanha-Majamaa, I. (2008). Decomposition of stumps in a chronosequence after clear-felling vs. clear-felling with prescribed burning in a southern boreal forest in Finland. *Forest Ecology and Management*, 255 (10): 3606-3612.

Stahlschmidt, P. & Brühl, C. A. (2012). Bats as bioindicators–the need of a standardized method for acoustic bat activity surveys. *Methods in Ecology and Evolution*, 3 (3): 503-508.

Sugar, A. (2000). *The long-term impacts of clear-cut logging on insect communities in the boreal mixedwood forests of northeastern Ontario*.

Sundling, P. L., J. Y.; Tomter, S. M.; Dalen, L. S. (2023). Skog. *Store norske leksikon*. Available at: http://snl.no/skog.

Ulrich, W., Sachanowicz, K. & Michalak, M. (2007). Environmental correlates of species richness of European bats (Mammalia: Chiroptera). *Acta chiropterologica*, 9 (2): 347-360.

Vié, J.-C., Hilton-Taylor, C., Pollock, C., Ragle, J., Smart, J., Stuart, S. N. & Tong, R. (2009). The IUCN Red List: a key conservation tool. *Wildlife in a changing world–An analysis of the 2008 IUCN Red List of Threatened Species*: 1.

Viljur, M. L., Abella, S. R., Adámek, M., Alencar, J. B. R., Barber, N. A., Beudert, B., Burkle, L. A., Cagnolo, L., Campos, B. R. & Chao, A. (2022). The effect of natural disturbances on forest biodiversity: an ecological synthesis. *Biological Reviews*, 97 (5): 1930-1947.

Vonhof, M. J. B., R. M. R. (1996). Roost-site selection and roosting ecology of forest-dwelling bats in southern British Columbia. *Canadian Journal of Zoology*, 74 (10): 1897-1805. doi: https://doi.org/10.1139/z96-200.

Wermundsen, T. & Siivonen, Y. (2008). Foraging habitats of bats in southern Finland. *Acta theriologica*, 53: 229-240.

Wildlife Acoustics. (2024a). *Can the SMM-U2 be used in the rain?* wildlifeacoustics.com. Available at: https://www.wildlifeacoustics.com/resources/faqs/can-the-smm-u2-be-used-in-the-rain (accessed: 17.04).

Wildlife Acoustics. (2024b). *Kaleidoscope Pro Analysis*. Available at: https://www.wildlifeacoustics.com/products/kaleidoscope-pro.

7 Appendices

Appendix 1: Site names and coordinates

Table A1: Coordinates and site names for both site types (clear-cut and near-natural) at all study sites.

Site name	Site	Site type	Latitude	Longitude
Gullenhaugen	EF2	NN	60.352613	10.796628
		CC	60.369963	10.787187
Hemberget	EF3	NN	60.915115	12.206472
		CC	60.921114	12.188859
Braskreidfoss	EF4	NN	60.73977197	11.92845999
		CC	60.74758901	11.92636502
Särkilampi	EF5	NN	60.187711	12.508022
		CC	60.200019	12.529663
Øytjern	EF6	NN	60.838906	10.38122
		CC	60.843198	10.408981
Tretjerna	EF7	NN	60.583648	10.226522
		CC	60.577289	10.228499
Halden	EF8	NN	59.079766	11.546541
		CC	59.079808	11.55948
Blåfjell	EF9	NN	59.783114	10.381255
		CC	59.788026	10.386507
Marker	EF11	NN	59.36014	11.79003
		CC	59.38347	11.75902
Langvassbrenna	EF12	NN	60.201837	10.473849
		CC	60.200996	10.497976

Appendix 2: Detector settings

Table A2: Song Meter SM4Bat settings.

UTC	+ 2:00
Gain	12 dB
16k high filter	Off
Sample rate	256 kHz
Min duration	1.5 ms
Max duration	None
Min trigger frequency	12 kHz
Trigger level	12 dB
Trigger window	3 s
Max length	15 s
Compression	None

Appendix 3: Decay stage classification

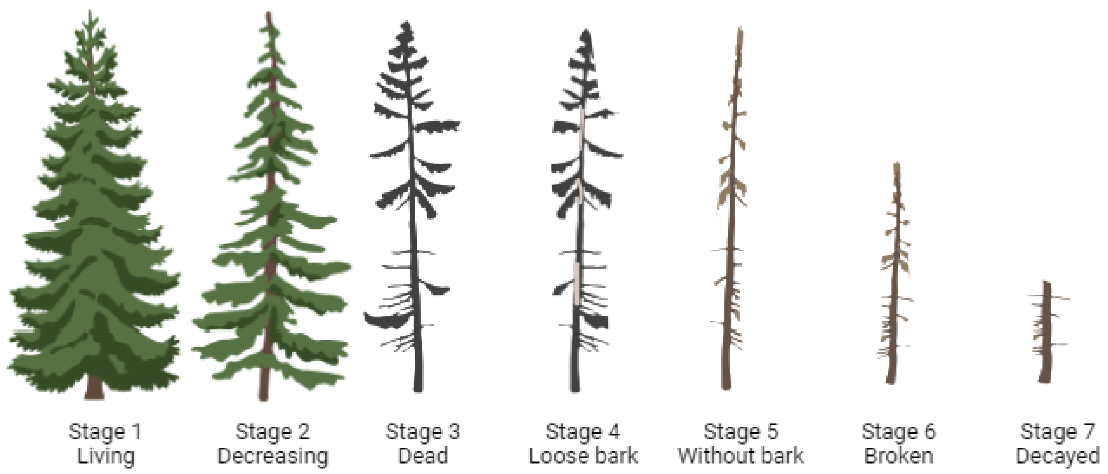

Figure A1: Decay stages of trees utilized in habitat survey,

Appendix 4: Bat activity

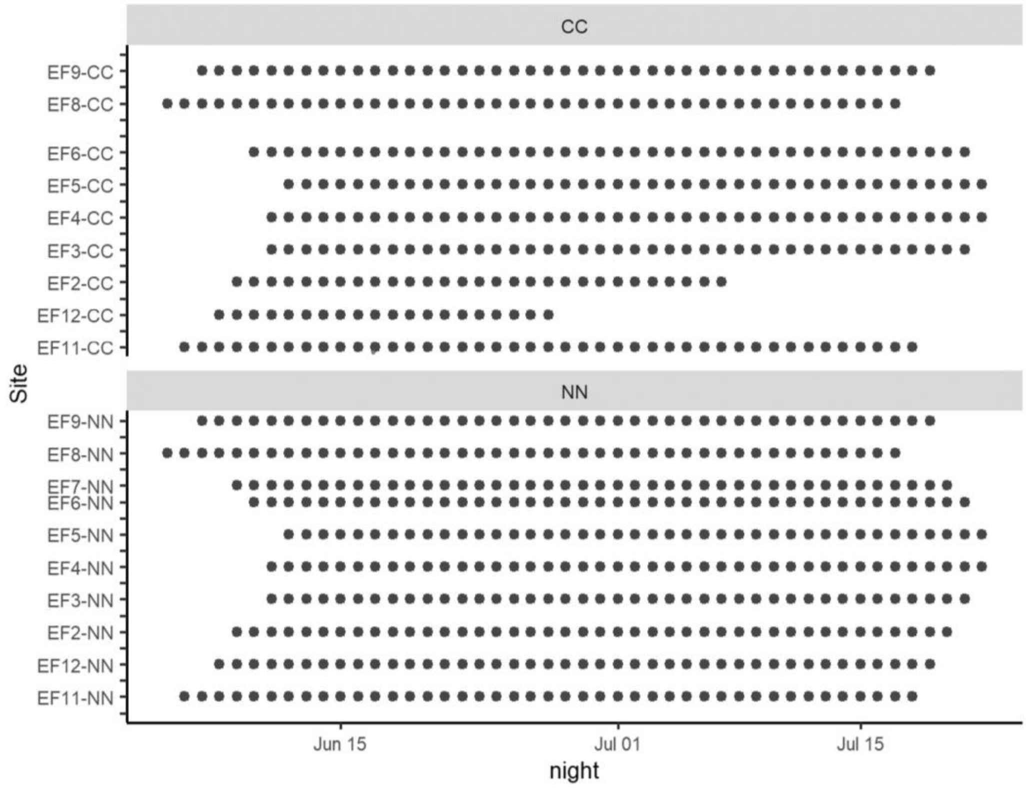

Figure A2: Survey effort, each point represents an active sampling night.

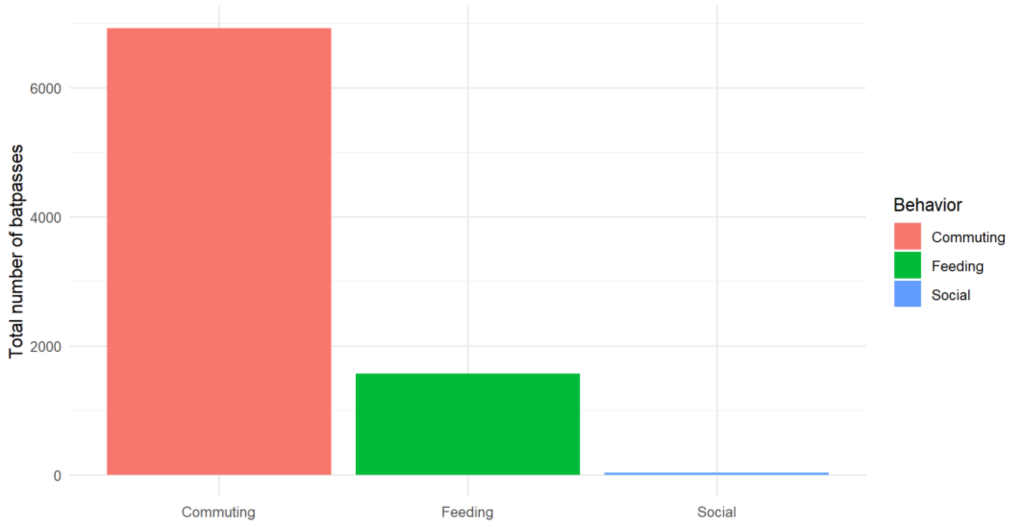

Figure A3: Total number of bat passes of each behavior.

Appendix 5: Forest structure variables

Table A3: Total number of forest structure variables; snags, decay stages, broken tops, dead branches, loose bark, and cavities registered in habitat survey.

Site type	Site	Sum of							
		Snags	Decay stage 1-2	Decay stage 3-4	Decay stage 5-7	Broken tops	Dead branches	Loose bark	Cavities
Near-natural	EF9	6	3	5	1	4	3	3	0
	EF8	11	0	9	2	1	0	10	0
	EF7	15	4	8	7	10	0	8	1
	EF6	10	3	8	2	6	5	7	2
	EF5	6	2	4	2	3	2	5	8
	EF4	12	3	10	2	6	1	8	1
	EF3	15	5	14	1	7	3	10	7
	EF2	12	4	12	0	6	2	12	3
	EF12	4	7	3	1	6	6	4	1
	EF11	1	1	1	0	1	1	1	0
	Sum	92	32	74	18	50	23	68	23
Clear-cut	EF9	25	10	22	4	20	3	25	2
	EF8	3	1	2	1	1	0	1	0
	EF7	2	17	2	0	14	5	5	1
	EF6	3	10	1	1	11	2	2	1
	EF5	8	7	5	3	8	6	0	3
	EF4	5	0	5	0	4	0	4	0
	EF3	0	1	0	0	1	0	0	0
	EF2	17	3	16	0	14	1	8	0
	EF12	4	1	4	0	3	0	4	0
	EF11	1	0	0	1	1	0	1	0
	Sum	67	50	57	10	77	17	50	7

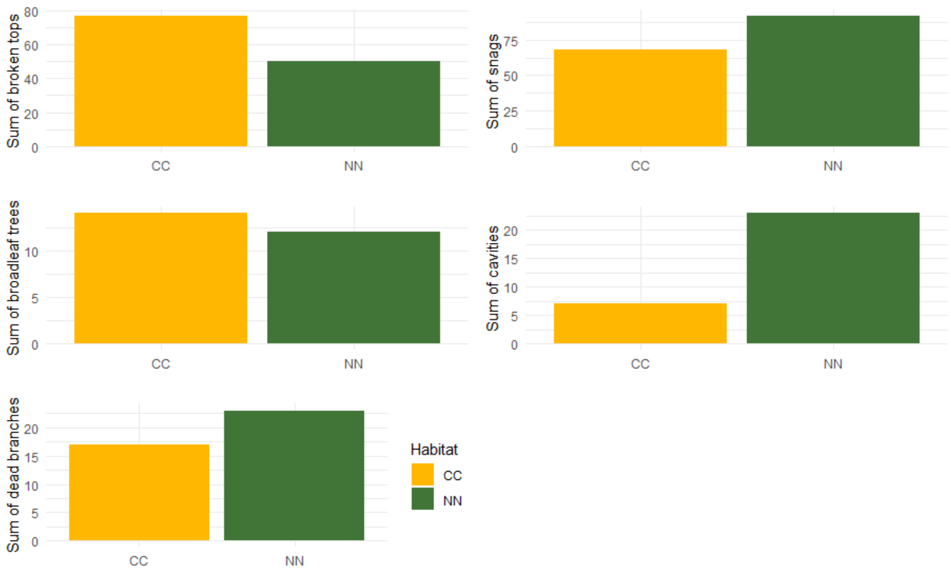

Figure A4: Distribution of total amount of forest habitat attributes; broken tops, broadleaf trees, dead branches, snags, and cavities in each site type (clear-cut and near-natural).

Table A4: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes and total volume of downed dead wood.

Variables	**χ2**	**Df**	**p**
Intercept	9.28	1	0.0023 **
fSiteType	1.33	1	0.25
sdowned_Total_Volume	0.18	1	0.67

*Significance codes: 0 '***', 0.001 '**', 0.01 '*', and 0.05 '.' No mark, no significance.*

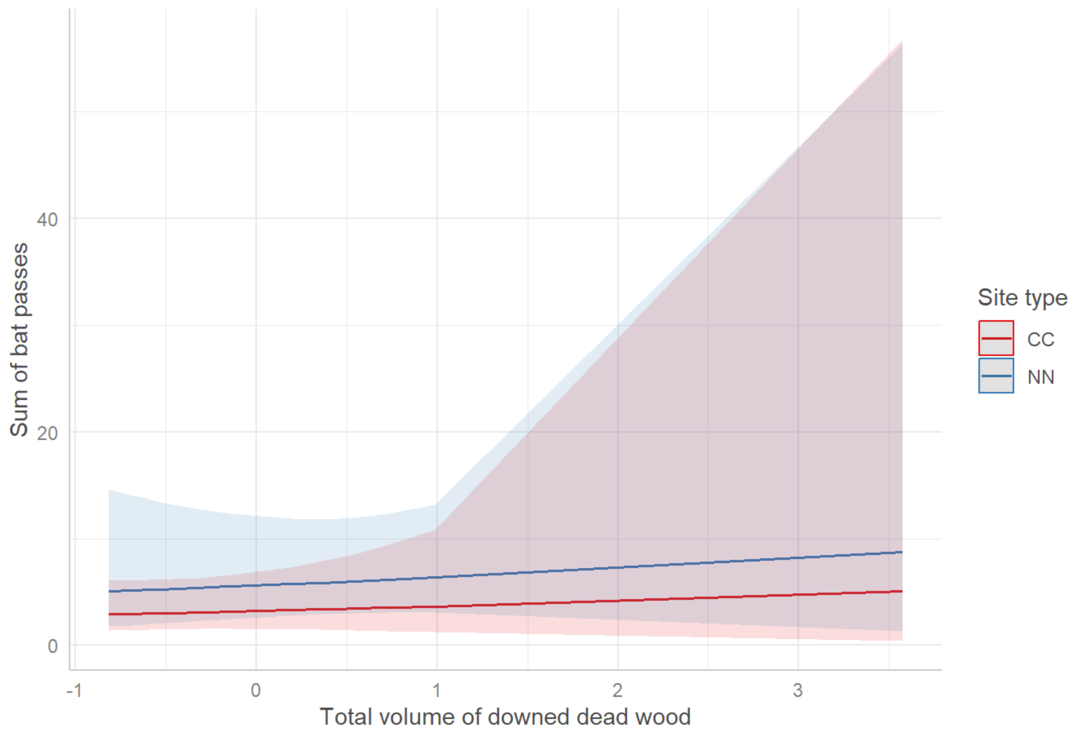

Figure A5: Predicted distribution of downed dead wood in relation to total amount of northern bat passes.

Table A5: Results of Type III Wald chi-square test of the interaction between total number of northern bat passes and total volume of standing dead wood.

Variables	**χ2**	**Df**	**p**
Intercept	8.98	1	0.0027 **
fSiteType	2.50	1	0.11
sStanding_Total_Volume	0.037	1	0.85

*Significance codes: 0 '***', 0.001 '**', 0.01 '*', and 0.05 '.' No mark, no significance.*

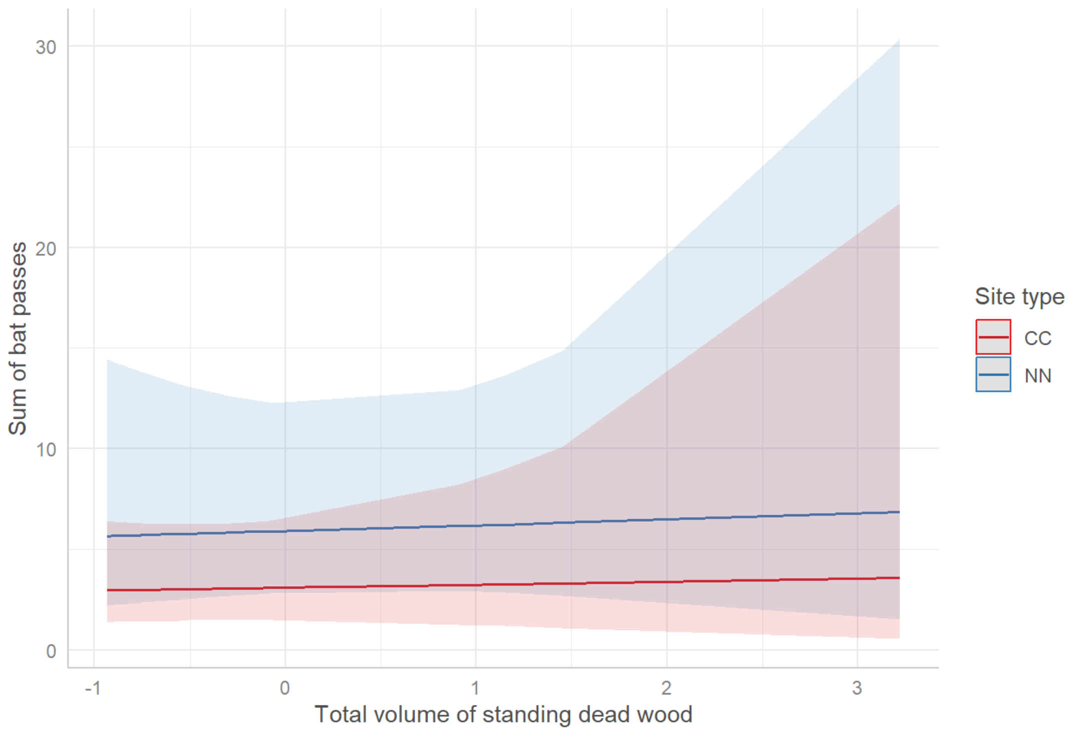

Figure A6: Predicted distribution of standing dead wood in relation to total amount of northern bat passes.

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

Postboks 5003
NO-1432 Ås
Norway