Norwegian University
of Life Sciences

Master's Thesis 2021 60 ECTS
The Faculty of Environmental Sciences and Natural Resource Management

Bats, Insects and Weather: Spatial - Temporal Trends on a Boreal Forest Wind Facility in Norway

Sarah E. Johns
Master of Science in General Ecology

Acknowledgements

A tremendous thank you is in order to my main supervisor, Katrine Eldegard. The first five minutes after meeting you and April I knew I had to work with you both. I am thankful to have had the chance to work with a supervisor who is patient, passionate, knowledgeable and fair. You have gently pushed me out of my comfort zone numerous times and given me so many new opportunities. I am wholeheartedly grateful for this experience with you and to have had your guidance through this process.

Another tremendous thank you is in order for my advisor, April Riderbo McKay (and Pacho of course). Thank you for being my mentor and opening my eyes to the wonders of bats. Your knowledge and hard core, larger than life, passion for these wee guys is astounding and inspirational. The bats are so lucky to have such an advocate in you. Most of all, thank you for being my friend when I needed someone the most. You have seen the best and worst in me over the past two years. I will never put two spaces after a period again without thinking of you. I couldn't have done any of this without you lady. Thank you.

To my co-supervisor, Tone Birkemoe, thank you for your guidance and expertise during this process. I am especially thankful for you bringing the Master's Meeting group together. One of my favorite things over this past year was meeting up with everyone over zoom to discuss our theses. Those meetings were amazingly helpful for the learning process and keeping our sanity during these Covid times.

A big thank you to Ronny Steen for your contribution to my thesis and fieldwork. I am grateful for all of your guidance, knowledge and time spent helping me with camera trapping, programming and R codes. Knowing I could call you was such a relief and I learned so much from you.

Thank you to Richard Bischof for always being ready to help with an R-Studio coding crisis. You are a life saver to many.

Thank you so much to all of the people who made contributions to this thesis in tremendous ways: **Tor Harald Rørvik** of Rørvik Campground in Ørje for providing the two American girls and dogs with a lovely and absolutely perfect place to live and do field work. It was one memorable summer. **Roar Økseter** from NMBU for withstanding the driving rain to help us with our field equipment at the beginning/end of the field season. **Jeroen van der Kooij** for always being ready to assist and educate the next generation about the treasures of bats. **The Rambøl brothers** for their assistance in deploying the at height detectors and their work in designing an amazing microphone stand to hold our precious gear. Thank you to **the Norwegian Environmental Agency (Miljødirektoratet**) for providing funding for the data collection. Thank you to the **Marker Vindpark** for allowing us to conduct research on the facility as well as **the landowners** of each site who gave us permission to deploy detectors.

Thank you, a thousand times, over to my parents, sister, my Tommy, and all of my family and friends for the constant love and support. I am so grateful for your words of encouragement that surrounded me always. Thank you for believing in me when I didn't believe in myself.

Table of Contents

Abstract

Bats and insects are valuable indicators of ecosystem health. As both organisms are potential bioindicators, it is important to understand how they interact with each other and their environment. Bats and insects are facing numerous threats to their habitat and resources; one being wind energy development. I monitored patterns in bat and insect activity on a wind facility located in boreal forest in Norway during summer and early autumn of 2020. Turbine pads and potential bat and insect 'control' habitats were sampled. Bat activity was monitored using acoustic detectors set to record calls from one hour before sunset and until one hour after sunrise. Insect activity was monitored using camera traps. Weather was monitored using data loggers erected in the field and wind turbine data. The aim of this study was to increase our understanding of bat species community composition on a wind facility in a boreal forest and monitor the spatio-temporal relationship between bat activity, insect abundance and weather (temperature and wind speed). My main questions were where does spatial variation in bat activity occur across habitats (control/turbine sites/at height), what temporal patterns in bat activity are detected, does weather have a significant effect on this activity, and is insect abundance related to bat activity on the wind facility? Long range echolocators, which includes Northern bats (*Eptesicus nilssonii),* were the most prevalent bat guild across the facility. Spatially, average bat activity across the season did not differ between turbine pads and control habitats. Temporally, bat activity was highest later in the summer (late July and early August) at the turbine pads and earlier in summer (July) at control habitats. Temperature had a significant positive effect on bat activity and insect abundance while wind speed had a negative effect on insect abundance and bat activity. Bat activity was positively related to insect abundance, but my results suggest temperature influences bat activity more strongly than does insect abundance on the Marker Vindpark. My findings may have implications for unknown or detrimental impacts on unknown bat populations in boreal forests due to land use and climate change and the increasing development of wind turbines in Scandinavia. The methods development component (simultaneous non-invasive sampling of bats and insects) of the study contributes to Norway's and the global effort of creating consistent, long term and broad scale monitoring necessary for understanding and mitigating defaunation.

Key Words

Norway, bats, *Eptesicus nilssonii,* insects, wind energy, weather, spatial, temporal, activity, abundance, boreal forest, long range echolocator, short range echolocator

1 Introduction

Bats are the second largest order of mammals (*Chiroptera*) making up over 20% of the global mammal species (Hutson et al., 2001; Bat Conservation Trust, 2021). In Norway, bats make up a quarter of the mammal species and the majority are on the national red list (Henriksen and Hilmo, 2015). Many of these species are present and studied throughout Europe but much is still uncertain regarding their population dynamics, behavior and migratory status within the northernmost boundaries of their ranges in the boreal forest regions of Fennoscandia. All of the bat species in Norway are insectivores, as are many of the more than 1,400 species of bat found worldwide (Burgin et al. 2018; Kunz, et al; 2009; Hutson et al, 2001).

Both bats and insects contribute greatly to countless vital environmental processes (MacGregor et al. 2020; Yang & Gratton, 2014; Ghanem & Voigt, 2012). Insectivorous bats aid in controlling insect populations (Vilas, 2016; Maine, et al. 2015) while insects are pollinators and a primary food source for many aquatic and terrestrial organisms (Scudder, 2017). In addition, bats and insects are considered potential bioindicators of ecosystem health (Jones, et al. 2009; McGeoch, 2007; Parikh et al. 2020; Park, 2015). This status makes them important for monitoring as changes in their populations or activity, on a regional or local level, can be indicative of major ecosystem changes (Stahlschmidt & Bruhl, 2012).

Today there are many anthropogenic threats to bat and insect populations globally. Habitat destruction and land use change are occurring at rates that make it difficult for wildlife to adapt and for ecosystems to maintain their functions (Dietz & Kiefer, 2016. pp. 27-31; Voigt & Kingston, 2016; Jung & Threlfall, 2016; Russell, et al, 2009). These factors as well as pollution, such as insecticides and pesticides, have also contributed significantly to the global decline in insect populations witnessed over the past few decades (Wagner, 2020; Ruczyński et al. 2019). Bats and insects are both sensitive to relatively small changes in weather and climate conditions. Climate change models are predicting increased temperatures and intense weather occurrences, more forest fires, and species range shifts northward which will increase competition, risk of pests and pathogens (Rydell et al. 2020; Pureswaran, et al. 2015). These factors are expected to and have already begun occurring in the world's boreal zones (Venäläinen, et al. 2020; Pureswaran, et al. 2015). Boreal forests are extremely important as they contain much of the world's carbon storage (Chen & Luo, 2015). In Europe, boreal forests also provide important habitat for many species well-adapted to this region as well as numerous migratory species (Sundseth, 2009), despite being generally considered ecologically unimportant and lacking in biodiversity (Kirkpatrick et al, 2018). Bats have also been observed in boreal production forests that have been felled for the construction of wind turbine facilities (Kirkpatrick et al, 2017A). Scandinavian bat populations exist in and around these boreal forests but their behavior and populations are uncertain.

There has been a dramatic increase in the global demand for renewable energy resources and this trend is expected in continue. Specifically in Norway, wind energy production is expected to increase in the coming years (NVE, 2021; https://www.nve.no/energiforsyning/kraftmarkedsdata-og-analyser/ny-kraftproduksjon/). Land use change associated with increased wind energy will impact what kind of habitat is available for wildlife who depend on boreal forests; including bats. This can lead to decreases in bat populations either from displacement or death of individuals. Wind turbines threaten bats in both direct and indirect manners. Indirectly, wind turbines contribute to loss of habitat, roost and foraging opportunities (Apoznański et al, 2018; Millon et al. 2018). Directly, wind turbines cause death via impact from the blade or barotrauma (intense air pressure changes near rotor blades) (Dietz & Kiefer, 2016, pp. 30-31., Kunz et al. 2007). Wind turbines also have a direct effect on insects as a recent study from Germany estimated wind turbines contributed to 1.2 trillion insect fatalities per year alone (Voigt et al. 2021A). In Northern Europe, Rydell et al (2010B) found that 98% of bats found dead at wind turbines belong to the feeding guild of aerial-hawking species in the genera *Nyctalus, Eptesicus, Vespertilio*, and *Pipistrellus.* These are species adapted to foraging in open spaces and higher altitudes (Straka, et al. 2019). Bat fatalities can be even higher when turbine heights reach above 60 meters (Baerwald & Barclay, 2009) and blade length increases (Rydell et al. 2010A). Research suggests that bat fatalities are highest on warm and low wind nights in late summer and fall (Cryan et al. 2014; Rydell et al. 2010A), which coincides with their main migration periods.

Although still under investigation, one reason for bat presence around wind turbines is insect presence and activity. Long et al. (2010) suggests that bats are congregating near turbines because of insect swarming behaviour, while other studies suggest accumulation of insect carcasses on the blades as a possibility for bat presence (Corten & Veldkamp, 2001). Insect activity and attraction around wind turbines may be due to numerous factors such as migration (Voigt et al. 2021B), insect hill topping behavior (Rydell et al. 2010B), or attraction to the color of the wind turbines (Long et al. 2010). Insectivorous bats have been seen foraging at and around wind turbines in the United States (Foo et al. 2017) and evidence from necropsies performed on bat carcasses below turbines in Europe have found that many bats are feeding on insects when or close to the time that they perish (Rydell et al. 2010B). In a study by Ahlen et al. (2009) regarding offshore wind turbines in Sweden, bats were witnessed to be gleaning insects off or near the turbines and roosting within the nacelles for periods of up to a few days. Bat activity and foraging length appeared to be directly impacted by insect abundance (Ahlen et al. 2009). This might also apply to onshore turbines. Understanding where and when, and under what conditions, insect and bats are abundant are important to understand the effect of wind turbines on bat populations. Norway is obligated through the EUROBATS agreement (https://www.eurobats.org/) to develop strategies to monitor bat populations within the country as well as on wind facilities, but they have yet to develop a clear methodology for how to accomplish this.

An efficient method for monitoring bats is recording their acoustic activity (Dezinger & Schnitzler, 2013; Knornschild, et al. 2012). Many bats generate calls for echolocation by emitting sound out into the space in front of them via their larynx and/or noses (Jakobsen, et al; 2018). When these sound waves bounce off an object or prey, they travel back towards the bat, who then quickly uses this information to analyze their surroundings (Jones & Teeling, 2006). Bat call frequencies vary by taxa and additional variation occurs depending on the atmospheric conditions, environmental factors and the type of behavior or activity the bat is engaging in (feeding (ie. feeding buzzes), socializing, foraging) (Dietz & Kiefer, 2016. pp. 112-127, Griffin, D.R., 1941).

Bat taxa can be identified based off these unique foraging and call characteristics from the recordings on their acoustic activity (Jennings et al, 2008; Vaughan et al, 1997). In recent years, the use of passive acoustic detection technology and machine learning software has grown in popularity (Zamora-Gutierrez et al. 2021). This often results in the collection of large volumes of sound files and machine learning software is frequently used to process this information. Machine learning may be used for the entire analysis of these files, or may only be used in the initial stages to sort and scrub data before a manual analysis is done by a trained expert. It is used as a non-invasive and cost-effective method for collecting and quickly analyzing large amounts of acoustic data on numerous taxa such as birds, bats, amphibians, and insects (Browning et al. 2017). Machine learning software should be utilized with caution (Rydell et al, 2017; Russo & Voight, 2016) and adequate knowledge by the surveyor is important to effectively distinguish between the calls of each bat taxa found in a specific region. Machine learning software is beneficial but not full proof and automatic identifications should be checked via manual identification to ensure accuracy as the software has been known to misclassify genera and species incorrectly (Rydell et al. 2017; Rughetti et al. 2019; Brabant et al. 2018). A possible strategy for more in depth and effective understanding of bat activity is to simultaneously monitor their prey. Numerous resources and sampling techniques for use in the field are available for the study of insect taxa, their distribution and abundance levels (McCravy, 2018; McGavin, G.C., 1997). These techniques can be classified as density traps, active or passive activity trap but neither is well suited for detection of flying bat prey at night. Ruczyński et al. (2019) provided a relatively unbiased methodology that allowed for non-invasive monitoring and quantifying of nocturnal flying insect abundance while simultaneously observing the spatial and temporal fluctuations.

The overall aim of this study was to increase our understanding of the relationship between bat activity and their potential insect prey at wind facilities in boreal forests. I also looked at how bat activity and insect abundance may vary across space, time and in relation to weather conditions. More specifically I asked:

1. Is there spatial variation in bat activity and community composition between the different sites?
   a. Comparing the acoustic detectors at ground level (turbine and control habitats) to those at height (detectors monitoring above the forest canopy)
   b. Comparing the ground level detectors on turbine pads to those at control sites.
   c. Comparing the different heights above the forest canopy.

2. What temporal patterns in bat activity between ground level and at height acoustic detectors can be detected during the summer and autumn seasons?

3. How are temporal patterns in bat activity related to weather conditions throughout the summer?
   a. Temperature
   b. Wind speed
   c. Barometric pressure

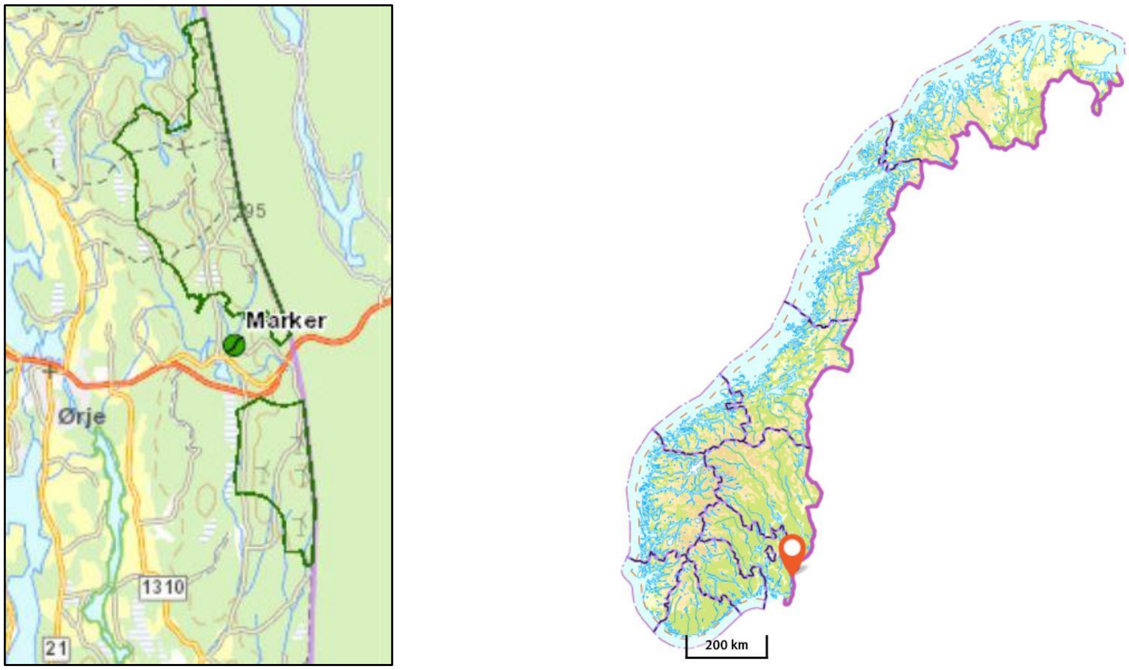
4. Is insect abundance related to weather conditions?

5. Is bat activity on wind farms related to insect abundance?

2 Materials and methods

2.1 Study area

The study was carried out between July 1st and September 29th 2020, at the BKW/Scanergy AS Marker Vindpark located in Ørje (Viken Kommune) (Figure1b) Norway along the Norwegian-Swedish border. For the full site map with turbine locations and numbering see Figure A1 in Appendix. The wind park contained fifteen Vestas V136 3.6MW turbines (Peikko Group, 2020) dispersed between two separate facilities, known as Joarknatten and Høgås. Each turbine is 142 meters in height at the nacelle with 68-meter-long blades (Peikko Group, 2020). Eight turbines stand on the north (Joarknatten) facility and seven on the south (Høgås) (Figure 1a). The terrain within and surrounding the wind park consists of primarily young to secondary growth coniferous forest, cultural landscapes, ponds, lakes, and wetlands. The turbines are situated on gravel pads and connected via a network of gravel roads. The wind park's location is an important study site for further bat research in Norway due to the combination of numerous factors such as above average height of the turbines, location within a boreal forest and the potential suitability for both bat & insect habitat.



a. b.

Figure 1. Maps indicate the location of the north and south wind facility (a) and the study area location within Norway (b). Images sourced from NVE.no (a) & Norgeskart.no (b).

2.2 Study species: Bats

There are 13 species of bat documented in Norway, with 11 species (* in Table 1) having documented reproducing populations in the country (Norsk Rødlist, 2021). All species of bat belong to the family *Vespertillionidae,* and most are found in the southern portion of the country (artskart.artsdatabanken.no). Many of these bat species are considered stable across Europe (IUCN, 2020) but are near threatened, vulnerable or critically endangered in Norway (Table 1) (Norsk Rødlist, 2021). *Nyctalus noctula, Pipistrellus nathusii, Pipistrellus pygmaeus, Vespertilio murinus*, and *Eptesicus nilssonii* comprise most of the fatalities at wind facilities in Northwestern Europe (Rydell, et al. 2010A). These species are listed as near threatened or vulnerable in Norway and feed by aerial-hawking or open-air space hunting. They are expected to be present at the study location.

Bats in Norway experience a colder and wetter environment than their conspecifics at the southern regions of their ranges. Fennoscandia has long, harsh winters, extended summer photoperiods and shorter windows of insect availability due to shorter summers. These conditions may play a role in how bats living in this region may behave differently than populations of the same species inhabiting southern Europe. Despite this, most studies on species occurring in Norway are carried out outside Fennoscandia. Due to the unique environmental conditions of living at such high northern latitudes, there is a need for regional specific bat monitoring strategies.

I characterized the species into three guilds: short, medium and long range echolocators (Froidevaux et al. 2014) based off each bat species' call frequency range and foraging strategy. Short range echolocators (hereby referred to as SRE) include *Barbastella barbastellus, Myotis* spp.*, and Plecotus auritus.* They are typically low flying, clutter, gleaning or edge space foragers with calls that are primarily frequency modulated (hereby referred to as FM). These call ranges tend to be shorter and of low detectability. *Barbastelles* were included in the SRE grouping as they are typically edge space foragers (Frey-Ehrenbold et al. 2013), their calls are mostly FM and their detection range is within 15 meters so they are diagnostically more similar to *Plecotus auritus* and *Myotis* spp. (Dietz & Kiefer, 2016). Medium range echolocators (hereby referred to as MRE) (*Pipistrellus* spp.) are bats with more mixed foraging strategies and emit calls with intermediate bandwidth. Long range echolocators ((hereby referred to as LRE) (*Eptesicus spp., Nyctalus noctula*, and *Vespertilio murinus*) are generally high flying, open air space foragers (frequency modulated foraging calls with peak frequencies below 35 khz and call duration greater than 9ms) (Schnitzler & Kalko, 2001; Frey-Ehrenbold et al. 2013; Froidevaux et al. 2014). (Table 1).

Table 1. Bat species found in Norway (Norwegian Environmental Agency, 2014), guild assignments based on echolocation range (Froidevaux et al. 2014) and their status on the Norwegian Red List (Henriksen & Hilmo, 2015, Proposed Red List 2021). Abbreviations: Critically Endangered (CR), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Not Applicable (NA); Short range echolocators (SRE), Medium range echolocators (MRE) and Long range echolocators (LRE) (Frey-Ehrenbold et al. 2013; Schnitzler & Kalko, 2001).

Taxonomic Name	**Norwegian Name**	**Common Name**	**Guild**	**Red List 2015**	**Red List 2021**
Barbastella barbastellus*	Bredøre	Western Barbastelle Bat	SRE	CR	CR
Eptesicus serotinus	Sørflaggermus	Serotine Bat	LRE	NA	NA
Eptesicus nilssonii*	Nordflaggermus	Northern Bat	LRE	**LC**	**VU**
Myotis brandtii*	Skogflaggermus	Brandt's Bat	SRE	LC	LC
Myotis daubentonii*	Vannflaggermus	Daubenton's Bat	SRE	LC	LC
Myotis mystacinus*	Skjeggflaggermus	Whiskered Bat	SRE	LC	LC
Myotis nattereri*	Børsteflaggermus	Natterer's Bat	SRE	CR	CR
Nyctalus noctula*	Storflaggermus	Noctule Bat	LRE	VU	VU
Pipistrellus nathusii*	Trollflaggermus	Nathusius's Pipistrelle	MRE	**VU**	**NT**
Pipistrellus pipistrellus	Tusseflaggermus	Common Pipistrelle Bat	MRE	**VU**	**NA**
Pipistrellus pygmaeus*	Dvergflaggermus	Soprano Pipistrelle Bat	MRE	LC	LC
Plecotus auritus*	Brunlangøre	Brown Long-eared Bat	SRE	LC	LC
Vespertilio murinus*	Skimmelflaggermus	Parti-Coloured Bat	LRE	NT	NT

*species with documented reproducing populations in Norway

2.3 Study species: Insects

The insects of particular interest in this study are flying, nocturnal insects. Due to limitations regarding the use of time lapse cameras, there are certain insects that will not likely occur in our study; but are still a potential and important food source for bats in the area. Since the cameras will be set facing sky-ward they will mainly capture insects with the ability to fly. The cameras are of too low resolution to identify insects to any lower taxonomic level and some bias may occur when selecting for presence as insect size and distance from the camera may make it difficult for detection. The insect species that are both bat prey and present in the study area are listed in Table 2.

Table 2. The following orders of insets are found in southeast Norway, are prey species of bats and may be present during the study but not necessarily encountered in the photos.

Orders	Description
Coleoptera	Beetles
Diptera	Flies
Ephermeroptera	Mayflies
Hemiptera	True Bugs
Lepidoptera	Butterflies & Moths
Orthoptera	Grasshoppers, crickets & locusts
Trichoptera	Caddisflies

2.4 Acoustic Monitoring

Acoustic surveys were completed using sixteen Song Meter (SM4-BATFS) Bioacoustics Recorders (hereby referred to as detectors), five omni-directional U1 ultrasonic microphones (SMM-U1 Ultrasonic Microphone) and eleven cardioid directional U2 microphones (SMM-U2 Ultrasonic Microphone) from Wildlife Acoustics, Inc (2020). Detectors were set to begin recording bat vocalizations one hour before sunset and stop one hour after sunrise (Rodrigues, L., et al. EUROBATS No. 6. 2014) (see Appendix TableA1 for comprehensive detector settings.) Detectors were deployed at seven of the fifteen turbines and two were deployed on a meteorological tower (Table 3). At each turbine, an acoustic detector was placed at both a primary and a control site. The wind facility only allowed detectors deployed on the turbine pads to be on specified gravel or soil crane auxiliary pads in order to avoid electrical wires and be out of the way. The primary sites were thus placed at these designated locations which ranged from about 50-98 meters distance from the base of the turbine. Control sites were situated within 80-120 meters distance from the turbine and primary site in habitat more ideal for natural bat activity such as near a water source, marsh, clear cut grassland, or a forest edge/corridor. The control sites were defined, not by their proximity to the turbines, but by the types of habitats surrounding them. The goal was to sample as many varieties of bat habitat available at the wind park as possible within the turbine sites granted permission to us (Table 4). U2 microphones were primarily used for sites at turbines two, eight, nine, ten and fourteen. This microphone reportedly decreases background noise, thus giving higher quality calls and increasing ability to record fainter bats, echolocation pulses and calls from farther distances (Wildlife Acoustics, Inc; 2020). The U1 microphone was deployed at turbines four, eleven and the meteorological tower. The U1 microphone records sound from all directions and was ideal for use on the meteorological tower.

The detectors were secured to thick wooden stakes at breast height using rubber/metal gear ties (Nite Ize, Inc, 2021). The U2 & U1 microphones were attached to the detector via a five-meter cable and situated on top of wooden stakes approximately two meters off the ground (Ruczyński et al, 2019) (Figure 2). Additionally, all U1 microphones were directed at a 45-degree angle and the azimuth of the microphone direction recorded at each deployment. Detectors were deployed in two transects, A and B. Transect A consisted of turbines two, eight, and ten. Transect B consisted of turbines four, nine, eleven and fourteen. Each transect contained a mix of sites from both the north and south facility. This allowed for continuous monitoring of both the north and south facility throughout the study. The study took place over 91 days and both transects were deployed a total of three times (Appendix Table A4). Each deployment lasted twenty days with a ten day overlap where both transects were deployed together. At any given time, at least one of the transects was recording data in the field. The units were checked the day after deployment and every 3-4 days until retrieval. Transect A was deployed on the first of July and Transect B was deployed ten days after, on the tenth of July. The two detectors deployed on the meteorological (MET) tower consisted of two U1 microphones oriented slightly upward at approximately 45 meters (Met A) and 95 meters (Met B) high. The 45-degree angle positioning of the microphone is not necessary when monitoring at height. Met A and Met B microphones were situated to face north and east respectively. The detector units were at ground level in a metal padded box. Each detector was protected from electrical damage with a surge protector and the microphones were grounded to the MET tower (Figure 3).

Table 3. Location of project monitoring devices at the wind facility such as the SM4 acoustic detectors, camera traps and weather stations.

Marker Vindpark	SM4 Acoustic Detectors (2 per site)	Camera Traps (2 per site)	Weather Stations (1 per site)
North Facility: Joarknatten	Turbine 2 Turbine 4 Turbine 8	Turbine 8	Turbine 8
South Facility: Høgas	Turbine 9 Turbine 10 Turbine 11 Turbine 14 Meteorological Tower	Turbine 11	Turbine 11

Table 4. **CFE**-Coniferous Forest Edge; **LCFE**-Lowland Coniferous Forest Edge; **Ro/Gr**-Road & Gravel Pad; **LM**-Lowland Marsh; **M/W**-Marsh/Wetland; **G**-Grassland; **CL**-Clear cut; **ST**-stream/riparian; **LG**-Lowland grassland.

Location	Habitat Sampled	
Meteorological Tower	Coniferous Forest & Powerline/logging road corridor	
	Primary Site	**Control Site**
Turbine 2	CFE, Ro/Gr	M/W, CFE
Turbine 4	CFE, Ro/Gr	M, LCFE
Turbine 8	G, CL, Ro/Gr	G, CL
Turbine 9	CFE, Ro/Gr	LCFE corridor, ST
Turbine 10	CFE, Ro/Gr	CFE, CL
Turbine 11	CFE, Ro/Gr	LG, ST, CFE
Turbine 14	CFE, M, Ro/Gr	LM, CFE

Figure 2.
Acoustic detector primary site turbine 4.

Figure 3.
Microphone placement (top) at meteorological tower and box surge protector (bottom).

2.5 Camera Trap Insect Monitoring

Camera traps, similar in design and methodology to those used in Ruczyński, et al (2019), were utilized to observe and analyze patterns in activity and abundance of various insect species. Camera traps were deployed at turbines eight and eleven with a control and primary site within five meters of the respective acoustic detectors (Figure 4). The cameras used in the study were Ricoh WG-6 (Digital) Waterproof 20m/65.6ft; Model R02050 2019. The camera was set on Scenery/Interval shooting and took a photo every ten minutes with a flash for twenty-four hours a day/night (additional program settings can be found in the Appendix Table A2) (Figure 5).

The cameras were mounted to a sheet of glass (measuring 18 x 24 cm) and connected to a small tripod (Joby Gorillapod). The tripod/camera unit was then secured to the top of a thick wooden pole at a height of two meters. A power inverter (Biltema Art. 38-122; Appendix Table A3) was connected to a battery, the camera and a charger. The charger & inverter were contained in a waterproof box mounted to the pole. The waterproof box was sealed against weather using silicon (Tec 7). A small hole was cut into the bottom of the box for air flow, water drainage and to allow the cords to come down and attach to the battery (Figure 4).

Seven 12V 45 Ah car batteries (battery life lasting roughly two days) and one 12V 86 Ah battery (battery life lasting three-four days) were used as the electrical power source for the cameras in the field. The 45 Ah batteries were chosen as the terrain proved difficult to maneuver carrying the large 86 Ah batteries and could be a potential safety risk.

The cables connecting the battery to the inverter were soldered to a fuse holder containing a glass fuse (Brand: 6,3 x 32 mm x 5st./stk./kpl12/24 V). Attaching the battery and power inverter together at each camera trap were one to two electrical cords for cigarette lighters.

a. b.

Figure 4. Camera trap set up at a.) control site turbine eleven and b.) control site turbine eight.

Figure 5. Image of insects captured w/flash at night.

2.6 Weather & Climate Monitoring

Micro station data loggers (HOBOware Onset Computer Corporation; H21-USB 20875) were utilized to measure barometric pressure, temperature, and solar radiation on the north and south facility (Table 5; Figure 6). Two HOBO stations, each mounted on wooden poles, were deployed at turbines eight and eleven. Weather station sites were located between the control and primary sites for camera traps and acoustic detectors. Care was taken to situate the loggers in a clearing or open space so as not to subject the device to too much shade or other disturbances. The loggers took readings every ten minutes twenty-four hours a day. The weather station data was retrieved and recorded weekly. The light sensor was mounted southward, otherwise instruments were mounted securely as to not interfere with each other. Weather data collected by local weather stations as well as from the nacelles of wind turbines will also be included in analyses (Table 5).

Table 5. Illustrates the weather/climate variables collected and the specific locations monitoring took place throughout the wind facility

Turbines	Temperature (C*)	Barometric Pressure (mbar)	Avg. Windspeed (m/s)	Solar Radiation (W/m^2)
2	✓		✓	
4	✓		✓	
8	✓	✓	✓	✓
9	✓		✓	
10	✓		✓	
11	✓	✓	✓	✓
14	✓		✓	

Figure 6. HOBOware data logger set up between turbine & control site numbers eight and eleven.

2.7 Data Handling

2.7.1 Bat Acoustic Data

Bat calls (.wav file) were interpreted using Wildlife Acoustics Kaleidoscope Pro Analysis Software automatic classifier (settings in Appendix Table A6). Noise files were removed using R-studio. Since sampling nights occur across different dates (i.e. sampling starts in the evening of July 19 and ends in the morning of July 20), I used a cumulative day and cumulative night number to effectively account for this. The cumulative day number begins at the start of the study periods with the first day of observations (ie. July 1st equals day 1; Sept. 29 equals day 91). Cumulative night number was created by sorting the data by time and assigning all data collected after midnight the cumulative day number minus 1. The data was aggregated using R-studio software for mean bat activity, sum bat activity, activity per hour and night length for each day and site/habitat (one data point for each cumulative night number). Periods of inactivity or malfunctions where data was not collected were noted with an NA to illustrate gaps in sampling and a 0 indicated an active detector with no activity.

2.7.2 Insect Camera Trap Data

All photos were organized by turbine number and habitat location (turbine pad or control site). R studio packages (EXIF and Maptools) were first used to sort photographs by date, time, and GPS location. The time-series metadata was extracted from the photos to create a data table to run through R. By using GPS location to sort the photographs, I accounted for the rapidly changing sunrise/sunset times experienced during Scandinavian summers. Each photo taken one hour before sunset and one hour after sunrise was copied and sorted appropriately. In order to have a count summary for the number of insects present at each time; VGG Image Annotator (Dutta and Zisserman, 2019) was used to manually annotate each photo. This metadata was then combined with the extracted time-series metadata from all of the photos to create the spreadsheet used in the data analysis. In order to visualize the sampling design and account for periods where monitoring did not occur; a 1 was assigned to photos containing insects, a zero for photos with no insect presence (days where the detector was active but no insects were present), and NA for unsure photos, days where malfunctions occurred and/or no active detectors were present in the field. Dates were changed to cumulative day and night number (see Bat Acoustic Data section), and the data was aggregated to find the sum and mean insect abundance for each day, site, and habitat.

2.7.3 Weather Data

Temperature and wind speed data collected by the wind facility was primarily used for analyses because collectively there were little to no gaps in sampling in comparison to the HOBO data loggers. Barometric pressure data was used from the HOBO data loggers. The raw data was visualized and aggregated to contain one average wind speed and temperature point of data for each site, habitat and date.

2.8 Statistical Analysis

I used paired t-tests to look for significant differences in average bat activity between the meteorological tower heights (45 and 95 meters), the meteorological tower compared to all ground level detectors (north and south facility); and the meteorological tower to southern facility ground level detectors. I used a two-way ANOVA to compare bat species assemblage (i.e. long, short and medium range echolocators) across all habitats and sites (met tower, turbine pads and control). I used a post-hoc pairwise combination Tukey (HSD-Honest Significant Difference) test to compare multiple means and explore which of the combinations (bat species assemblage (LRE, SRE) and habitats (turbines, controls, met tower), were significantly different from each other.

To test the influence of time, temperature, and wind speed on average bat activity across all sites and habitats I applied a generalized additive model (GAM). The model is a powerful, yet simple technique that allows for variation and comparison between both linear and non-linear relationships without overfitting the data (Zuur, 2012). A Gaussian process smoother was applied as my data was a combined time series system and the observations (bat and insect activity, wind speed and temperature) were not expected to be independent of each other. I averaged the data (explanatory and response variables) at the site level to take into account the time periods where monitoring did not occur or there was a malfunction in the field (see Appendix Table A4). Although I found there to be a significant difference between the north and south facility, a random effect mixed model (i.e. including turbine site location as random effect) was not needed because the study design was balanced in terms of sampling effort between the turbine pads and control sites at each turbine site location (see Appendix Table A4).

To test the relationship between bat activity and insect abundance, I fitted multiple regression models for all possible combinations of the candidate predictor variables using insect abundance, temperature, and wind speed as predictors. Model comparison and selection was carried out by comparing AIC values. Model validation was carried out by visual inspection of standard diagnostic plots (QQ plots, residuals versus fitted values, residuals versus predicters, histogram of residual values) (Zuur, 2012).

3 Results

3.1 Spatial Variation in Bat Activity and Community Composition

Over the course of the 91-day study (July 1-Sept. 29), a total of 18,746 bat calls (*.wav files) were recorded. It is important to note that these calls were automatically identified by the Kaleidoscope software and are not reliable until manually identified for accuracy and comparison. *E. nilssonii* appeared to be the most prevalent species throughout the study area. The second most prevalent species was *Myotis* spp (2,702), followed by *Plecotus auritus* (523), *Nyctalus noctule* (300), *Vespertilio murinus* (250); *Pipistrellus* spp (91); and *Barbastella barbastellus* (84). 1,201 calls were not identified automatically (NoID) (Figure 7). The bat activity varied among sites and appeared to be higher at ground level than at heights of 45 or 95-meters (Figure 7, Appendix Figure A2).

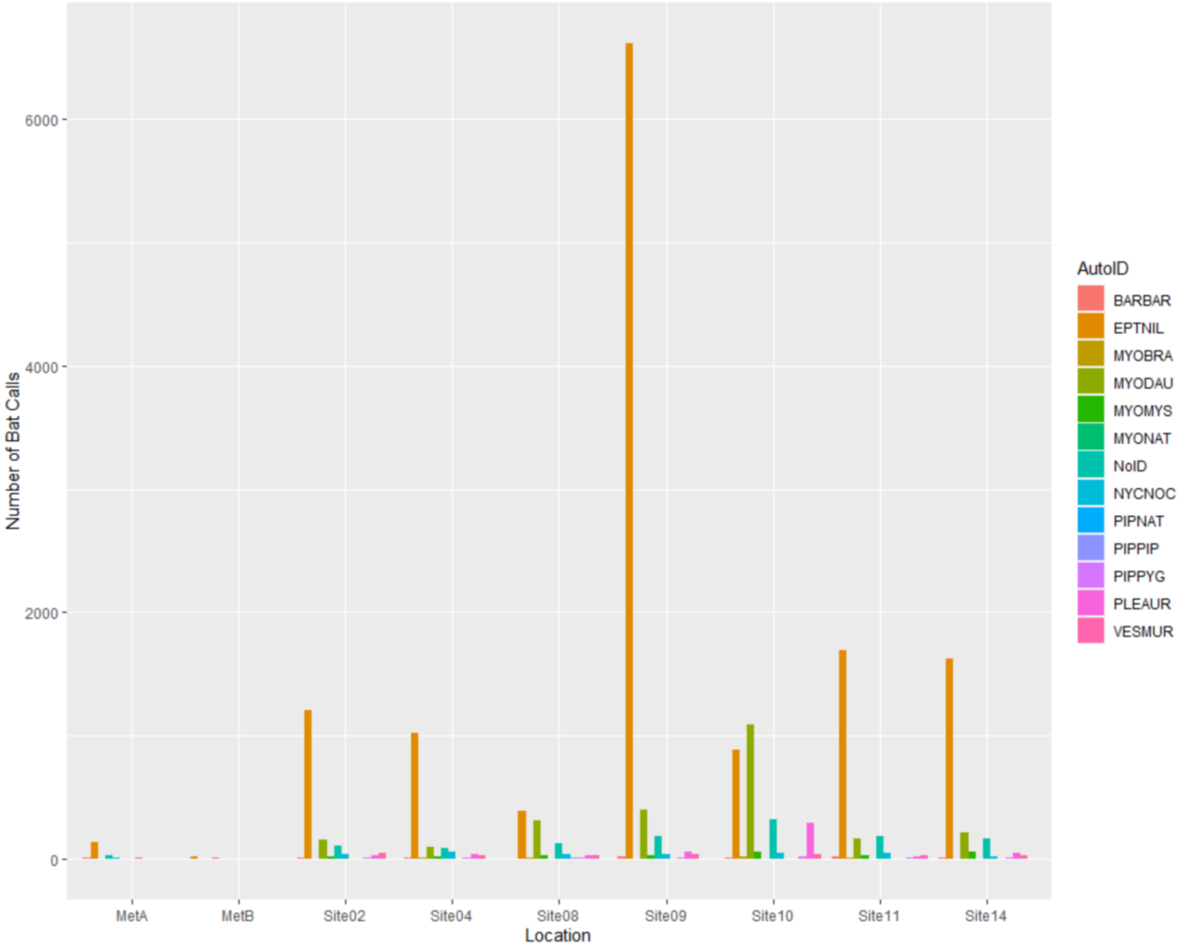


Figure 7. Frequency distribution of bat species present at each study site based on automatically identified species ID's by the Kaleiodoscope Pro Software (AutoID) for bats of Europe 5.2.1. These species counts have not been verified with manual ID and should not be considered highly accurate. The different colors represent different species (see Table 1 for full species names). The y-axis is the number of bat calls (i.e., *.wow-files) recorded per night. MetA (45 meters above ground) and MetB (95 meters above ground) represent the locations in the meteorological tower. The other locations represent measurements at ground level (turbine & control sites combined). See appendix Figure A2 for a similar graph, but where EPTNIL and No ID recordings were removed.

The LRE bats (*E. nilssonii, N.noctula*, *V. murinus*) were the most prevalent and could be found at every site including the meteorological tower (Figure 8 and 9). SRE bats (*Myotis* sp, *Plecotus auritus*, *B. barbastellus*) were second most prevalent and MRE bats (*Pipistrellus* spp.) had a comparatively low prevalence (Figure 8 and 9). At the meteorological tower, LRE were the most prevalent at 45 meters high (count= 50 calls), with some SRE presence (count=10). At a height of 95 meters, the only assemblage present was LRE (count=16) (Figure 8).

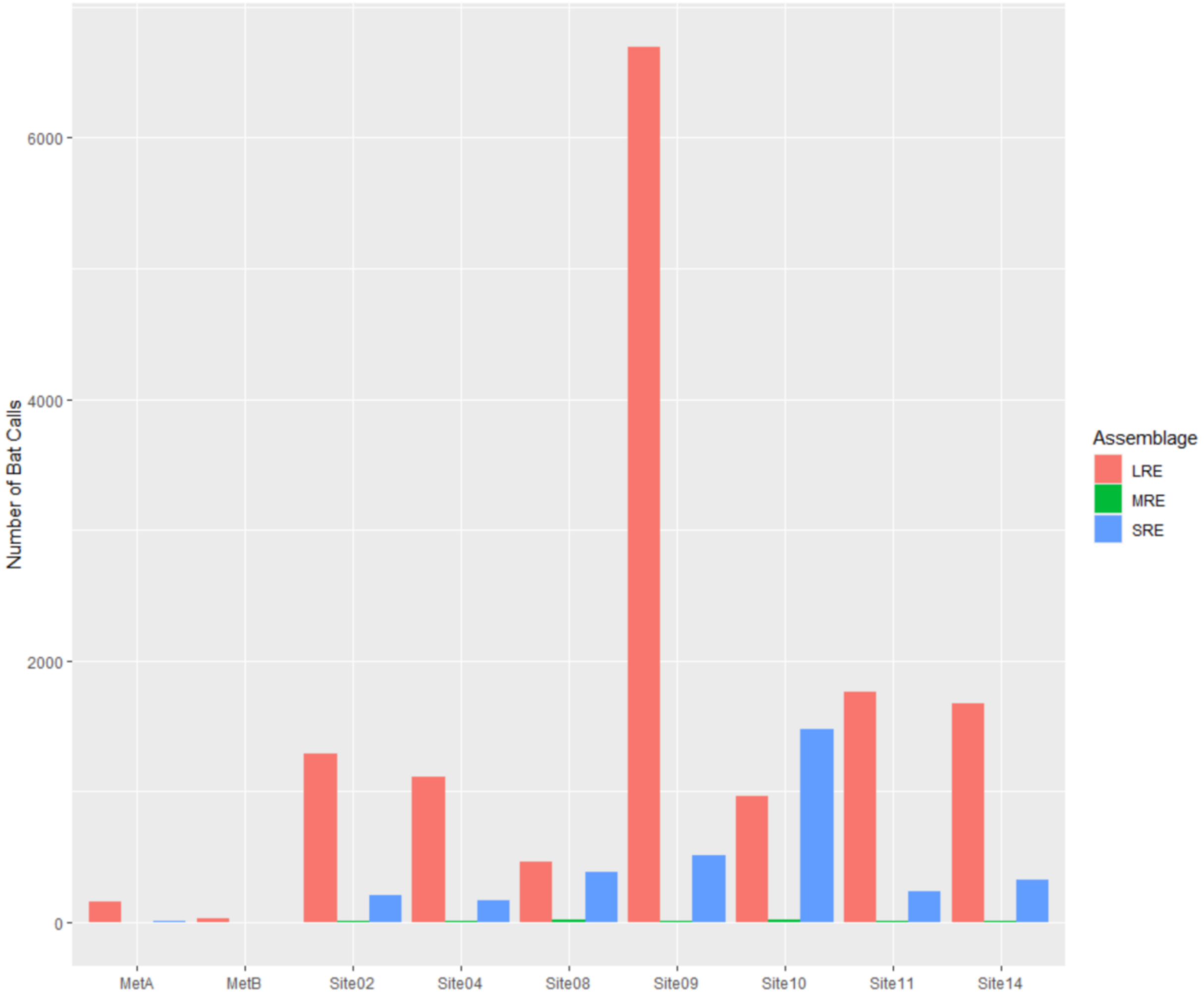


Figure 8. Frequency distribution of calls from long (LRE), medium (MRE) and short (SRE) range echolocator-bats. The y-axis indicates the number of bat calls recorded per night. Met A (45 meters) and Met B (95 meters) represent the locations on the meteorological tower monitored at height. The site numbers represent each study site monitored at ground level.

There was a statistically significant difference in bat activity among habitats (Met, Control, Turbine Pads) and bat assemblages (SRE and LRE), and the difference between SRE and LRE depended on habitat (Table 6). Due to the low count of MRE, they were dropped from the statistical test for significance.

Table 6. Results of a Two-Way ANOVA (Type III) test with to test if bat activity differed among habitats (three levels: meteorological tower, Control, Turbine Pads) and between bat assemblages (SRE and LRE). The response variable was average count of bat calls per night per location in the period from the 16th of July to the 22nd of September i.e., throughout the period when the detectors in the meteorological tower were active.

Variables	Sum Sq.	DF	F	p
Intercept	107611	1	111.24	<0.0001
Habitat (turbine pad, control, met tower)	28621	2	14.79	<0.0001
Assemblage (LRE, SRE)	16158	1	16.70	<0.0001
Habitat × Assemblage	9303	2	4.81	0.008316
Residuals	1198577	1239	4.81	0.008316

To understand group differences in the two-way ANOVA in Table 6, I conducted a post hoc Tukey HSD test to assess the significance of differences between all possible pairs of group means (Table 7). There was more bat activity (both LRE & SRE assemblages) at the turbine & control sites than the meteorological tower (Figure 9, Table 7). LRE bat species dominated the landscape and were found, in greater numbers, at all three habitats (Met, Control, Turbines) than SRE (Figure 9, Table 7). On average there are about twenty LRE bat passes (mean= 20.30) for every six SRE bat passes (mean= 6.04).

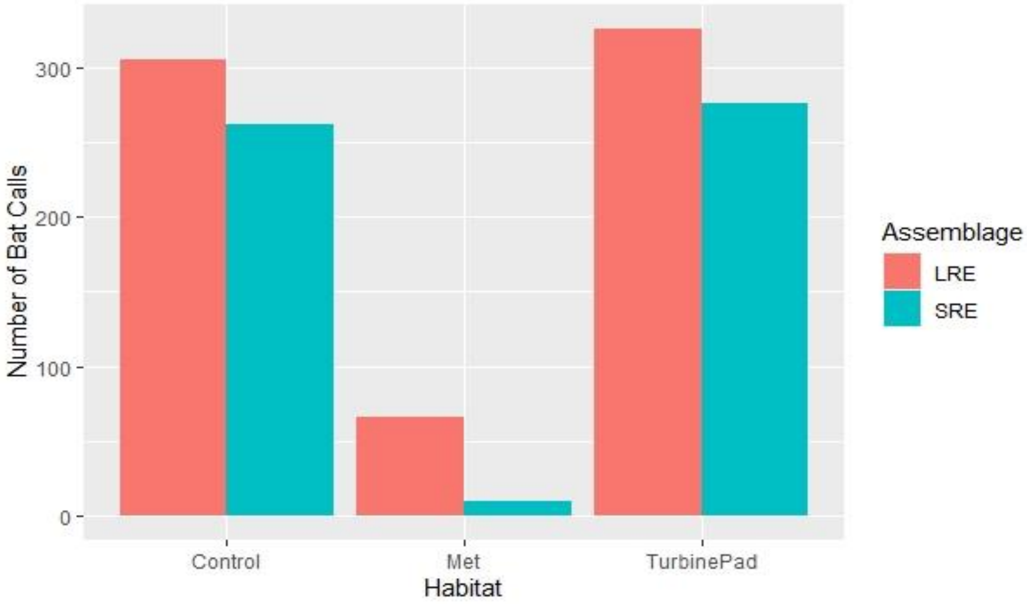


Figure 9. Activity of two different bat species assemblages (MRE excluded) in three different habitats (Turbine Pad, Control, Met tower (45 m and 95 m combined)). LRE, MRE and SRE stands for long, medium and short range echolocators, respectively. The y-axis indicates the number of bat calls recorded per night.

Table 7. Tukey HSD multiple comparisons of means test based off model presented in Table 6. Variable indicates the variables in the model that are being compared. diff= the difference between the means of the two groups. lwr/upr=the lower and upper end point of the confidence interval set at 95%. P adj= the p-value after adjustment for the multiple comparisons.

Variable	diff	lwr	upr	p adj
Habitat				
Met *vs* Control	**-11.18**	**-20.09**	**-2.26**	**0.009**
TurbinePad *vs* Control	1.79	-2.48	6.06	0.587
TurbinePad *vs* Met	**12.97**	**4.08**	**21.85**	**0.002**
Assemblage				
SRE *vs* LRE	-15.17	-18.66	-11.69	**<0.0001**
Habitat:Assemblage				
Met:LRE *vs* Control:LRE	-15.89	-27.94	-3.84	**0.002**
TurbinePad:LRE *vs* Control:LRE	6.44	-0.63	13.52	**0.098**
Control:SRE *vs* Control:LRE	-10.71	-18.18	-3.23	**<0.0001**
Met:SRE *vs* Control:LRE	-17.68	-46.21	10.85	0.486
TurbinePad:SRE *vs* Control:LRE	-14.50	-21.88	-7.13	**<0.0001**
TurbinePad:LRE *vs* Met:LRE	22.34	10.34	34.32	**<0.0001**
Control:SRE *vs* Met:LRE	5.18	-7.04	17.41	0.832
Met:SRE *vs* Met:LRE	-1.79	-31.92	28.33	0.999
TurbinePad:SRE *vs* Met:LRE	1.39	-10.78	13.55	0.999
Control:SRE *vs* TurbinePad:LRE	-17.15	-24.52	-9.79	**<0.0001**
Met:SRE *vs* TurbinePad:LRE	-24.13	-52.63	4.37	0.151
TurbinePad:SRE *vs* TurbinePad:LRE	-20.95	-28.21	-13.67	**<0.0001**
Met:SRE *vs* Control:SRE	-6.98	-35.58	21.63	0.982
TurbinePad:SRE *vs* Control:SRE	-3.79	-11.45	3.86	0.718
TurinePad:SRE *vs* Met:SRE	3.18	-25.39	31.76	0.999

3.2 Temporal Variation in Bat Activity

3.2.1 Ground level sites vs. At Height

Ground-level bat activity was highest in July and August (day 1-62) across all turbine and control sites with some activity seen in September, especially at the turbine sites (Figure 10). Bat activity per hour followed a similar pattern when compared to bat activity per night (See Appendix Figure A3 for bat activity per hour visuals). Activity at both the turbine pads and the control sites began to decrease in September and barely any activity is seen at the end of the field season. There are two significant peaks in activity at the turbine pads around day 75-80 (Sep. 13-18th).

Bat activity at the meteorological tower at 45-meters occurred earlier in the summer and fluctuated nightly in July and August until it decreased into September, with a few peaks in activity at the end of the season (day 80-85) (Figure 11). At 95 meters high, activity occurred later and there were more periods where monitoring occurred but activity was not detected with rapid increases and decreases in activity. There was a significant difference in mean bat activity between 45 meters (mean = 2.84) and 95 meters (mean=0.51) (Figure 11). Bat activity was highest at 45 meters high than 95 meters (paired t-test: $t= 7.6$, $df=68$, $p<0.0001$, 95% CI for difference in means: -1.7, 2.9; Figure 11).

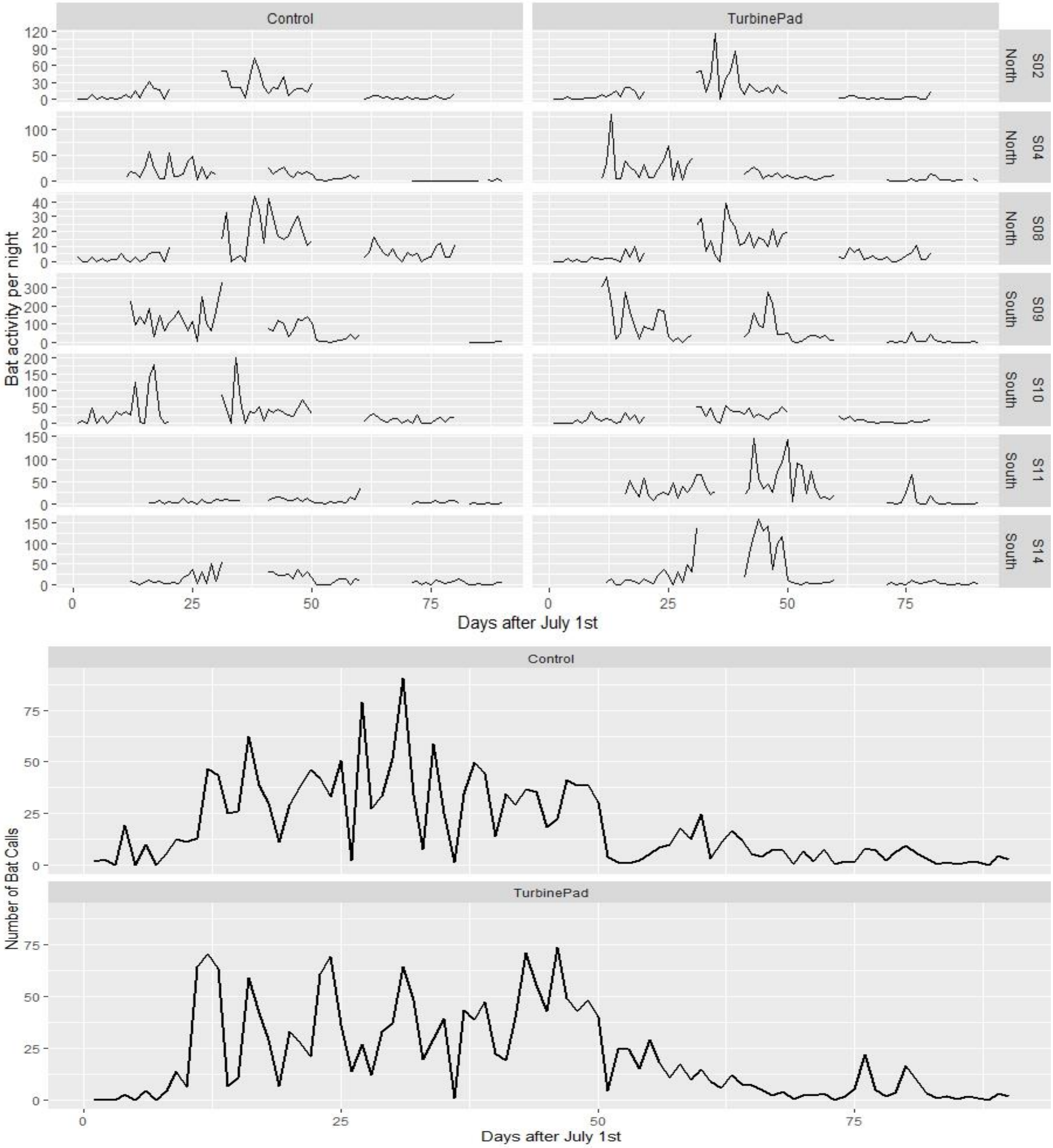


Figure 10. *Top*: Bat activity (number of calls) per night at each habitat and site during the study period. The x-axis indicates the days of the study period from day 1 (July 1st) until day 91 (September 29th). North and South indicate which part of the wind facility the site was located. Control and TurbinePad indicate which habitat was sampled. S followed by a number on the right axis (ie. S02) indicates the site and turbine number in which monitoring took place. Gaps in the time series are mainly planned periods of no sampling (see Appendix Table A4 for sampling design). Bottom: Average bat calls per night at the habitats sampled (turbine and control sites).

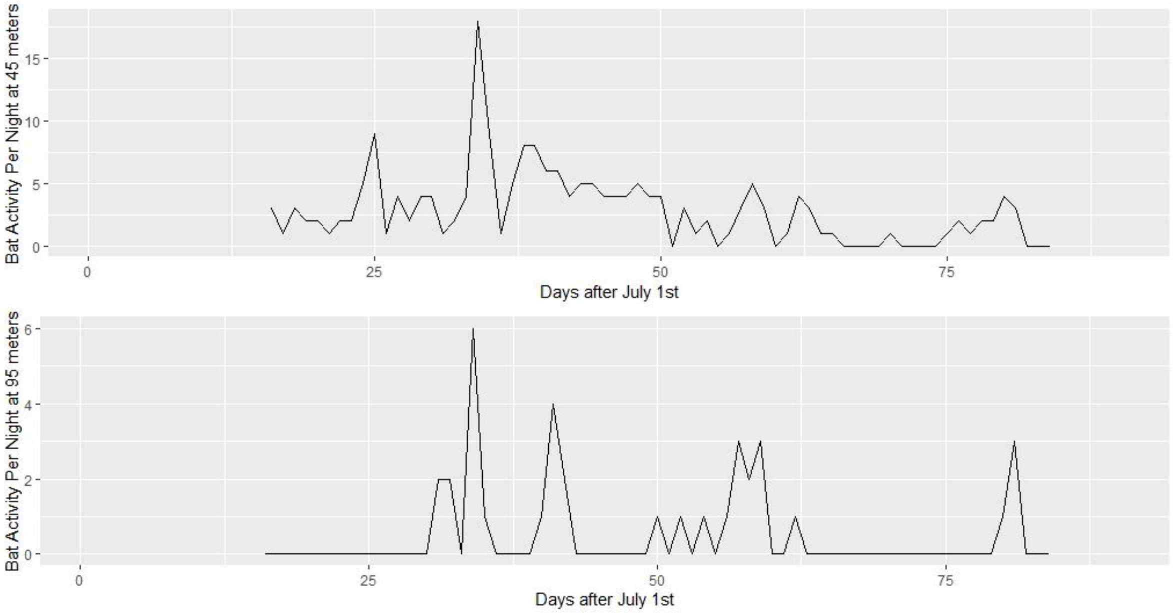


Figure 11. Average bat activity per night at each height sampled at the meteorological tower during the study. The y-axis indicates the bat calls recorded per night at 45 meters high (top) and 95 meters high (bottom). There were no observations for bat activity between July 1-15 (days 1-15) at the meteorological tower due to monitoring beginning on July 16th at this location. Flat lines (value zero) indicate days where active monitoring occurred but no bats were detected. Regions with no lines (day 1-15 (July 1-15) & day 85-91 (September 23-29th)) indicate dates where detectors were not deployed or actively monitoring.

Overall, there was more bat activity at ground level sites than at height throughout the summer and early autumn sampling period (Figure 12). Mean activity per location per night was higher at the ground level sites (mean=23) than at height (the meteorological tower) (mean= 1.67) (Figure 12) (paired t-test: t=9.6, df=68, p<0.0001, 95% CI difference in means: 16.6-25.4).

Additionally, the mean sum of bat activity on the south facility is almost three times higher than on the north facility (mean South=31.13; mean North= 11.10). Due to this, and because the meteorological tower was located on the south facility, I statistically compared the meteorological tower to all sites on the south facility as well. I found a significant difference between bat activity on sites on the south facility (mean=28.96) and the meteorological tower (mean=1.67) (paired t-test: t=9.5, df=68, p<0.0001, 95% CI difference in means: 21.5-33.0). Ground level sites consistently showed higher rates of bat activity.

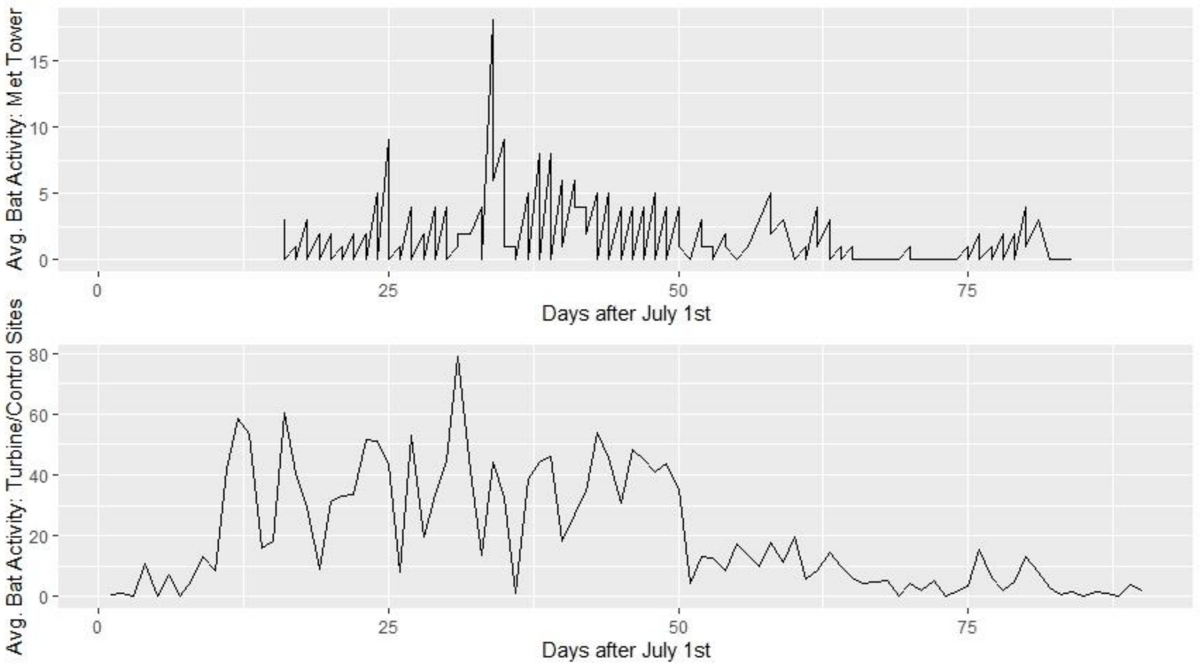


Figure 12. Average bat activity per night at the meteorological tower (all heights) and all ground level (turbine/control) sites. The y-axis indicates the average bat calls recorded per night at the meteorological tower (top) and the ground level detectors (bottom). The x-axis indicates the days of the study period from day 1 (July 1st) until day 91 (September 29th). Flat lines (value zero) indicate days where active monitoring occurred but no bats were detected. Monitoring of the meteorological tower began on July 16th and ended on September 23rd; day 1-15 (July 1-15) and day 85-91 (September 23-29th)) indicate dates where detectors were not deployed.

3.3 Influence of Weather Conditions: Temperature and Wind Speed

Weather conditions fluctuated throughout the sampling period (Figure 13) and decreased when wind speed increased (Figure 13). In July, temperature across all sites was low (very rainy/windy month) with two rapid declines in early and late July. After these declines, the temperature steadily increased into August until about day 45 (August 14th) where it peaked and then steadily dropped into September. Temperatures were highest during August with three peaks in temperature seen in September (Figure 13, Appendix Figure A4). Wind speeds were highest in early July and late September with some high peaks in wind speed in late July and one in August. August exhibited low wind speeds with a significant increase in wind speeds around day 55. Wind speeds began to increase again late August into September (Figure 13, Appendix Figure A5).

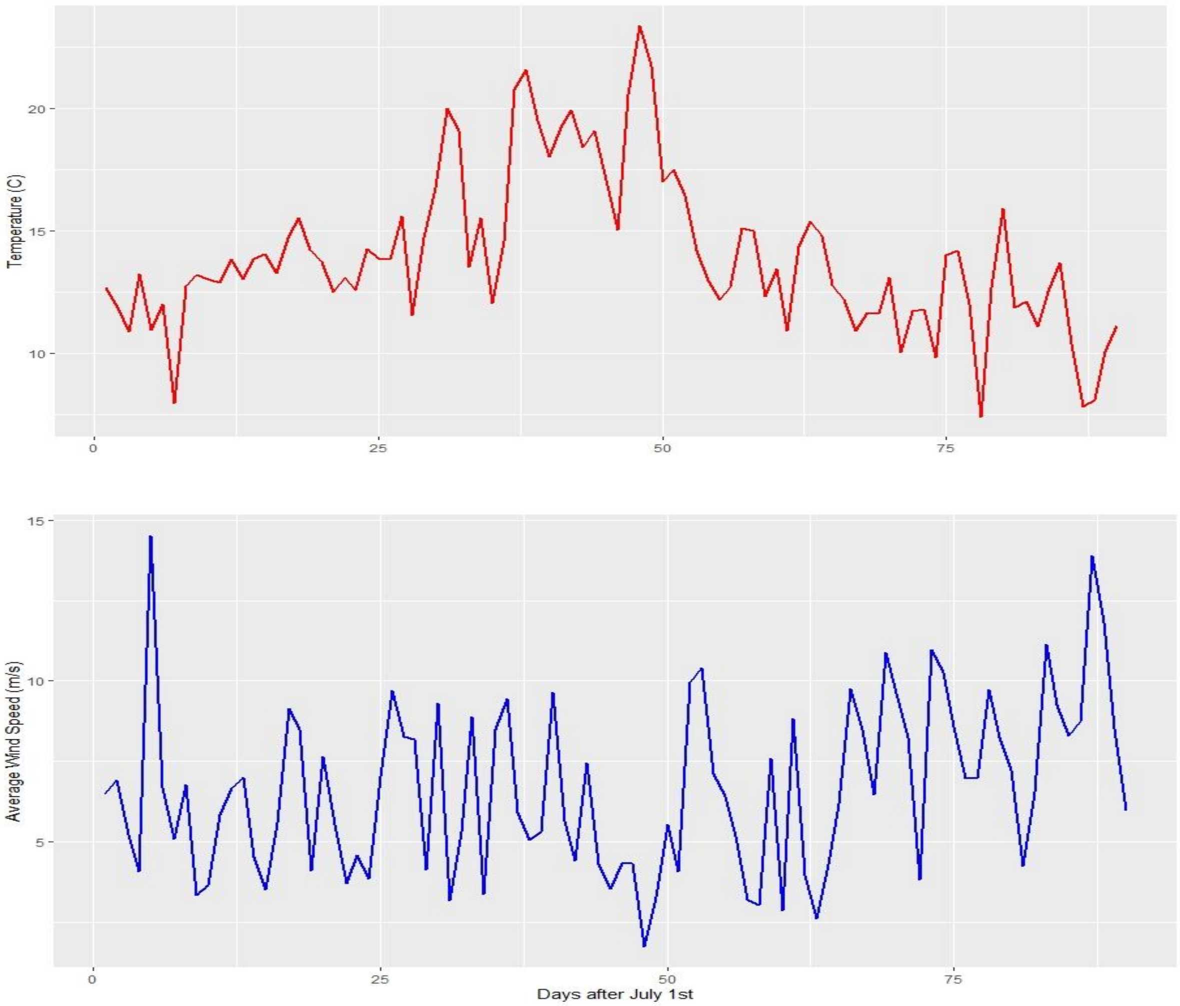


Figure 13. Average temperature in Celsius (top) and wind speed (meters per second (m/s) (bottom) at the wind facility between kl. 22 (10 in the evening) until kl. 4 (4 in the morning) (y-axis) over the course of the study period (July 1st until September 29th) (x-axis). See Appendix Figure A4 and A5 for temporal pattern in temperature and wind speed for each turbine location.

I found that there was a strongly significant temporal pattern in bat activity throughout the sampling period (Table 8, Figure 14). There was some support for a difference in the temporal pattern in bat activity between turbine sites and control habitats, but the average bat activity did not differ between habitats (Table 9, Figure 14). I modelled bat activity as a function of time and ground-level habitat (turbine pad versus control). The model with one smoother for time with habitat as a categorical variable (M1b in Table 8), performed equally well to the model with one smoother for time, habitat as a categorical variable, and an interaction between them (M1a in Table 8) (i.e. extending the additive model to two smoothers; one for each habitat). I also found that weather conditions influenced bat activity: When I compared M1b with models with different combinations of the candidate predictors: time, temperature, wind speed and habitat, based on the AIC; the models with Time + Temperature + Wind + Habitat, Time + Temperature + Wind, and Time + Temperature as predictors, performed equally well (Table 8 and 9). Using bat activity per hour (rather than per night) as response variable did not qualitatively change the overall results (Appendix Table A5) and thus the bat activity per night was used as the response variable in further analyses.

Table 8. Comparison of GAM models explaining the relationship between bat activity per night and habitat (turbine pad or control) and weather conditions (temperature and wind speed) over time (July 1st to September 29th). Weather conditions were average values per night between 10 PM and 4 AM. For each response – in step 1 – a model with Time and Habitat as explanatory variables, fitting a separate smoother for each Habitat, was compared to another model with Time and Habitat as explanatory variables, but with one common smoother for both habitats. In step 2, the best model from step 1 was compared to other models with all possible combinations of Time, Habitat, Temperature and/or Wind speed as explanatory variables. For each step, the model with the smallest AIC value – as well as models with an AIC-value within Δ2 – are shown in bold. Models with an AIC value that differ with less than a value of 2 are considered equally good.

Model No.	Model variables	AIC	DF	Deviance explained (%)
Response variable: Average Bat Activity Per Night				
	Step 1			
M1a	s(Time, by= Habitat) + Habitat	**1487.80**	12.79	53.8
M1b	s(Time) + Habitat	**1487.05**	7.88	51.1
	Step 2			
M1c	s(Time) + s(Wind) + s(Temp)	**1466.28**	12.44	57.9
M1d	s(Time) + Habitat + s(Wind) + s(Temp)	**1467.16**	13.44	58.1
M1e	s(Time) + s(Temp)	**1468.17**	9.99	56.2
M1f	s(Time) + Habitat + s(Temp)	1469.09	10.99	56.5
M1g	s(Time) + s(Wind)	1476.28	10.92	54.7
M1h	s(Time) + Habitat + s(Wind)	1477.23	11.92	55.0
M1b	s(Time) + Habitat	1487.05	7.88	51.1

Table 9. Estimated parametric coefficients and associated standard errors, test statistics and p-values, and significance of smooth terms, for explanatory variables that influenced on bat activity in the best M1 GAM models (i.e. the models with lowest AIC values) in Table 8.

		Parametric coefficients					**Smooth terms**			
Model No.	**Variable**	**Estimate**	**SE**	**t**	**p**	**Variables**	**edf**	**Ref. df**	**F**	**p**
M1a	Intercept (Habitat Control)	19.0	1.5	12.5	<0.0001	s(Time): Habitat Control	4.7	5.8	14.4	<0.0001
	Habitat TurbinePad	2.1	2.2	0.97	0.33	s(Time): Habitat TurbinePad	6.1	7.2	13.9	<0.0001
M1b	Intercept (Habitat Control)	19.0	1.5	12.3	<0.0001	s(Time)	5.9	7.1	24.6	<0.0001
	Habitat TurbinePad	2.1	2.2	0.96	0.34					
M1c	Intercept	20.0	1.0	19.7	<0.0001	s(Time)	5.2	11	7.7	<0.0001
						s(Wind)	1.4	9	0.51	0.0327
						s(Temp)	1.6	9	1.9	<0.0001
M1d	Intercept (Habitat Control)	19.0	1.4	13.2	<0.0001	s(Time)	5.2	11	7.7	<0.0001
						s(Wind)	1.4	9	0.51	0.0327
	Habitat TurbinePad	2.1	2.0	1.0	0.304	s(Temp)	1.6	9	1.9	<0.0001
M1e	Intercept	20.0	1.0	19.5	<0.0001	s(Time)	5.2	11	7.6	<0.0001
						s(Temp)	1.3	9	2.6	<0.0001

Time and temperature were included in all the three best models, whereas wind was included in two and habitat was only included in one of the best models (Table 8 and 9). Although I did not find a significant difference in the average number of bat calls per night between the turbine pads and control sites, there appeared to be a difference in temporal activity patterns between the habitats (Figure 14a, Table 8 and 9). There was one gradual and large peak in activity at the control sites earlier in the study season (mid/late July (day 25-31) and early/mid-August (day 32-45)) that decreased as the temperatures got colder later in the season (Figure 14b). At the turbine pads, there were two peaks in bat activity. The first, and smaller peak, occurred in mid-July (day 20) and the second peak, in mid-August (day 35-45) that rapidly declined as September approached (day 63).

The highest bat activity occurred on nights where temperatures were higher, or warmer. By increasing average temperature per night from 12 to 15 degrees Celsius (i.e., 2^{nd} and 4^{th} quantiles), bat activity increased from approximately 33 calls to 40 calls per night (Figure 14b). Bat activity was also highest at lower wind speeds. By increasing the average wind speed from 4 meters/sec to 8 meters/sec (i.e., 2^{nd} and 4^{th} quantiles), bat activity is reduced from approximately 42 calls per night to 34 calls per night (Figure 14c).

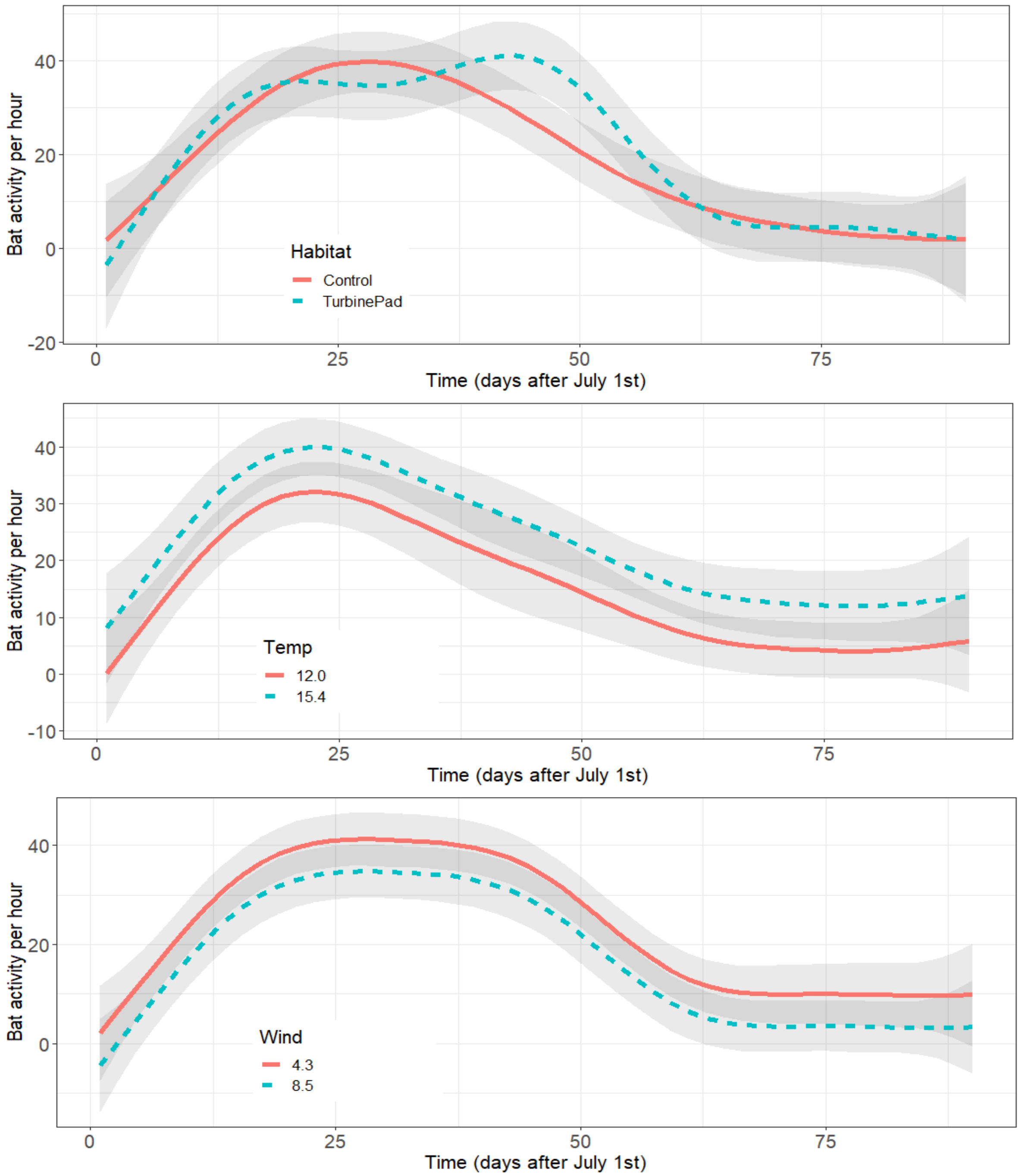


Figure 14. *Top(a)*. Predicted temporal pattern in bat activity at each ground-level habitat type (turbine pads and control sites). Estimated relationships and associated 95% confidence intervals for the GAM model M1b in Table 8. *Middle(b)*. Predicted temporal pattern in bat activity over the course of the study period at different temperatures (2nd and 4th quantiles). Temp is the average temperature per night, in Celsius, from kl. 22 in the evening until kl. 04 in the morning. *Bottom(c)*. Predicted temporal pattern in bat activity over the course of the study period at different wind speeds (2nd and 4th quantiles). Wind is the average wind speed (m/s=meters per second) per night from kl. 22 in the evening until kl. 04 in the morning. The common x-axis are the days of the study period beginning July 1st (day 1) and ending on September 29th (day 91).

3.4 Influence of Insect Abundance

A total of 11, 420 photos were taken throughout the study period to quantify insect abundance. The camera recorded photos beginning one hour before sunset and ending one hour after sunrise. 578 photos (5%) across all sites contained an insect, no insects were present in 10,072 photos (88%) and 770 photos (7%) were of too low quality for insect detection. There was substantial among-site and within site variation in insect abundance during the study period, and there were also planned and unplanned gaps in the data series collected (see Appendix Figure A6 for a visualization and details about how I dealt with this).

Both bat activity measures (i.e., per night and per hour) were statistically correlated with insect abundance and weather factors such as temperature and wind (Table 10). Both bat activity and insect abundance increased when temperatures increased and decreased when wind speed increased. Barometric pressure did not have an apparent affect (Table 10).

I found a moderate positive correlation between insect abundance and bat activity (Table 10, Figure 15). The correlation strength increased after removing one outlier (Table. 10, Figure 15). The per hour metrics had stronger correlations than per night measures and therefore used in further statistical analysis. Insect abundance was strongly and positively correlated with temperature, and moderately and negatively related to wind speed (Table 10, Appendix Figure A5). The insects responded similarly to temperature and wind speed as the bats (Table 10).

Multiple regression models for the relationship between bat activity and all possible combinations of the candidate predictors variables; insect abundance, temperature, and wind speed showed strongest support for the models with Temperature, Insect abundance + Temperature, and Temperature + Wind Speed as explanatory variables (Table 11). A closer look at the performance of the models which included insect abundance as a predictor variable revealed that when I included only insect abundance as a predictor (M1 in Table 12), insect abundance had a clear positive influence on bat activity (Table 12, Figure 16). However, when I also included Temperature in the model (M4 in Table 12), the influence of temperature appeared to “mask” the positive influence of insect abundance, probably because there was a positive correlation between insect abundance and temperature (Table 10).

Table 10. Results of Pearson's product-moment correlations between bat activity and insect abundance. r = Pearson's correlation coefficient. *indicates that one outlier was removed from the dataset (see Figure 15).

y	x	t	df	p	r	95% CI	
						lower	upper
Bats/night	Insects/night	2.71	72	0.008	0.304	0.081	0.498
Bats/ hr	Insects/ & hr	2.31	72	0.024	0.263	0.036	0.561
Bats/ hr*	Insects/ & hr *	3.46	71	0.001	0.379	0.164	0.561
Bats/ hr*	Temperature	7.73	71	<0.0001	0.676	0.528	0.784
Bats/ hr*	Wind speed	-2.44	71	0.017	-0.278	-0.478	-0.051
Bats/ hr*	Barom. pressure	-0.116	60	0.908	-0.015	-0.264	0.236
Insects/ & hr *	Temperature	5.24	71	<0.0001	0.528	0.339	0.676
Insects/ & hr *	Wind speed	-2.74	71	0.008	-0.309	-0.503	-0.085
Insects/ & hr *	Barom. pressure	1.16	60	0.249	0.149	-0.105	0.384

*indicates that one outlier was removed from the dataset (see Figure 15).

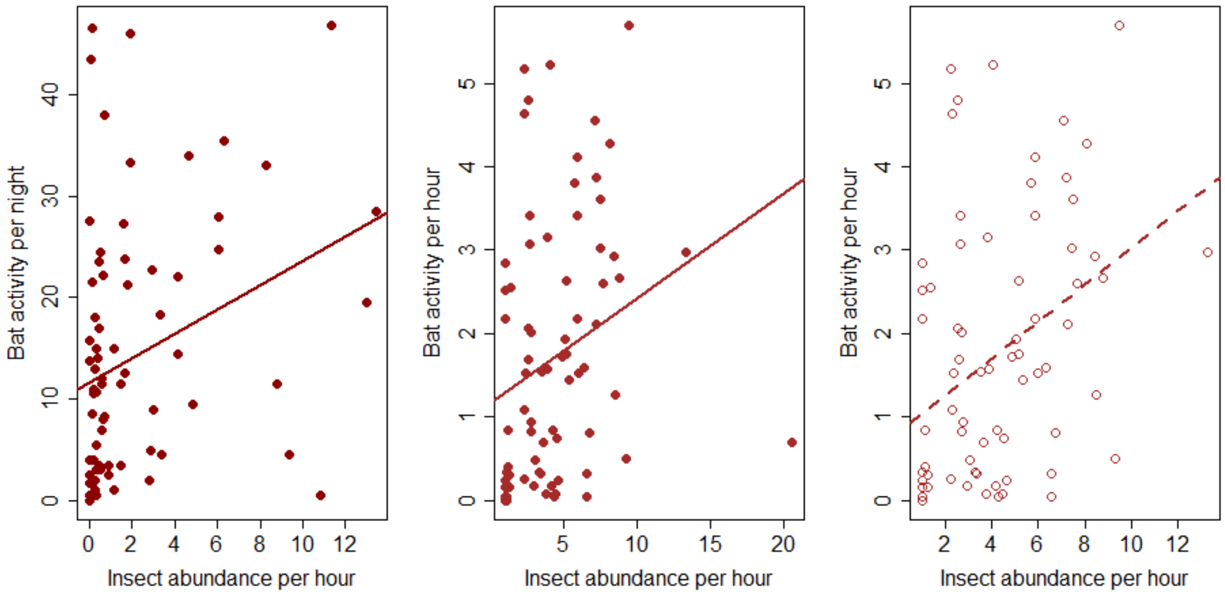


Figure 15. Scatterplots and fitted regression lines for relationships between bat activity per night and average insect abundance per hour (left) and average bat activity per hour and average insect abundance per hour (middle). The panel to the right has had the outlier removed (ie. insect abundance >20), but otherwise has the same comparison variables as the middle panel.

Table 11. Model performance of multiple regression models of the relationship between bat activity per hour and different combinations of explanatory variables: Insect = insect abundance per hour; Temp = average temperature between 10 pm and 4 am; and Wind = average wind speed between 10 pm and 4 am. The lower RMSE value indicates better model performance and the higher R^2 value (closer to 1) indicates the regression line fits the data well and better model performance. Models with an AIC value that differ with less than a value of 2 are considered equally good.

Model	Variable(s)	df	AIC	RMSE	R^2
M1	Insect	3	266.1921	1.437922	0.1442888
M2	Temp	3	**232.9820**	1.145376	0.457059
M3	Wind	3	271.6848	1.493049	0.07741936
M4	Insect + Temp	4	**234.8838**	1.144606	0.4577892
M5	Insect + Wind	4	265.7093	1.413676	0.1729035
M6	Temp + Wind	4	**233.7330**	1.135619	0.4662701
M7	Insect + Temp + Wind	5	235.6030	1.134608	0.4672194

Table 12. Estimated coefficients, standard errors, test statistics and p-values for models in Table 11 which included Insect = insect abundance per hour as explanatory variable.

Model	**Variable(s)**	**Estimate**	**SE**	**t**	**p**
M1	Intercept	0.82043	0.31649	2.592	0.011568
	Insect	0.22159	0.06404	3.460	0.000918
M4	Intercept	-2.60110	0.59466	-4.374	<0.0001
	Insect	0.01856	0.06045	0.307	0.76
	Temp	0.29951	0.04708	6.362	<0.0001
M5	Intercept	1.68432	0.63747	2.642	0.01015
	Insect	0.18954	0.06667	2.843	0.00586
	Wind	-0.10701	0.06877	-1.556	0.12417
M7	Intercept	-3.46290	0.98012	-3.533	0.000737
	Insect	0.02118	0.06040	0.351	0.726929
	Temp	0.32616	0.05283	6.174	<0.0001
	Wind	0.06905	0.06248	1.105	0.272944

Finally, I ran two separate GAM models to compare and test for significance between a) bat activity per hour and time (BatActivityHr ~ s(Time); (AIC=224. 36, df=7.27) and b) bat activity per hour and time with insect abundance per hour as an additional predictor term (BatActivityHr ~ s(Time) + s(InsectHr); AIC=226.51, df= 8.18) (Figure 17). These models revealed that bat activity per hour was mainly influenced by time (temporal) variation. Yet, adding insect abundance as a second smoother gave an increase in the AIC value of only about Δ2, which indicates some support for this model, too (Figure 17). Indeed, insect abundance was minimal below 10C and seemed to follow a similar trend with bat activity in response to temperature (Table 10, Appendix Figure A6). Between 10-15C, insect abundance increased until about 20C when insect activity began decreasing (Appendix Figure A6).

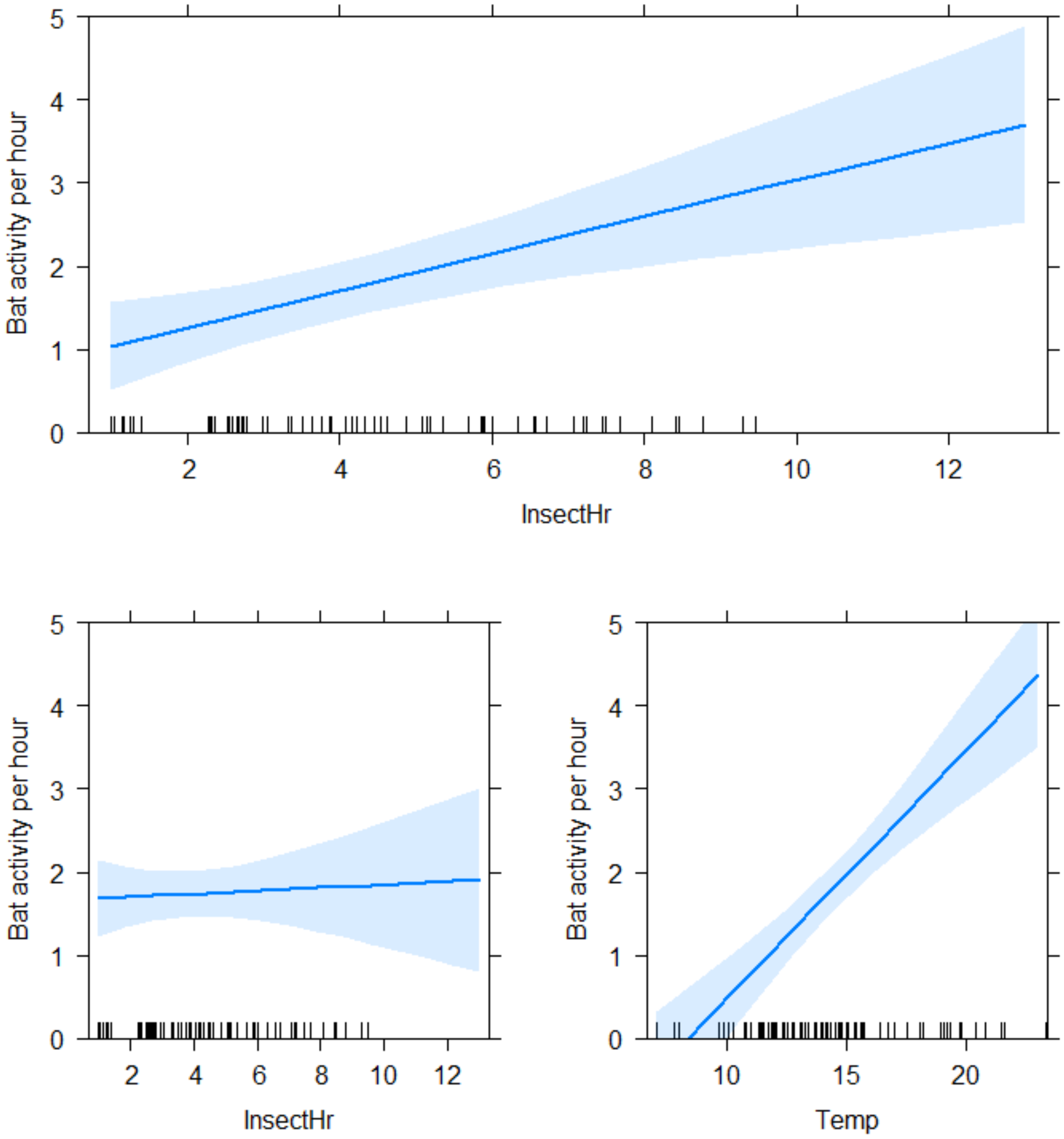


Figure 16. Predicted relationships between bat activity and predictor variables. Upper panel: prediction plot based on M1 in Table 11 and 12 (Insect abundance per hour (InsectHr) as predictor). Lower panels: prediction plots based on M4 in Table 11 and 12 (Insect abundance per hour and Temperature as predictors).

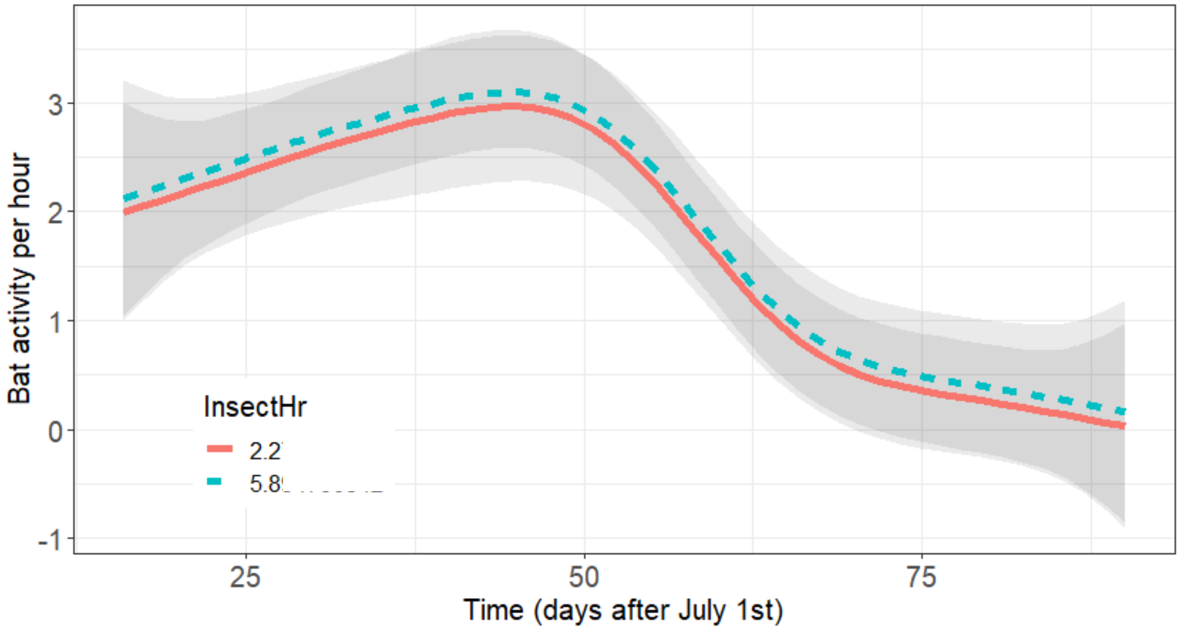


Figure 17. Predicted temporal pattern in average bat activity at two different levels of average insect abundance per hour/night (2nd [25%] and 4th [75%] quantiles). InsectHr= average insect abundance per hour. Insect monitoring did not begin until mid-July.

4 Discussion

4.1 Main findings

I found there was spatial variation amongst bat species assemblages and community composition. LRE (*E. nilssonii, N. noctula, V. murinus*) were the most prevalent amongst all the ground level sites (turbine & control) and at height (meteorological tower). At the meteorological tower, LRE and SRE (*Myotis* spp., *P. auritus*, *B. barbastellus*) were present at 45 meters high; but only LRE were detected at 95 meters high. Bat activity followed a temporal trend across the wind facility in two ways. First, ground-level activity was collectively higher in July and August across all sites. Second, average bat activity did not differ significantly between turbine pads and control sites, but activity at the turbine pads was higher in late summer (late July and August) while activity at control sites was higher earlier in the summer (July). At the meteorological tower, activity was highest at 45 meters, but overall lower than at ground level sites. These patterns in bat activity were correlated with insect abundance, temperature, and wind speed. Both bat activity and insect abundance increased when temperatures increased and decreased when wind speed increased.

4.2 Bat Community Composition & Spatial Patterns

LRE calls were the most common bat guild represented at the facility, and within the LRE group, the AUTO ID suggests that most of these calls belonged to *E. nilssonii*. When strictly using automatic identification without manually identifying the calls, I cannot rule out the possibility for misclassification with other species (Rydell, et al. 2017; Russo & Voigt, 2016). Species such as *V. murinus, N. noctula* and *E. nilssonii* all have similar call structure and possibilities exist for frequency range overlap (Rydell, et al. 2017; Dietz & Kiefer, 2016. pg.118). *E. nilssonii* is still likely the most prevalent species in the area but possibly not in such high numbers as the classifier is reporting. Additionally, there are some species that were minimally or not detected at all. Lack of appearance by some species in acoustic data does not mean they are not present. Bat species vary in their detectability by passive acoustic monitoring, as some are quiet, do not echolocate loud or often, or may fly very high or out of the sampled habitat making detectability difficult (Collins et al. 2009). For example, *P. auritus* emits low intensity calls which may escape detection by microphones (Collins et al. 2009; Waters & Jones, 1995). Bat calls may overlap, or patterns may shift in response to a behavior or the environment which may confuse both human analysts and machine learning software. In order to improve identification of bat taxa, researchers can use mist netting and observational surveys alongside acoustic monitoring practices. Ideally, I would have performed supplemental monitoring with mist net surveys alongside the acoustic surveys to improve accuracy of species identification and compare with the acoustic data from the area. Due to the coronavirus, mist netting could not be performed but a subset of acoustic data will be manually identified by an expert at a later time to compare with the automatic identifications.

The patterns in spatial variation at ground level and at the meteorological tower recorded between LRE & SRE is characteristic of these foraging guilds. The LRE activity at the turbine sites and strictly at 95 meters high, is typical of LRE bat species. Bats in this guild are known to fly in open space and often migrate long distances. *Pipistrellus* spp. (MRE) are also frequently found flying this high in other studies, but did not make up a large portion of our sample (Mathews et al. 2016; Kirkpatrick et al. 2018). SRE bat species tend to be low flying, edge space and gleaning species (Dietz & Kiefer, 2016; Frey-Ehrenbold et al. 2013; Froidevaux et al. 2014) and utilize space indicative of the control sites. Collins et al (2009), found that in open habitats, bat activity is higher at lower heights (2-10 m) whereas bat activity in forested habitats was higher above the canopy (greater than 10 m), especially with particular species such as *Nyctalus* and *Eptesicus* species (LRE). I witnessed these patterns in my study, to a certain extent. The open turbine pad sites exhibited high activity rates which is in line with what Collins et al (2009) found. LRE and SRE species activity at 45 and 95 meters high (at the meteorological tower), situated within a forest and above the canopy, was low compared to open ground level sites. Similar to Collins study though, LRE species were highest above the canopy than SRE species at both 45 and 95 meters high at Marker Vindpark. Although I did not observe higher average overall bat activity above the canopy in my study, these results have implications for further research of bat activity above the canopy versus open habitats, especially on wind facilities where bats are at risk.

Although activity for both LRE and SRE was, in total, highest at the turbine sites, average bat activity across the study period at turbine pads was not significantly different from control site activity. One would expect activity by SREs at control sites to be higher than at turbine sites because these sites provided more natural cover and typical foraging conditions. LRE activity at turbine sites is higher since there is more open-air space which is also still close to vegetation. One possible reason for these relatively similar patterns in activity amongst the ground level sites are the sites relative proximity and similar distances from the turbine bases themselves. Control and turbine sites did vary in distance from the base of the turbine; but average distance between the turbine and control sites from the turbine pads were about the same. Some control sites were over 100 meters from the base of the turbine while some were about the same distance from the turbine as the turbine sites. I cannot say for sure if attraction to the turbine is a likely explanation for bat activity at these sites but attraction to the control sites due to foraging opportunities at specific habitats may be a better explanation. Another possibility could be the wind facilities location within a slightly mono-cultural and young coniferous forest (Buchholz et al. 2021). Generally deemed less ecologically valuable in comparison to their old growth and mixed wood forest counterparts, there is evidence that coniferous production forests are important for local bat populations in summer and host a diverse mix of bat species and high activity rates (Humphrey et al. 2003; Apoznański et al, 2018; Buchholz et al. 2021). The forest surrounding the wind turbines at Marker Vindpark were dominated by young coniferous trees, wetlands, ponds and a sprinkling of various other types of vegetation. The roads and turbine pads create gaps in the forest which make the otherwise homogenous forest more diverse which could be potentially providing more desirable bat habitat (Kirkpatrick et al. 2017A; Kirkpatrick et al. 2017B) and increased foraging opportunities for all guilds. The tree lined roads may also act as a linear navigational tool for commuting bats (Medinas et al. 2019; Fensome et al. 2016). These aspects may contribute to a more suitable and accessible habitat and increased bat activity, despite the risk of collision, injury, or death from turbines.

4.3 Temporal Patterns in Bat Activity

Bat activity at ground level sites was highest in July and August across all turbine and control sites with some incidents of increased activity seen in September. I found a positive correlation between insect abundance and bat activity and both were highest in July and August. Bat activity at the meteorological tower, although relatively low, continued into September when activity at ground level began to decrease. Activity at the turbine pads and meteorological tower was highest in late summer while activity at control sites was highest slightly earlier. These findings agree with bat summer foraging and fall migratory patterns witnessed during other studies throughout Fennoscandia (Rydell et al. 2014; Šuba et al. 2012). My findings also concur with Froidevaux et al. (2014) which states that variation in bat activity, on a temporal scale, was specific to habitat and species. At the Marker Vindpark, habitat did not specifically play a significant role in average bat activity but there was a significant temporal difference in bat activity at the habitats. The turbine sites may have experienced higher bat activity later in the season because the nights became longer and darker allowing the bats to forage for longer periods. The turbine pads may also have provided an open area, near the forest that likely also contained higher rates of insects which tend to rely on warmer environments. The peak in bat activity in July and early August seen at the control sites corresponds with a period when I expect juvenile bats of several species are becoming volant (Collins, 2016), thus increasing the overall activity of foraging bats in the area. Activity at control sites could also be contributed to more availability of resources such as water, shelter and prey which has the potential to be lacking at open, and often barren, turbine sites.

A 1991 study from Sweden (de Jong & Ahlen), found that bat activity was correlated with insect abundance and was higher in mid-summer (July) as insects were more abundant and bats had more foraging opportunities across habitats. The control sites in my study may have also experienced the same trend which would explain the higher activity witnessed in early summer. Numerous other studies across the United States have reported similar seasonal trends of increasing bat activity in mid-late July until mid-August (Hayes, 1997; Erickson & West, 2002; Wolbert et al. 2014). Halat et al, (2018) found that the length of time in which bats forage was correlated with insect abundance and insect emergence patterns in Poland. Another study from Poland, found that insect activity in a coniferous forest peaked over shorter time periods and a high occurrence of *E. nilssonii* and LRE were observed (Apoznański et al, 2020). I found this occurred at my study sites as *E. nilssonii* and LRE were the most observed taxa and the highest rates of insect abundance at my sites occurred over short periods of time (July-August). The activity at differing time periods at the control and turbine sites may be driven by insect abundance and increased foraging opportunities as have been witnessed in previous studies.

Another explanation for the temporal trends in bat activity were weather conditions. I found that temperature, and also wind, appeared to have a stronger influence on bat activity than did specific habitat characteristics. Bat activity at many sites increased with insect abundance as well as temperature increases. The Bat Conservation Trust and EUROBATS publication No.5 state an optimal temperature at sunset for bat activity is 10 degrees Celsius or above with minimal activity occurring below this threshold (Collins, 2016; Battersby et al, EUROBATS No. 5. 2010). In my study, some bat activity below the 10-degree Celsius threshold was observed, although still quite low. This may be due to average summertime temperatures in Norway being much colder than in temperate climates and bats must be active in colder weather or they will have decreased foraging seasons and opportunities. Bat activity was minimal in my study until about 10-12 degrees Celsius. Bat activity increased rapidly between 10-15 degrees Celsius.

The highest individual activity points occurred between 16-23 degrees Celsius roughly (Appendix Figure A4). July and August were relatively warm months despite the poor weather experienced in July. These high temperatures corresponded with increases in both bat and insect activity witnessed at the control sites. In August and September, turbine site temperatures may have been slightly higher than the control sites which would be more shaded and less exposed to wind and solar radiation during these times. This could have accounted for the higher bat activity and insect abundance as they both thrive in warmer temperatures. Peaks in bat activity in September appeared to strictly correspond with temperature increases rather than insect abundance. This was also a period of lower temperatures and higher winds which bats may have been able to forage and be active in but most insects could not.

The wind park experienced poor weather and high winds in July and early August. The control sites may have experienced higher bat activity during these times because wind speeds may have been curtailed by the vegetation which could have provided shelter. Insects may have also been more abundant here as wind speeds would have been lower within vegetation. Bat activity at the turbine sites in early summer may have been lower due to higher wind speeds across the open turbine pads, thus deterring bat and insect flight. Wind speeds were lower in August and parts of September which could also account for the increased activity at turbine sites as the temperature was still relatively high which would increase foraging opportunities for LRE species.

Many LRE species (*Eptesicus* and *Nyctalus),* and MRE species (*Pipistrellus* spp.) all showed high activity rates in coniferous forest zones (Buchholz et al. 2020). Many bat fatalities at wind facilities primarily consist of migratory, LRE or aerial hawking and open-air species with fewer, but still significant, cases of low flying non-migratory species fatalities (Arnett, et al. 2016). The patterns in bat activity in August and September at the meteorological tower and the turbine sites also occur during possible fall migration periods (Rydell et al. 2014). This could place LRE bat species guilds at an increased risk of mortality (Wolbert et al. 2014; Arnett et al. 2008; Voigt et al. 2015). This is concerning for bat species in Norway considering that several of them are threatened or near threatened (Table 1). Notably, the most common bat species in Norway and in the study area in Marker Vindpark, *E. nilssonii*, was assessed as least concerned LC in the Norwegian Red List 2015 (Henriksen & Hilmo, 2015) will now be listed as vulnerable VU on the Norwegian Red List and Species 2021 due to declines in population size (Table 1, Katrine Eldegard, pers. Comm.). The higher activity rates seen by *E. nilssonii* at height and the turbine sites can also be potentially fatal as it shows that this species is present and quite active on the wind facility during these critical periods. *E. nilssonii* carcasses are one of the most common bat fatalities observed at wind facilities during the late summer and early autumn within Fennoscandia (Rydell et al. 2017; Gaultier et al. 2020). Other species of bat that were present at Marker Vindpark (*N. noctula* (LRE), *V. murinus* (LRE) and *Pipistrellus* spp. (MRE)) constitute the majority of bat fatalities at wind facilities in Northwestern Europe (Rydell et al, 2010A). In Norway specificall*y,* there is uncertainty regarding fatality rates because post-construction monitoring for bat fatalities is not standard practice at wind facilities. Determination of bat fatalities based off bat activity alone cannot be done sufficiently strictly through the use of acoustic monitoring methodology (Solick et al. 2020). Using mixed methodologies alongside acoustic monitoring such as DNA barcoding, intensive trapping, roost and emergence surveys can increase accuracy of identifying bat species (Montauban et al. 2021) in a given area.

Since insect activity peaks at Marker Vindpark occurred over a relatively short period, and LRE were the most prevalent species group, this may have implications for future management decisions at this facility because the wind turbines are situated within a coniferous forest. Additionally, a study conducted in parallel with this study, found two bat carcasses during carcass searches at the Marker Vindpark (Mckay et al. 2020. Unpublished). This facility has the potential to be causing bat fatalities given the observations from this study and others from the Fennoscandia regions.

4.4 Bat & Insect Relationship: Is bat activity on wind farms related to insect abundance?

At the Marker Vindpark, I found that both bat activity and insect abundance were strongly linked to temperature and moderately to wind. Bat activity was responsive to insect abundance, but temperature fluctuations appeared to have a stronger influence on bat activity than insect abundance. Specifically, peaks in bat activity at the turbine sites in September had a stronger correlation with temperature than insect abundance. The trend of temperature possibly being a main driver of bat activity rather than prey availability has been observed in previous studies such as on forested wind facilities in the United States and locations where bat activity peaked before insects were even abundant but temperatures were warming (Wolbert et al. 2014; Meyer, 2015).

Bat emergence in spring from hibernacula within Fennoscandia and nightly activity rates have been linked with warming outside ambient temperatures (Blomberg, 2021) as well as availability of insect prey. Insects are cold-blooded ectotherms and are physiologically, metabolically, and behaviorally impacted by temperature changes. Their rates of development and timing of life stages are dependent on temperatures staying within a certain range and can be impacted by seasonal, daily, and even hourly temperature fluctuations (Régnière et al. 2012) in weather or climate (Humphrey et al. 2003). Ruczyński et al, (2019), also observed that insect abundance was strongly influenced by temperature and wind conditions. Insects, like bats, are more active on warm nights with moderate wind speeds and/or precipitation (Halat et al. 2018). There was evidence of insect activity during precipitation events on the wind facility as some photos contained flying insects when it was obviously raining. This suggests insects are reactive more strongly to temperature fluctuations first and then wind and precipitation so long as these are at moderate to low levels.

Throughout the study period, bat and insect activity levels rose and fell in relation to increasing temperature and decreasing wind speed. Insect abundance at the sites monitored on the wind facility were minimal below 10 degrees Celsius. Between 10-15 degrees Celsius, insect abundance increased until about 20 degrees Celsius, when activity dropped as temperatures increased (Appendix Figure A4). Bat activity appeared to follow a similar trend but their temperature tolerance seemed greater and bat activity was witnessed in colder and warmer temperatures than were insects. In September, the turbine pads across the facility exhibited small spikes in bat activity and the control sites experienced consistently less activity. At the sites monitored for insects, there are no such spikes and little to no insect activity in September. There was an increase in wind speed and decrease in temperature at this time which may have kept the insect numbers down but temperatures may not have fallen enough to deter bat activity. These observations are possibly indicative of a threshold temperature in which insect activity was limited at certain sites on the wind facility. Bats are more mobile ectotherms and are not as limited by temperature as insects.

Temperature and insect abundance are thus both important drivers of bat activity on the Marker Vindpark and possibly other wind facilities across Norway. Bat activity and insect abundance are both dependent on temperature fluctuations first and then wind speed. To explore further, long term post-construction monitoring is suggested (Rodrigues et al (EUROBATS), 2014). Future research should also consider including at height monitoring of insect abundance alongside ground level monitoring. Increasing insect monitoring effort to more sites and implementing more sites dedicated to at height monitoring of bats may also be helpful. Monitoring bats at height can be challenging as it is costly, appropriate structures for mounting may be difficult to access and recording acoustic data in these locations is mechanically more challenging. Despite these limitations, studying bats at various heights is valuable to include in monitoring strategies because it gives the researcher a sense of what species may be active close to the turbine blades and when this activity peaks.

5 Conclusion

Increased exploration of the data is needed to determine if there is more than a causal relationship between bat activity, insect abundance and weather conditions on the Marker Vindpark. Future studies should continue to explore how all bats, but especially those in the LRE guild in Fennoscandia may be vulnerable to wind energy infrastructure in boreal forests. Although the MRE guild was not highly represented at my study sites, it is important to note this guild makes up about half of the reported fatalities in Europe (Rydell et al, 2010A) and it will be important to monitor the impacts of wind energy on them as well.

As weather conditions play a key role in bat activity and insect abundance, one implication from this study could be that climate change predictions, land use change and the expected increased development of wind energy infrastructure in Scandinavia (Weir, 2018) may have unknown detrimental impacts on bat population numbers and their activity within boreal forests. Another implication, is that wind turbines built in forested habitats, especially coniferous production forests may be a threat to bats as these areas may be of ecological value to bats in the boreal region. Long-term monitoring efforts will be important for understanding the relationship between bats and insects and their environment on wind facilities in their northernmost ranges. Currently bat monitoring programs are being developed in Norway to address knowledge gaps and collect valuable information necessary to address threats to Norwegian bat populations.

I have shown that through simultaneous and non-invasive monitoring of insect abundance and bats using camera traps and passive acoustic monitoring; it is possible to describe the relationships between these taxa and their environment with minimal bias and disturbance to the study species. The methods used in this study can be a practical guide to future study efforts in similar areas. This study contributes to Norway's goals to develop bat monitoring programs for the region, as well as the global effort to create consistent, long term and broad scale monitoring of bat populations that will be necessary to understand and mitigate defaunation.

6 Appendix

6.1 Appendix Figures

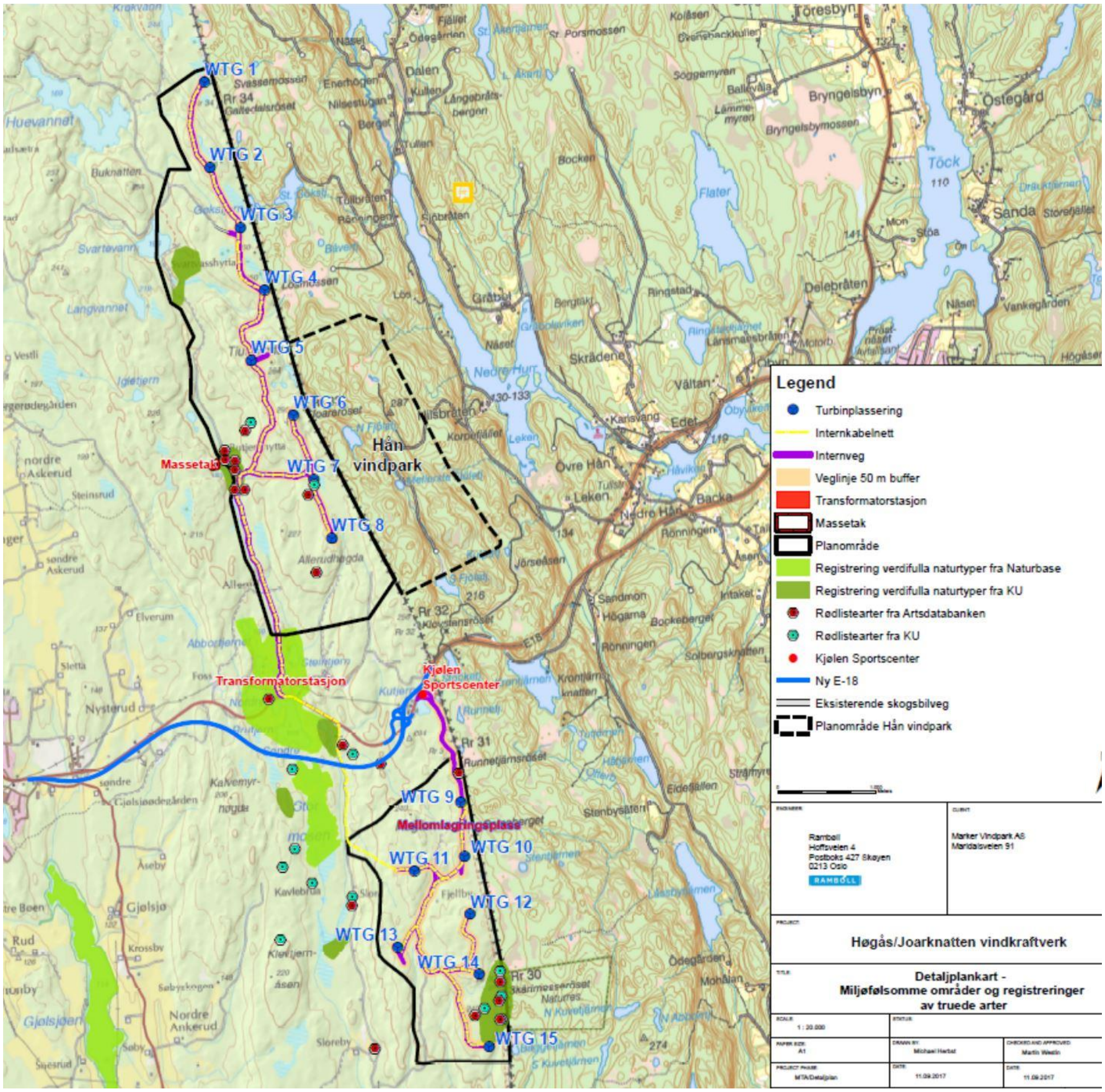


Figure A1. Site map of the Marker Vindpark. Illustrates each of the wind turbine locations and numbering as well as ecologically important areas and sites. Map sourced from Marker Vindpark AS: https://webfileservice.nve.no/API/PublishedFiles/Download/201701449/2184528

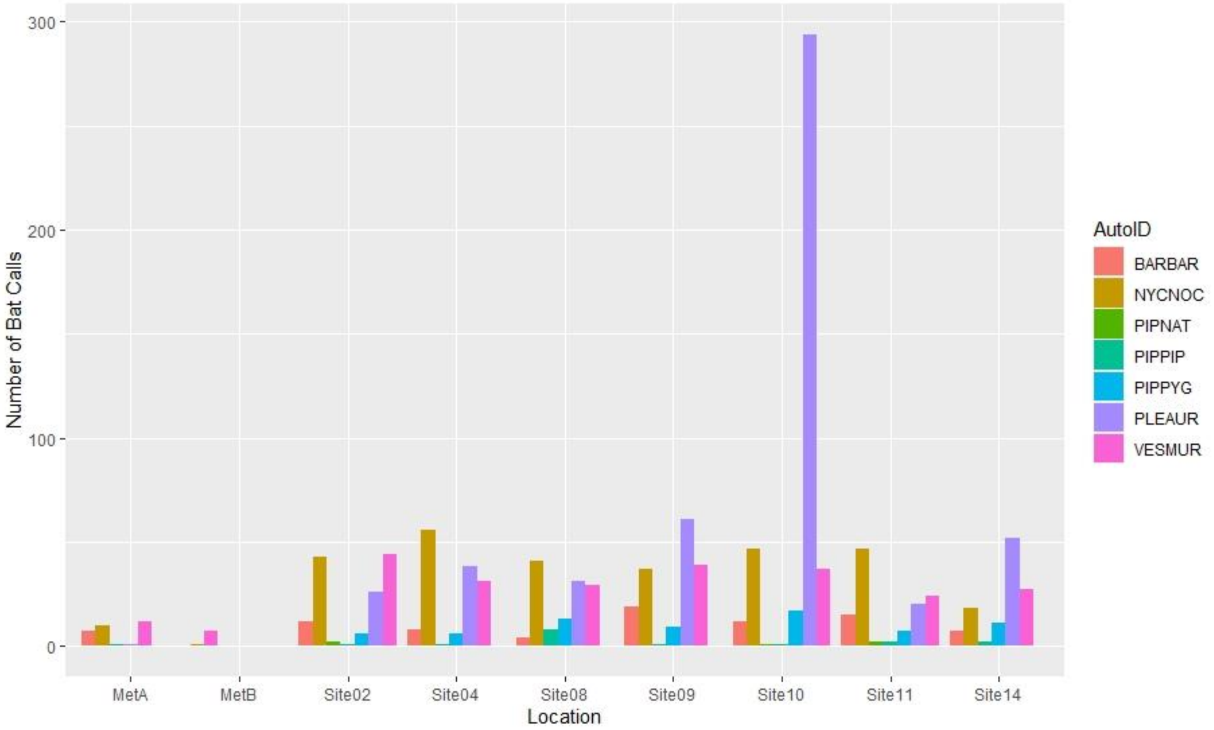


Figure A2. Frequency distribution of bat species present at each site after Myotis spp., *Eptesicus nilssonii* (EPTNIL) and No ID recordings were removed in order to better visualize relative occurrence of the other species. Species ID's automatically identified by the Kaleiodoscope Pro Software (AutoID) indicate the species using the first three letters of the genus and species. See Table 1 for full species names. The y-axis is the number of bat calls (i.e., *.wow-files) recorded per night. The x-axis contains the study sites or the location in which sampling took place. MetA (45 meters) and MetB (95 meters) represent the locations on the meteorological tower monitored at height. The site numbers represent each study site monitored at ground level. Species level determinations made by auto ID are not reliable. Manual identification needed to ensure accuracy.

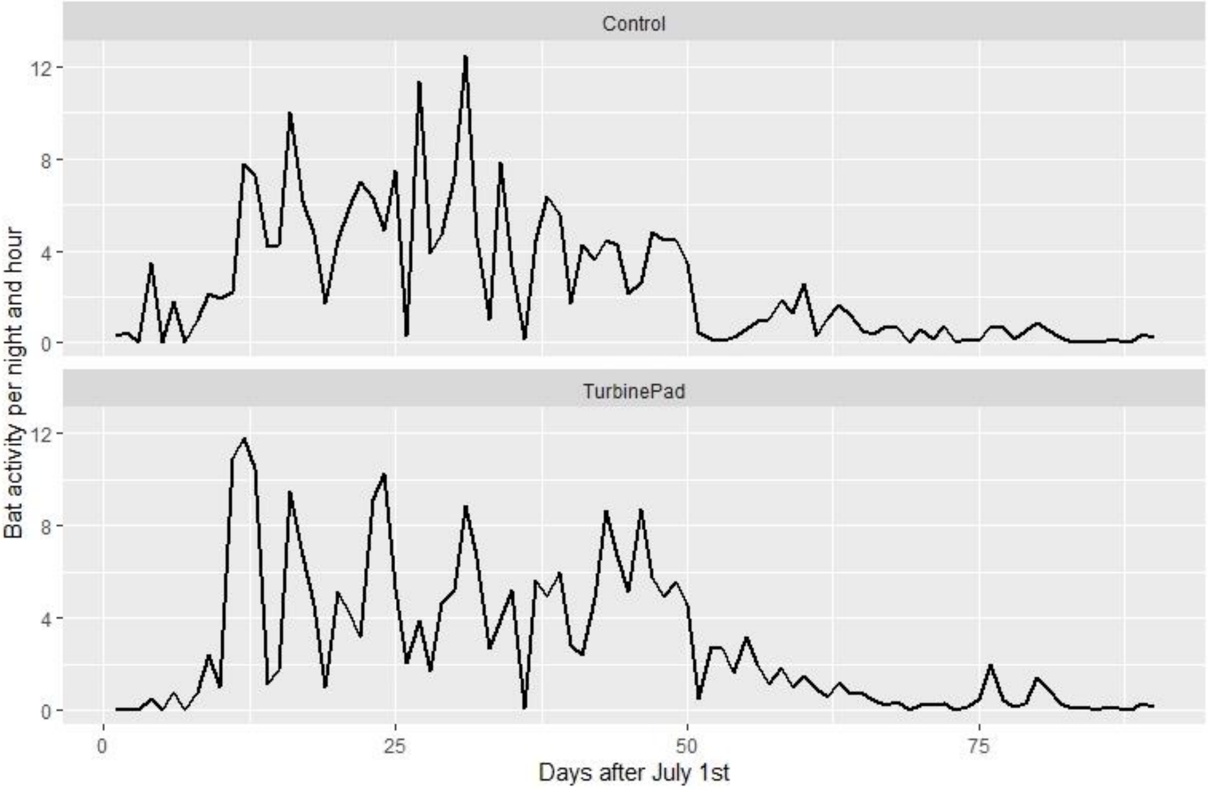


Figure A3. Average bat activity per hour (y-axis-response) across the habitats (turbine & control site-explanatory). The x-axis illustrates the days in the study period beginning July 1st (day 1) and ending September 29th (day 91).

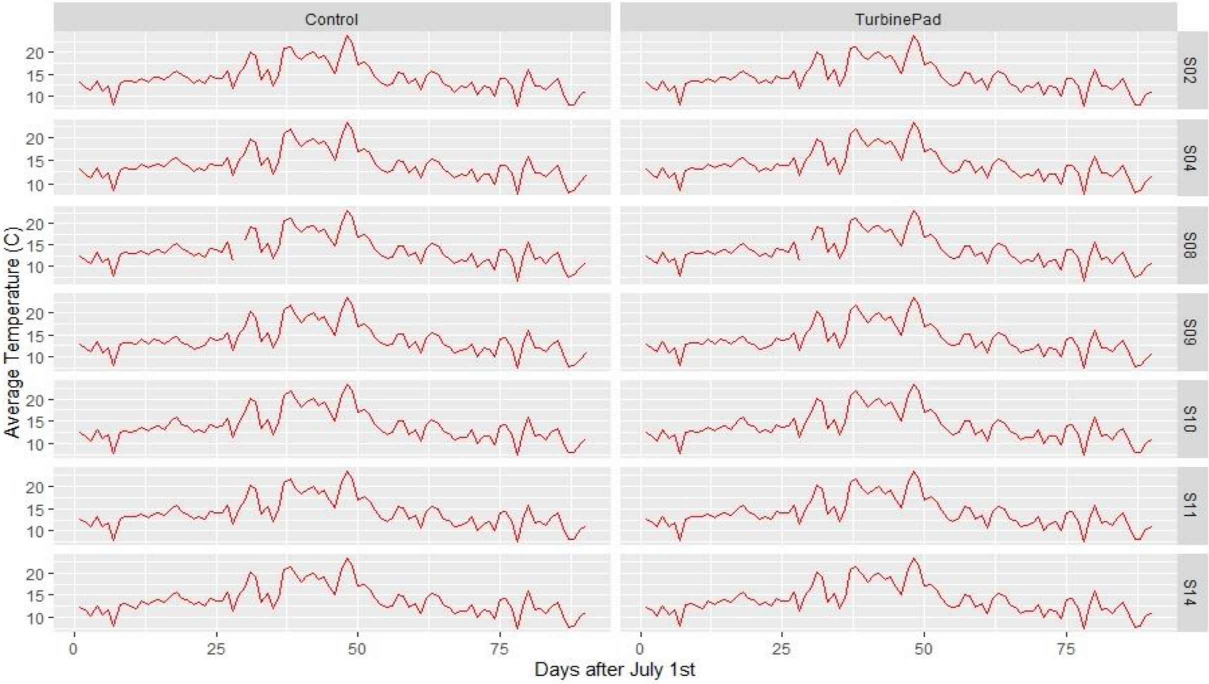


Figure A4. Average temperature in Celsius per night between kl. 22 (10 in the evening) until kl. 04 (4 in the morning) (y-axis) at all sites and habitats (excluding the meteorological tower) during the study period. The x-axis indicates the days of the study period from day 1 (July 1st) until day 91 (September 29th). At turbine 8 there was a break in sampling sometime in late July/early August (for both wind & temp).

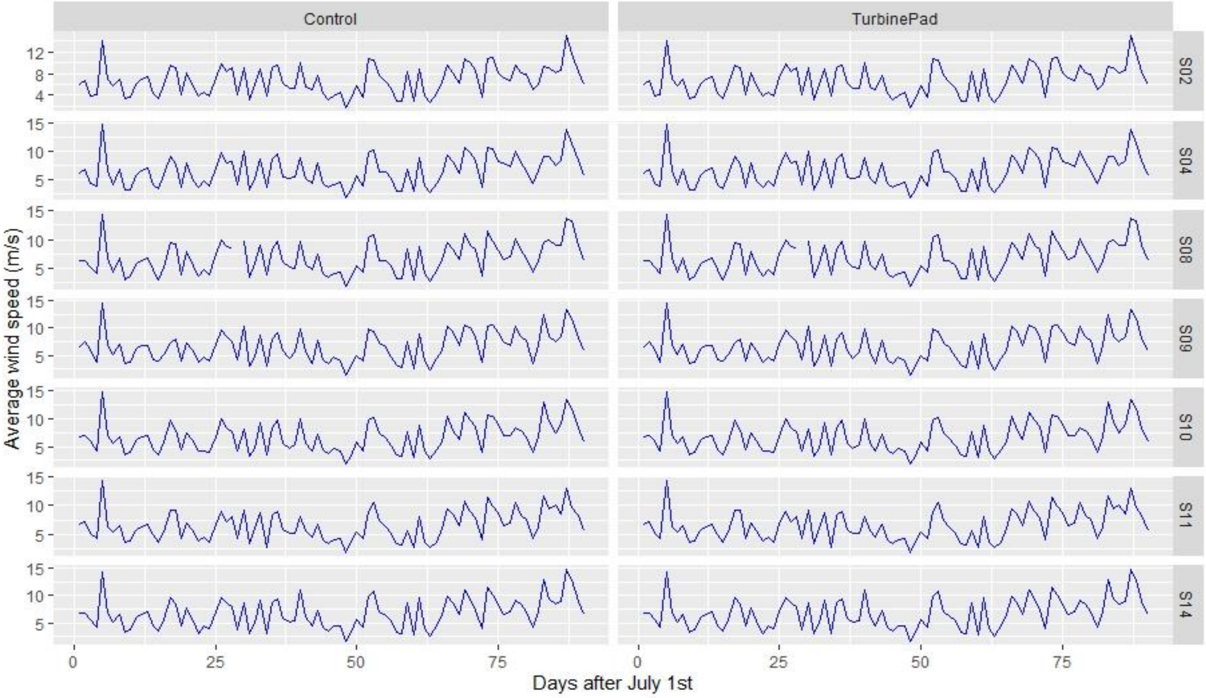


Figure A5. Average wind speed (meters per second (m/s)) per night between kl. 22 (10 in the evening) until kl. 04 (4 in the morning) (y-axis) at all sites and habitats (excluding the meteorological tower) during the study period. The x-axis indicates the days of the study period from day 1 (July 1st) until day 91 (September 29th). At turbine 8 there was a break in sampling (for both wind & temp).

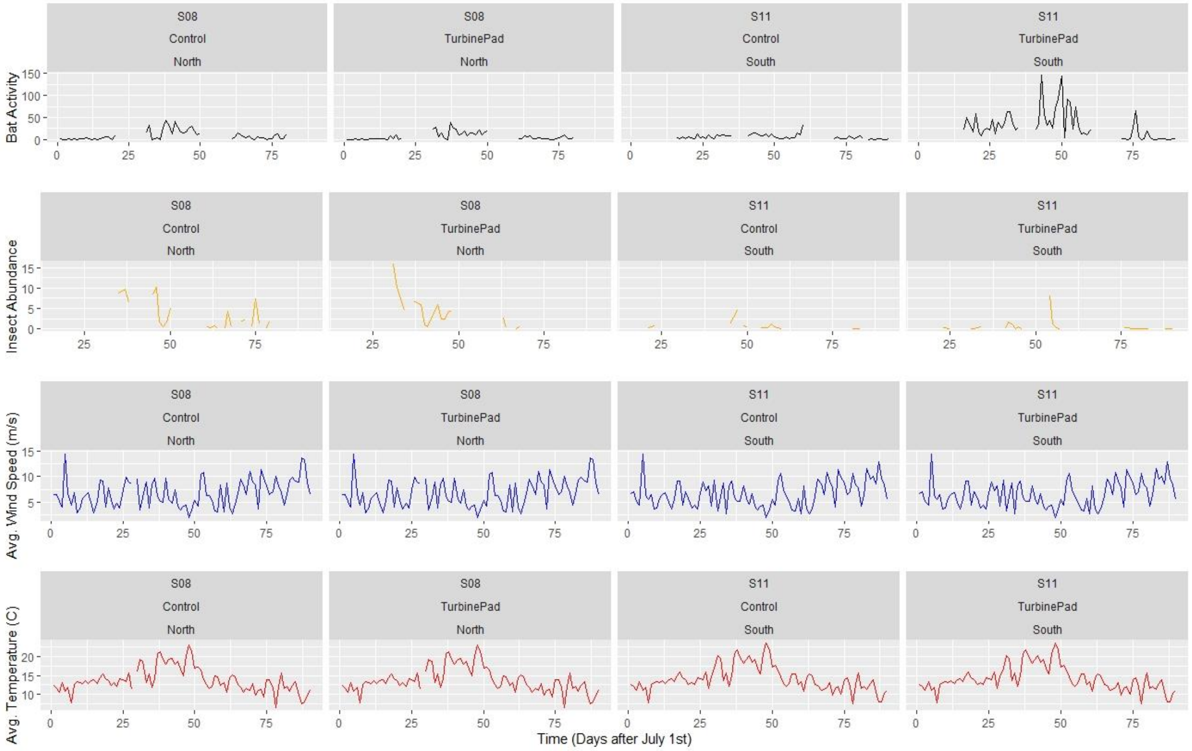


Figure A6. Average bat activity and insect abundance per night (top panel) and day. Average wind speed (meters per second) from kl. 22 (10 in the evening) till kl. 04 (4 in the morning) per night and day (middle panel). Average temperature in Celsius from kl. 22 (10 in the evening) until kl. 04 (4 in the morning) per night and day (bottom panel). X-axis indicates the days in the study period beginning July 1st (day 1) and ending September 29th (day 91). Insect monitoring did not begin until mid-July.

There were 10-day gaps in data collection at all bat and insect sites. This was explained by the study design, as each transect was deployed for twenty days of active monitoring (three times) with ten days between each deployment.

Site eight (north facility) experienced higher insect activity in late July, throughout August and slightly into September. The control site experienced insect activity a bit later in the season than the turbine pad, but activity drops off completely from mid-September until the end of the study season at both sites. Site eleven (south facility) had fewer peaks in insect activity throughout the season but activity appeared to begin earlier in July and continues into late September. The turbine pad at site eleven appeared to have high peaks in bat and insect activity around day 50 (August 19th). Insect activity was minimal (Site eleven) or non-existent (Site eight) from day 75 (September 13th) till the end of the study period which corresponded with lower temperatures and higher wind speeds. Because of a high proportion of missing values – and because there was no strong indication of a difference in average bat activity per night between the habitats – I pooled the turbine and control site data from both site eight and site eleven. For each night (from 1 hr. before sunset to 1 hour after sunrise), I calculated average bat activity; both per night, and per night and hour. For each night, I also calculated both average insect abundance per night, and per night and hour.

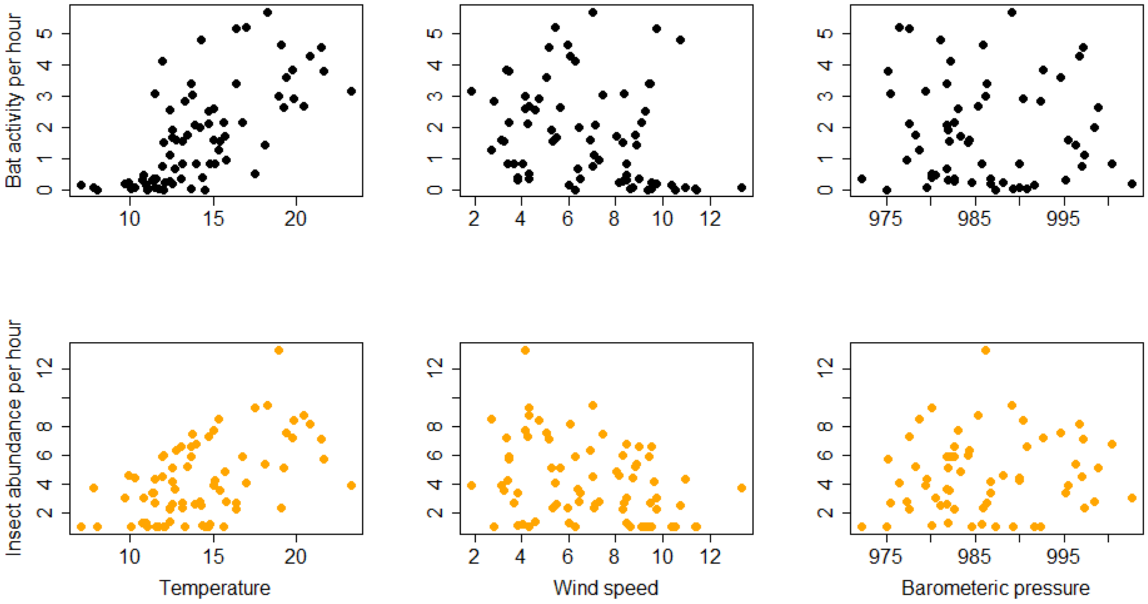


Figure A7. Top: Bat (black) activity per hour and night compared to average temperature (C), wind speed (m/s) and barometric pressure (atm) at sites 8 and 11. Bat activity is the average of the bat calls made per hour and night. Bottom: Insect (orange) abundance per hour and night compared to average temperature (C), wind speed (m/s) and barometric pressure (atm) at sites 8 & 11.

6.2 Appendix Tables

Table A1. Settings & Firmware Wildlife Acoustics Song Meter SM4Bat FS Bioacoustics Recorder

Firmware: 2.3.0	
UTC	+2:00
Gain	12dB
16k high filter	off
Sample rate	256 kHz
Min duration	1.5 ms
Max duration	none
Min trig freq	12 kHz
Trigger level	12 db
Trigger window	3s
Max length	15 s
Compression	none

Table A2. Camera Model and Program Settings

Camera Model: R02050 2019. Ricoh WG-6 (Digital) Waterproof 20m/65.6ft.

Program Settings: SCN (Scenery)-Interval Shooting: Every 10 min. 1000 shots

Shooting:		**Customize:**	**Tools:**	
Dimensions	5184 x 3888	CALS Pixels-L	**Embed Info**	On
Focus	Infinity	CALS Pixels Quality-3 stars	**Volume**	Off
AF	Multi		**Sound**	Off
Auto Macro	Off		**Auto Power**	Off
Focus Assist	Off			
Flash Mode	Flash On			
Face/Blink Detection	Off			
Digital Zoom	Off			
Quality Level	3 stars			
Image Tone	Natural (STD)			

Table A3: Power Inverter Settings

Biltema Art.38-122 DC 5V 500 mA	
Continuous Power	150W
Peak Power	300W
Input Voltage	12VDC
Output Voltage & Frequency	22-240V AC. 50 Hz/60Hz
Output Wave Form	Modified sine wave

Table A4. illustrates the nights and sites SM4 detectors were deployed and monitoring for bat activity from July 1st until September 29th. The table indicates a balanced study design and sampling effort across the wind facility. Green fill color means a detector was active and monitoring; while blank spaces indicate when there was no active detector deployed or a malfunction occurred and recording did not take place. C = control habitat. P = turbine pad. N = North facility. S = South facility. A = Transect A. B = Transect B

		NA	**NB**	**NA**	**SB**	**SA**	**SB**	**SB**			**NA**	**NB**	**NA**	**SB**	**SA**	**SB**	**SB**
Date Evening	**Cumulative Night No.**	**C02**	**C04**	**C08**	**C09**	**C10**	**C11**	**C14**	**MetA**	**MetB**	**P02**	**P04**	**P08**	**P09**	**P10**	**P11**	**P14**
7/01/2020	1	🟩		🟩		🟩					🟩		🟩		🟩		
7/02/2020	2	🟩		🟩		🟩					🟩		🟩		🟩		
7/03/2020	3	🟩		🟩		🟩					🟩		🟩		🟩		
7/04/2020	4	🟩		🟩		🟩					🟩		🟩		🟩		
7/05/2020	5	🟩		🟩		🟩					🟩		🟩		🟩		
7/06/2020	6	🟩		🟩		🟩					🟩		🟩		🟩		
7/07/2020	7	🟩		🟩		🟩					🟩		🟩		🟩		
7/08/2020	8	🟩		🟩		🟩					🟩		🟩		🟩		
7/09/2020	9	🟩		🟩		🟩					🟩		🟩		🟩		
7/10/2020	10	🟩		🟩		🟩					🟩		🟩		🟩		
7/11/2020	11	🟩	🟩	🟩		🟩					🟩	🟩	🟩	🟩	🟩		
7/12/2020	12	🟩	🟩	🟩	🟩	🟩		🟩			🟩	🟩	🟩	🟩	🟩		🟩
7/13/2020	13	🟩	🟩	🟩	🟩	🟩		🟩			🟩	🟩	🟩	🟩	🟩		🟩
7/14/2020	14	🟩	🟩	🟩	🟩	🟩		🟩			🟩	🟩	🟩	🟩	🟩		🟩
7/15/2020	15	🟩	🟩	🟩	🟩	🟩		🟩			🟩	🟩	🟩	🟩	🟩		🟩
7/16/2020	16	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
7/17/2020	17	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
7/18/2020	18	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
7/19/2020	19	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
7/20/2020	20	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
7/21/2020	21		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/22/2020	22		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/23/2020	23		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/24/2020	24		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/25/2020	25		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/26/2020	26		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/27/2020	27		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/28/2020	28		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/29/2020	29		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/30/2020	30		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
7/31/2020	31	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩		🟩	🟩	🟩
8/01/2020	32	🟩		🟩		🟩	🟩		🟩	🟩	🟩		🟩		🟩	🟩	
8/02/2020	33	🟩		🟩		🟩	🟩		🟩	🟩	🟩		🟩		🟩	🟩	
8/03/2020	34	🟩		🟩		🟩	🟩		🟩	🟩	🟩		🟩		🟩	🟩	
8/04/2020	35	🟩		🟩		🟩	🟩		🟩	🟩	🟩		🟩		🟩	🟩	
8/05/2020	36	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
8/06/2020	37	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
8/07/2020	38	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
8/08/2020	39	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
8/09/2020	40	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
8/10/2020	41	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/11/2020	42	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/12/2020	43	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/13/2020	44	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/14/2020	45	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/15/2020	46	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/16/2020	47	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/17/2020	48	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/18/2020	49	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/19/2020	50	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8/20/2020	51		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/21/2020	52		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/22/2020	53		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/23/2020	54		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/24/2020	55		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/25/2020	56		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/26/2020	57		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/27/2020	58		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/28/2020	59		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/29/2020	60		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
8/30/2020	61	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
8/31/2020	62	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		

9/01/2020	63	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/02/2020	64	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/03/2020	65	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/04/2020	66	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/05/2020	67	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/06/2020	68	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/07/2020	69	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/08/2020	70	🟩		🟩		🟩			🟩	🟩	🟩		🟩		🟩		
9/09/2020	71	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/10/2020	72	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/11/2020	73	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/12/2020	74	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/13/2020	75	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/14/2020	76	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/15/2020	77	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/16/2020	78	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/17/2020	79	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/18/2020	80	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9/19/2020	81		🟩					🟩	🟩	🟩		🟩		🟩		🟩	🟩
9/20/2020	82		🟩					🟩	🟩	🟩		🟩		🟩		🟩	🟩
9/21/2020	83		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
9/22/2020	84		🟩		🟩		🟩	🟩	🟩	🟩		🟩		🟩		🟩	🟩
9/23/2020	85		🟩		🟩		🟩	🟩				🟩		🟩		🟩	🟩
9/24/2020	86				🟩		🟩	🟩				🟩		🟩		🟩	🟩
9/25/2020	87		🟩		🟩		🟩	🟩				🟩		🟩		🟩	🟩
9/26/2020	88		🟩		🟩		🟩	🟩				🟩		🟩		🟩	🟩
9/27/2020	89		🟩		🟩		🟩	🟩				🟩		🟩		🟩	🟩
9/28/2020	90		🟩		🟩		🟩	🟩				🟩		🟩		🟩	🟩

Table A5. Comparison of GAM models explaining the relationship between bat activity per hour and habitat (turbine pad or control) and weather conditions (temperature and wind speed) over time (July 1st to September 29th). Weather conditions were average values per night between 10 PM and 4 AM. For each response – in step 1 – a model with Time and Habitat as explanatory variables, fitting a separate smoother for each Habitat, was compared to another model with Time and Habitat as explanatory variables, but with one common smoother for both habitats. In step 2, the best model from step 1 was compared to other models with all possible combinations of Time, Habitat, Temperature and/or Wind speed as explanatory variables. For each step, the model with the smallest AIC value – as well as models with an AIC-value within Δ2 – are shown in bold. Models with an AIC value that differ with less than a value of 2 are considered equally good.

Model No.	**Model variables**	**AIC**	**DF**	**Deviance explained (%)**
	Step 1			
M2a	s(Time, by=Habitat) + Habitat	789.30	15.10	54.5
M2b	s(Time) + Habitat	**785.42**	9.58	52.6
	Step 2			
M2f	**s(Time) + s(Temp)**	**768.95**	9.21	56.6
M2c	s(Time) + Habitat + s(Temp)	**770.42**	10.27	56.7
M2d	s(Time) + s(Wind) + s(Temp)	**770.54**	11.87	57.5
M2e	s(Time) + Habitat + s(Wind) + s(Temp)	771.88	12.86	57.6
M2b	s(Time) + Habitat	785.42	9.58	52.6
M2g	s(Time) + s(Wind)	778.41	10.73	55
M2h	s(Time) + Habitat + s(Wind)	779.79	11.72	55.2

Table A6: Kaleidoscope Pro Software Settings used for analysis of bat acoustic calls.

Bats of Europe 5.2.1-Bat Analysis Mode	
Include Auto ID for Bats	Check only bat species found in Norway (See Methods)
Signal Detection Parameters	• 8-140(khz) minimum and maximum frequency Range • 2-500(ms) Minimum and Maximum Length of Detected Pulses • 500(ms) Maximum inter-syllable gap • 2 Minimum number of pulses • **Check box:** When zero crossing for conversion or analysis, enhance with advanced signal processing
Batch	**Check the following boxes** **Input Directory** • "Include subdirectories" • "WAC files" • "WAV (and W4V) files" **Output Directory** • WAV (or W4V) files

7 References

Websites:

Artsdatabanken, 2021. [Online]. Knowledge Bank for Biodiversity. Available at: https://www.artsdatabanken.no/ (Accessed: 03/05/2020)

Bat Conservation Trust, (2021). [Online]. Types of Bats. Available at: https://www.bats.org.uk/about-bats/what-are-bats. (Accessed: 25.04.2021).

HOBOware Onsect Computer Corporation, 2021. [Online]. HOBO Microstation (H21-USB 2087). Available at: http://www.onsetcomp.com/manuals/h21-usb/ (Accessed: 03/05/2020).

IUCN (2020) *IUCN Red List of Threatened Species* [Online]. Available at: https://www.iucnredlist.org/ (Accessed: 26/03/20)

Nite Ize, Inc; 2020. GEAR TIE® MEGA™ TWIST TIE. [Online]. Available at: https://www.niteize.com/product/Gear-Tie-Mega.asp (Accessed: 03/05/2020).

NVE.no -Konsesjonssak- Høgås and Joarknatten (Marker) wind turbines. [Online] Available at https://www.nve.no/konsesjonssaker/konsesjonssak?id=225&type=A-1,A-6 & https://www.nve.no/ (Accessed: 03/05/2020).

NVE.no (2021). New Power Production. [Online]. Available at: https://www.nve.no/energiforsyning/kraftmarkedsdata-og-analyser/ny-kraftproduksjon/) (Accessed: 30.05.2021).

Peikko Group, 2020. Marker wind park, Ørje, Norway. [Online]. Available at: https://www.peikko.no/reference/marker-wind-park/ (Accessed: 03/05/2020).

Wildlife Acoustics, Inc; 2020: Song Meter SM4BAT FS ULTRASONIC RECORDER. [Online]. Available at: https://www.wildlifeacoustics.com/products/song-meter-sm4bat (Accessed: 03/05/2020)

Journals, Reports and Books:

Ahlen, I., Baagoe, H.J., Bach, L. (2009). Behavior of Scandinavian bats during migration and foraging at sea. *Journal of Mammalogy*, 90, 1318-1323.

Apoznański, G., Sánchez-navarro, S., Kokurewicz, T., Pettersson, S. & Rydell, J. (2018). Barbastelle bats in a wind farm: are they at risk? *European Journal of Wildlife Research,* 64**,** 43.

Apoznański, G., Kokurewicz, T., Błesznowska, J., Kwasiborska, E., Marszałek, T. & Górska, M. (2020). Use of coniferous plantations by bats in western Poland during summer. *Baltic Forestry,* 26.

Arnett, E. B., Brown, W. K., Erickson, W. P., Fiedler, J. K., Hamilton, B., Henry, T. H., Jain, A., Johnson, G. D., Kerns, J., Koford, R. R., Nicholson, C. P., O'Connell, T. J., Piorkowski, M. D. & Tankersley JR, R. D. (2008). Patterns of Bat Fatalities at Wind Energy Facilities in North America. *The Journal of Wildlife Management,* 72**,** 61-78.

Arnett, E. B., Baerwald, E. F., Mathews, F., Rodrigues, L., Rodríguez-Durán, A., Rydell, J., Villegas-Patraca, R. & Voigt, C. C. (2016). Impacts of Wind Energy Development on Bats: A Global Perspective. Bats in the Anthropocene: Conservation of Bats in a Changing World.

Baerwald, E. F. & Barclay, R. M. R. (2009). Geographic Variation in Activity and Fatality of Migratory Bats at Wind Energy Facilities. *Journal of Mammalogy,* 90**,** 1341-1349.

Battersby, J. (2010). EUROBATS No.5. Guidelines for Surveillance and Monitoring of European Bats.

Blomberg, A. S., Vasko, V., Meierhofer, M. B., Johnson, J. S., Eeva, T. & Lilley, T. M. (2021). Winter activity of boreal bats. *Mammalian Biology*.

Brabant, R., Laurent, Y., Dolap, U., Degraer, S. & Poerink, B. J. (2018). Comparing the results of four widely used automated bat identification software programs to identify nine bat species in coastal Western Europe. *Belgian Journal of Zoology,* 148.

Browning, E., Gibb, R., Glover-Kapfer, P. & Jones, K. (2017). Passive acoustic monitoring in ecology and conservation. *WWF Conservation Technology Series* 1(2). WWF-UK, Woking, United Kingdom.

Burgin, C. J., Colella, J. P., Kahn, P. L. & Upham, N. S. (2018). How many species of mammals are there? *Journal of Mammalogy,* 99**,** 1-14.

Buchholz, S., Kelm, V. & Ghanem, S. J. (2020). Mono-specific forest plantations are valuable bat habitats: implications for wind energy development. *European Journal of Wildlife Research,* 67**,** 1.

Chen, H. Y. H. & Luo, Y. (2015). Net aboveground biomass declines of four major forest types with forest ageing and climate change in western Canada's boreal forests. *Global Change Biology*, 21, 3675-3684.

Collins, J. A. J., G. (2009). Differences in Bat Activity in Relation to Bat Detector Height: Implications for Bat Surveys at Proposed Windfarm Sites. *Acta Chiropterologica,* 11**,** 343-350.

Collins, J. (ed.) (2016). Bat Surveys for Professional Ecologists: Good Practice Guidelines (3rd edn). *The Bat Conservation Trust*, London. ISBN-13 978-1-872745-96-1. p.20.

Corten, G. P. & Veldkamp, H. F. (2001). Insects can halve wind-turbine power. *Nature,* 412**,** 41-42.

Cryan, P. M., Gorresen, P. M., Hein, C. D., Schirmacher, M. R., Diehl, R. H., Huso, M. M., Hayman, D. T. S., Fricker, P. D., Bonaccorso, F. J., Johnson, D. H., Heist, K. & Dalton, D. C. (2014). Behavior of bats at wind turbines. *Proceedings of the National Academy of Sciences*, 111, 15126.

De Jong, J. and Ahlen., I. (1991). Factors Affecting the Distribution Pattern of Bats in Uppland, Central Sweden. *Holarctic Ecology*, 14, 92-96.

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, 164-164.

Dietz, C. & Kiefer, A. (2016). *Bats of Britain and Europe.* London, UK. Bloomsbury Wildlife Publishing

Dutta, Abhishek and Zisserman, Andrew. (2019). *The VIA Annotation Software for Images, Audio and Video.* [Online]. In Proceedings of the 27th ACM International Conference on Multumedia (MM'19), October 21-25. Nice France, ACM, New York, NY, USA, 4 pgs. https://doi.org/10.1145/3343031.3350535.

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, 17-24.

Fensome, A. G. & Mathews, F. (2016). Roads and bats: a meta-analysis and review of the evidence on vehicle collisions and barrier effects. *Mamm Rev,* 46**,** 311-323.

Foo, C. F., Bennett, V. J., Hale, A. M., Korstian, J. M., Schildt, A. J. & Williams, D. A. (2017). Increasing evidence that bats actively forage at wind turbines. *PeerJ,* 5**,** e3985-e3985.

Frey-Ehrenbold, A., Bontadina, F., Arlettaz, R., Obrist, M. K. & Pocock, M. (2013). Landscape connectivity, habitat structure and activity of bat guilds in farmland-dominated matrices. *Journal of Applied Ecology*, 50, 252-261.

Froidevaux, J., Zellweger, F., Bollmann, K. & Obrist, M. 2014. Optimizing passive acoustic sampling of bats in forests. *Ecology and Evolution*, 4.

Gaultier, S. P., Blomberg, A. S., Ijäs, A., Vasko, V., Vesterinen, E. J., Brommer, J. E. & Lilley, T. M. (2020). Bats and Wind Farms: The Role and Importance of the Baltic Sea Countries in the European Context of Power Transition and Biodiversity Conservation. *Environmental Science & Technology*, 54, 10385-10398.

Ghanem, S. J. & Voigt, C. C. (2012). Chapter 7 - Increasing Awareness of Ecosystem Services Provided by Bats. In: Brockmann, H. J., Roper, T. J., Naguib, M., Mitani, J. C. & Simmons, L. W. (eds.) *Advances in the Study of Behavior.* Academic Press.

Griffin, D. R. & Galambos, R. (1941). The sensory basis of obstacle avoidance by flying bats. *Journal of Experimental Zoology,* 86**,** 481-506.

Hałat, Z., Dechmann, D. K. N., Zegarek, M., Visser, A. E. J. & Ruczyński, I. (2018). Sociality and insect abundance affect duration of nocturnal activity of male parti-colored bats. *Journal of Mammalogy*, 99, 1503-1509.

Hayes, J. P. (1997). Temporal Variation in Activity of Bats and the Design of Echolocation-Monitoring Studies. *Journal of Mammalogy*, 78, 514-524.

Henrikson and Hilmo. (2015). Norsk Rødliste for arter 2015. Norge: Artsdatabanken.

Humphrey, J., Ferris, F., and Quine, C.P. (2003). Biodiversity in Britain's Planted Forests: Results from the Forestry Commission's Biodiversity Assessment Project. *Forestry Commission*: Edinburgh.

Hutson, A.M. Mickleburgh, S.P., Racey, P.A. (2001). Microchiropteran Bats: Global Status Survey and Conservation Action Plan. IUCN/SSC Chiroptera Specialist Group. *International Union for the Conservation of Nature and Natural Resources.* Gland, Switzerland & Cambridge, UK.

Jakobsen, L., Hallam, J., Moss, C. F. & Hedenström, A. (2018). Directionality of nose-emitted echolocation calls from bats without a nose leaf (*Plecotus auritus*). *The Journal of Experimental Biology,* 221, jeb171926.

Jennings, N., Parsons, S. & Pocock, M. (2008). Human vs. machine: Identification of bat species from their echolocation calls by humans and by artificial neural networks. *Canadian Journal of Zoology,* 86**,** 371-377.

Jones, G., Jacobs, D., Kunz, T. H. & Racey, P. (2009). Carpe noctem: The importance of bats as bioindicators. *Endangered Species Research*, 8, 93-115.

Jones, G. & Teeling, E. C. (2006). The evolution of echolocation in bats. *Trends Ecol Evol*, 21, 149-56.

Jung, K. & Threlfall, C. G. (2016). Urbanisation and Its Effects on Bats—A Global Meta-Analysis. *In:* Voigt, C. C. & Kingston, T. (eds.) *Bats in the Anthropocene: Conservation of Bats in a Changing World.* Cham: Springer International Publishing.

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

Kirkpatrick, L., Maher, S. J., Lopez, Z., Lintott, P. R., Bailey, S. A., Dent, D. & Park, K. J. (**2017B**). Bat use of commercial coniferous plantations at multiple spatial scales: Management and conservation implications. *Biological Conservation,* 206**,** 1-10.

Kirkpatrick, L., Graham, J., Mcgregor, S., Munro, L., Scoarize, M. & Park, K. (2018). Flexible foraging strategies in *Pipistrellus pygmaeus* in response to abundant but ephemeral prey. *PLOS ONE,* 13**,** e0204511.

Knörnschild, M., Jung, K., Nagy, M., Metz, M. & Kalko, E. (2012). Bat echolocation calls facilitate social communication. Proceedings of the Royal Society B: Biological Sciences, 279, 4827-4835.

Kunz, T. H., Arnett, E. B., Erickson, W. P., Hoar, A. R., Johnson, G. D., Larkin, R. P., Strickland, M. D., Thresher, R. W. & Tuttle, M. D. (2007). Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. *Frontiers in Ecology and the Environment*, 5, 315-324.

Kunz, T. H. & Parsons, S. (2009). *Ecological and Behavioral Methods for the Study of Bats*, Johns Hopkins University Press.

Long, C. V., Flint, J. A. & Lepper, P. A. (2010). Insect attraction to wind turbines: does colour play a role? *European Journal of Wildlife Research*, 57, 323-331.

Macgregor, K. A. & Lemaître, J. (2020). The management utility of large-scale environmental drivers of bat mortality at wind energy facilities: The effects of facility size, elevation and geographic location. *Global Ecology and Conservation*, 21.

Maine, J. J. and Boyles, J. G. (2015). Bats initiate vital agroecological interactions in corn. *Proceedings of the National Academy of Sciences,* 112**,** 12438.

Mathews, F; Richardson, S.; Lintott, P.; Hosken, D. (2016). Understanding the Risk of European Protected Species (Bats) at Onshore Wind Turbine Sites to Inform Risk Management. Report by *University of Exeter*. Report for RenewableUK. Report for UK Department of Energy and Climate Change (DECC).

Mccravy, K. W. (2018). A Review of Sampling and Monitoring Methods for Beneficial Arthropods in Agroecosystems. *Insects*, 9.

McGavin, G. C. (1997). Expedition Field Techniques INSECTS and other terrestrial arthropods, London, Geography Outdoors-*Royal Geographical Society*.

McGeoch, M. A. (2007). Insects and bioindication: theory and progress. Wallingford: CAB International.

Medinas, D., Ribeiro, V., Marques, J., Silva, B., Barbosa, A. M., Rebelo, H. & Mira, A. (2019). Road effects on bat activity depend on surrounding habitat type. *Science of The Total Environment*.

Meyer, C. (2015). Methodological challenges in monitoring bat population- and assemblage-level changes for anthropogenic impact assessment. *Mammalian Biology - Zeitschrift fur Saugetierkunde,* 80**,** 159-169.

Millon, L., Colin, C., Brescia, F. & Kerbiriou, C. (2018). Wind turbines impact bat activity, leading to high losses of habitat use in a biodiversity hotspot. *Ecological Engineering,* 112**,** 51-54.

Montauban, C., Mas, M., Tuneu-Corral, C., Wangensteen, O., Budinski, I., Martí-Carreras, J., Flaquer, C., Puig-Montserrat, X. & Lopez-Baucells, A. (2021). Bat echolocation plasticity in allopatry: a call for caution in acoustic identification of *Pipistrellus* spp. *Behavioral Ecology and Sociobiology,* 75.

Norwegian Environmental Agency. (2014). National Implementation Report Conservation of Populations of European Bats in Norway (Inf.MoP7_.33).

Park, K. J. (2015). Mitigating the impacts of agriculture on biodiversity: bats and their potential role as bioindicators. *Mammalian Biology,* 80**,** 191-204.

Parikh, G., Rawtani, D. & Khatri, N. (2020). "Insects as an Indicator for Environmental Pollution". *Environmental Claims Journal*, 33, 161-181.

Pureswaran, D. S., De Grandpré, L., Paré, D., Taylor, A., Barrette, M., Morin, H., Régnière, J. & Kneeshaw, D. D. (2015). Climate-induced changes in host tree–insect phenology may drive ecological state-shift in boreal forests. *Ecology,* 96**,** 1480-1491.

Regniere, J., Powell, J., Bentz, B. & Nealis, V. (2012). Effects of temperature on development, survival and reproduction of insects: experimental design, data analysis and modeling. *J Insect Physiol*, 58, 634-47.

Rodrigues, E. A. (2014). Eurobats No. 6 Guidelines for consideration of bats in wind farm projects. Revision 2014.

Ruczyński, I., Hałat, Z., Zegarek, M., Borowik, T., Dechmann, D. K. N. & O'hara, R. B. (2019). Camera transects as a method to monitor high temporal and spatial ephemerality of flying nocturnal insects. *Methods in Ecology and Evolution*, 11, 294-302.

Rughetti, M. & Toffoli, R. (2019). *Reliability of automated identification of bat echolocation calls*.

Russell, A., Butchkoski, C. M., Saidak, L. & Mccracken, G. F. (2009). Road-killed bats, highway design, and the commuting ecology of bats. *Endangered Species Research,* 8**,** 49-60.

Russo, D. & Voigt, C. (2016). The use of automated identification of bat echolocation calls in acoustic monitoring: A cautionary note for a sound analysis. *Ecological Indicators*, 66, 598-602.

Rydell. Jens, Lothar, B., Marie-Jo, D.-S., Martin, G., Luisa, R. & Anders, H. (**2010A)**. Bat Mortality at Wind Turbines in Northwestern Europe. *Acta Chiropterologica*, 12, 261-274.

Rydell, J., Bach, L., Dubourg-Savage, M.-J., Green, M., Rodrigues, L. & Hedenström, A. (**2010B)**. Mortality of bats at wind turbines links to nocturnal insect migration? *European Journal of Wildlife Research,* 56, 823-827.

Rydell, J., Lothar, B., Petra, B., Laura Guia, D., Joanna, F., Nina, H.-W, Eeva-Maria, K., Thomas, I., Matti, M., Marian Max, M., Gunrs, P., Juris, Š., Ville, V., Viesturs, V. & Anders, H. (2014). Phenology of Migratory Bat Activity Across the Baltic Sea and the South-Eastern North Sea. *Acta Chiropterologica,* 16**,** 139-147.

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

Rydell, J., Elfstrom, M., Eklof, J. & Sanchez-Navarro, S. (2020). Dramatic decline of northern bat *Eptesicus nilssonii* in Sweden over 30 years. *R Soc Open Sci*, 7, 191754.

Schnitzler H.U. and Kalko, E. K. V. (2001). Echolocation by insect-eating bats. *BioScience*, 51, 557-569.

Scudder, G. G. E. 2017. The Importance of Insects. *Insect Biodiversity.*

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**,** 503-508.

Straka, T., Wolf, M., Gras, P., Buchholz, S. & Voigt, C. (2019). Tree Cover Mediates the Effect of Artificial Light on Urban Bats. *Frontiers in Ecology and Evolution,* 7.

Šuba, J., Pētersons, G. & Rydell, J. (2012). Fly-and-Forage Strategy in the Bat *Pipistrellus nathusii* During Autumn Migration. *Acta Chiropterologica,* 14**,** 379-385.

Sundseth, K. (2009). Natura 2000 in the Boreal Region. *In:* Wegefelt, S. (ed.). Beligum: European Commission: Environment Directorate General.

Vaughan, N., Gareth, J.; and Harris, S. (1997). Habitat Use by Bats (Chiroptera) Assessed by Means of a Broad-Band Acoustic Method. *Journal of Applied Ecology: British Ecological Society,* 34**,** 716-730.

Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O.-P., Viiri, H., Ikonen, V.-P. & Peltola, H. (2020). Climate change induces multiple risks to boreal forests and forestry in Finland: A literature review. *Global Change Biology,* 26**,** 4178-4196.

Vilas, R. A. (2016). Ecological and Economical Impact of Bats on Ecosystem. *Int. J. of Life Sciences,* 4**,** 432-440.

Voigt, C. C., Lehnert, L. S., Petersons, G., Adorf, F. & Bach, L. (2015). Wildlife and Renewable Energy: German Politics Cross Migratory Bats. *European Journal of Wildlife Research,* 61**,** 213-219.

Voigt, C. C. & Kingston., T. (2016). *Bats in the Anthropocene: Conservation of Bats in a Changing World.*, SpringerOpen.

Voigt, C. (**2021A**). Insect fatalities at wind turbines as biodiversity sinks. *Conservation Science and Practice*.

Voigt, C. C., Russo, D., Runkel, V. & Goerlitz, H. R. (**2021B**). Limitations of acoustic monitoring at wind turbines to evaluate fatality risk of bats. *Mammal Review,* n/a.

Wagner, D. L. (2020). Insect Declines in the Anthropocene. *Annual Review of Entomology*, 65, 457-480.

Waters, D.A. and Jones, G. (1995). Echolocation call structure and intensity in five species of insectivorous bats. *The Journal of Experimental Biology*, 198, 475.

Weir, D. E. 2018. IEA Wind TCP Task 26–Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, Sweden, the European Union, and the United States: 2008–2016. NREL/TP-6A20-71844. National Renewable Energy Laboratory, Golden, CO (US). pp. 43–52. https://www.nrel.gov/docs/fy19osti/71844.pdf

Wolbert, S. J., Zellner, A. S., and Whidden, H. W. (2014). Bat Activity, Insect Biomass, and Temperature Along an Elevational Gradient. *Northeastern Naturalist*, 21, 72-85.

Yang, L. H. & Gratton, C. (2014). Insects as drivers of ecosystem processes. *Curr Opin Insect Sci*, 2, 26-32.

Zamora-Gutierrez, V., Macswiney G, M. C., Martínez Balvanera, S and Robredo Esquivelzeta, E. (2021). The Evolution of Acoustic Methods for the Study of Bats. *In:* Lim, B. K., Fenton, M. B., Brigham, R. M., Mistry, S., Kurta, A., Gillam, E. H., Russell, A. and Ortega, J. (eds.) *50 Years of Bat Research: Foundations and New Frontiers.* Cham: Springer International Publishing.

Zuur, A.F. 2012. A beginner's guide to generalized additive models with R. Highland Statistics, Ltd., Newburgh, UK.

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

Postboks 5003
NO-1432 Ås
Norway