Reducing Bat Fatalities Using Ultrasonic Acoustic Deterrent Technology: A Potential Mechanism for Conservation at Offshore Wind Energy Sites

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Reducing Bat Fatalities Using Ultrasonic Acoustic Deterrent Technology: A Potential Mechanism for Conservation at Offshore Wind Energy Sites

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Abstract

In 2018, wind energy grew 12% globally in response to offset greenhouse gas emissions (IEA, 2019). While land-based wind projects (LBW) still dominate the supply chain, offshore-based wind projects (OBW) are becoming more prevalent. With this increase in wind energy deployment, the probability of increased wildlife conflict also increases, particularly with bats.

Twenty-three of the 47 US bat species have been found as representative fatalities at LBW (AWWI, 2018). Insectivorous bats are echolocating mammals that use ultrasonic frequencies to hunt and avoid obstacles in air space. Technology such as ultrasonic acoustic deterrent (UAD) devices that emit high frequency sound, have been used on LBW projects with mixed but generally positive results. UADs placed on wind turbines that cause echolocation disorientation within ensonified areas can help divert bats from wind energy turbine air space and help to reduce bat related collision fatalities.

A primary objective of this project was to identify steps to reduce bat fatalities at OBW using information gathered from LBW that have employed UADs. A secondary objective was to determine abiotic factors that had effects on bat activity around wind turbines. A third objective was to use two echolocating mammals as proxy parameter comparisons to see if UADs would deter both groups of species from ensonfied areas similarly: bats and toothed whales (odontocetes). My assumptions were that UADs were effective at deterring bats from the ensonified areas of wind turbines and that high wind velocities, low barometric pressure and decreasing temperatures during seasonal migrations altered bat activity around wind turbines. Any successes from odontocete stranding event mitigation using aquatic UADs can be used as support for another echolocating mammal reacting to UAD use for deterrence from ensonified areas.

I analyzed data based on field tested bat studies using UADs at several North American LBW. Using generalized mixed modeling (GLMM), I identified abiotic variables that influence how and when bats interact with LBW. I compared these factors to wind energy sites that deployed UADs on some turbines and others were used as controls. As a smaller, secondary comparison, I evaluated odontocete stranding event data that deployed UADs to test if there was a feasible comparison proxy between two types of potential fatality events involving echolocating mammal species.

For the first model, the GLMM results showed that presence of operational UADs on LBW treatment wind turbines was statistically significant ($p < 0.001$) at reducing bat fatality events when compared to control wind turbines. For the second model, there was no statistically significant effects from any of the three abiotic variables on bat fatality reductions at treated LBW turbines. However, in model 3, average nightly wind speed was statistically significant at control LBW turbines. Due to insufficient data on odontocete stranding events and UAD deployment, this proxy was only used as anecdotal information. The results indicate that UADs are effective deterrents for reducing bat fatality events at LBW. Results also showed that wind speed was significant at wind turbines without deterrent technology. Nightly wind speed can act as an abiotic predictor variable on how bat activity reacts at LBW turbines. When looking to guide mitigative language for OBW, deploying UADs and monitoring for bat activity based on nightly wind fluctuations can influence bat fatality events.

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Chapter I

Introduction

To mitigate the negative effects of greenhouse gas emissions and climate change, developing smart renewable energy projects will continue to be a global priority. Wind energy is an established technology and one of the fastest growing industries in the world. Between 2010 and 2018, wind energy grew 30% globally (IEA, 2020). As with any fast-growing industry, ensuring protective policy language to support natural resources is pertinent. While land-based wind (LBW) projects have been working on environmental resource policy language for decades, offshore-based wind energy (OBW) projects are still relatively new in the United States. As with any new energy projects, effects on environmental resources and wildlife are unknown. Robust research based on cumulative and ecocentric effects on environmental resources should drive pre- and post-construction wind energy project permitting requirements.

Bats make up 1/5 of the total mammal species globally, represented by approximately 1,300 species (BCI, 2018). It is estimated that between 2001 and 2011, between 650,000 and 1.3 million total bats were killed due to wind turbine collisions in the US (Arnett & Baerwald, 2013). This is a substantial toll on multiple bat species, especially highly migratory species which make up nearly 75% of reported fatalities in the U.S. The introduction of ultrasonic acoustic deterrent (UAD) technology, devices that emit sound above human hearing frequencies, on and around wind turbines have shown some positive outcomes in preventing bat-blade collision fatalities (Arnett, Hein, Schirmacher, Huso, & Szewczak, 2013a), but additional research is needed to improve their performance.

In the offshore environment, marine mammal research regarding offshore structures has been, and continues to be, well studied with the support of federal agencies such as the National Oceanic and Atmospheric Administration (NOAA) and the Bureau of Ocean Energy Management (BOEM). Rescue groups and biologists have used UAD technology prior to and during stranding events to help deter animals from stranding in mud flats, sand banks and beaches. Since bats and odontocetes both use a type of biosonar called echolocation, and echolocate in the same frequency range, these two groups of species can be compared to determine if UADs can be used as mitigative devices.

As the renewable energy sector evolves, especially in the offshore environment, there will be increased interaction between species that rely on large open spaces for migration and foraging, and renewable energy installations. For OBW projects, this is particularly difficult to validate as bat activity in the offshore environment is poorly studied which leaves data gaps, as determined by preliminary literature searches. The gaps in research knowledge regarding bat activity in the coastal and offshore zones need to be addressed to alleviate potential detrimental effects to bat species with proposed OBW projects. Established bat activity and fatality patterns from LBW need to be extrapolated and fitted to OBW projects to assess bat-wind turbine interactions. Determining if UAD technology on wind energy turbines deters bats from turbine related collision events should be prioritized to fill knowledge data gaps for bat conservation.

Research Significance and Objectives

My research focused on determining how to use results from LBW UAD pilot studies to mitigate bat fatalities at OBW projects. I analyzed bat fatalities at established LBW energy sites with turbines that were used as control (without UADs) and treatment (with UADs). I also modelled abiotic variables to determine if they could affect bat activity around wind energy turbines. Outcomes from comparing control to treatment turbines can advise how UAD technology could be proactively installed at wind energy facilities to optimally reduce bat fatalities. Additionally, I analyzed odontocete stranding deterrence data as a possible proxy parameter for supplemental UAD support. Results from this research can help managers, stakeholders and industry leaders proactively enact wildlife mitigation policy language and monitoring plans to reduce bat fatalities at present and future wind energy project sites.

My objectives were to:

- Determine significant factors causing bat fatalities at LBW and OBW.
- Analyze environmental (abiotic) variables (wind speed, barometric pressure, temperature) during the annual bat fall migration period from LBW data to guide future OBW siting.
- Validate if UAD presence at wind energy sites can protect bat species.
- Propose conditional language for policy makers and regulators when determining wind project siting in relation to bat migration movement using UAD technology.
- Establish if odontocete stranding data using UAD deployment as a proxy parameter is an applicable comparison to UAD deployment on wind turbines for reducing bat fatalities.

Background

According to the International Energy Association's (IEA) 2018 report, global wind power capacity grew 12%, bringing the total world capacity to 539 gigawatts (GW) (IEA Wind, 2019). Offshore wind grew by 31% to reach an 18.8 GW capacity, but the potential for additional offshore wind development remains high (Figure 1). This includes new offshore locations for both fixed-bottom and floating wind turbines. Global offshore wind has been focused in Europe but is expanding to North America and Asia (Figure 2). In 2019, the *World Energy Outlook Special Report: Offshore Wind Outlook* provided guidance on managing a growing OBW fleet (IEA, 2019). When comparing LBW to OBW, factors such as wind potential, spatial siting, energy capacity and size of individual wind energy turbines all guide decisions on how and where to place wind energy facilities (Figure 3). Offshore winds offer greater consistency and capacity which leads to increased energy efficiency per wind turbine when compared to LBW. While this is advantageous, currently the cost to transmit offshore energy is higher than LBW. Managers and stakeholders need to balance the advantages and costs of both siting types to make the best decision for global energy needs.

Offshore wind turbines are essentially the same design as onshore wind turbines. They consist of a tower, or monopole, a hub (rotor), a nacelle where the generator is housed, and blades. Offshore turbines are delivered to their site by barges or ships and assembled at sea. Fixed-bottom wind turbines are often secured to the ocean floor by pile driving anchor points or drilling holes for pole embedding into the substrate for four types of base designs: monopole, jacket, gravity bucket and suction caisson. The towers of the floating wind turbines are not driven into the ocean substrate, but anchored to the ocean floor via cables, or suction baskets. Floating wind turbine have previously been tested and are currently operational in Scandinavia and the UK (Figure 4).

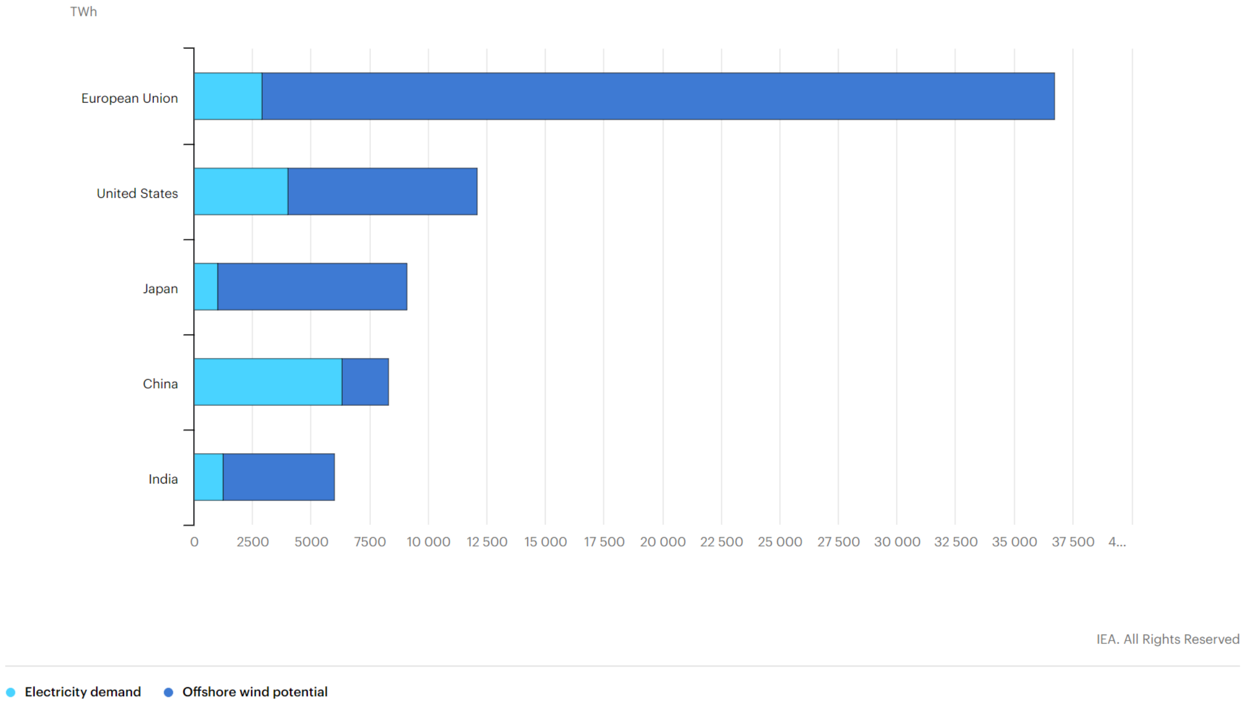


Figure 1. Offshore wind technical potential and electricity demand, 2017 (IEA, 2018).

The US is looking at new design concepts for wind energy projects off the East and West coasts. The first offshore wind project in US waters became operational in 2016 off the coast of Rhode Island (Block Island Wind Project). New OBW projects in Maine, New Jersey and New York are in planning stages (New York State Energy Research and Development Authority (NYSERDA), 2017). Together the Block Island Wind Project and those being planned have compiled data from pre-and potential post-construction environmental statements and environmental impact assessments (ES & EIA) along with operational outcomes from the European projects to evaluate how and why wind energy projects should proactively address wildlife conservation. The offshore data along with information from decades of LBW implementation and research may help managers guide wildlife mitigation policy needs.

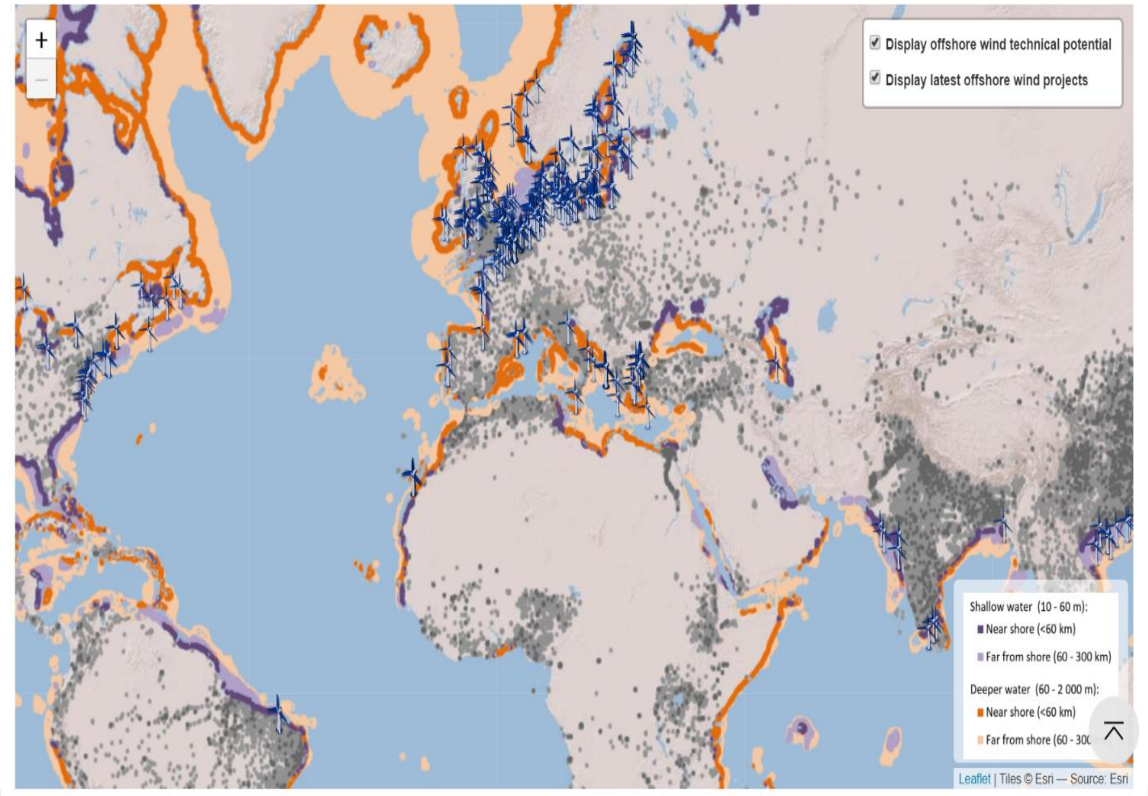


Figure 2. Interactive Geospatial Map showing technical potential, water depths, distance from land and existing offshore sites as of July 2019 (IEA and Imperial College London, 2019).

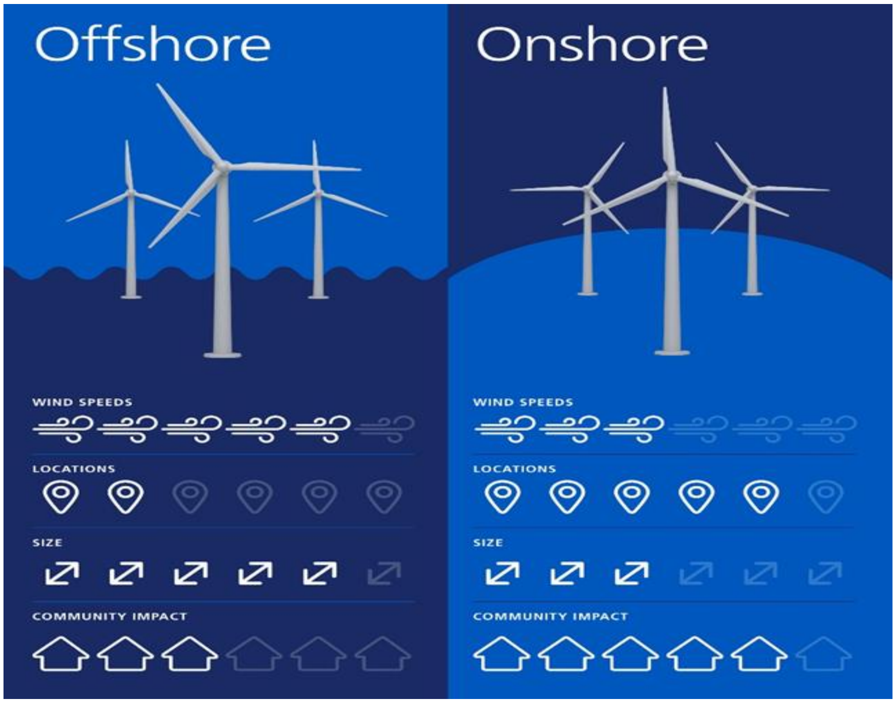


Figure 3. Comparison of offshore and onshore wind factors (EDF, 2020).

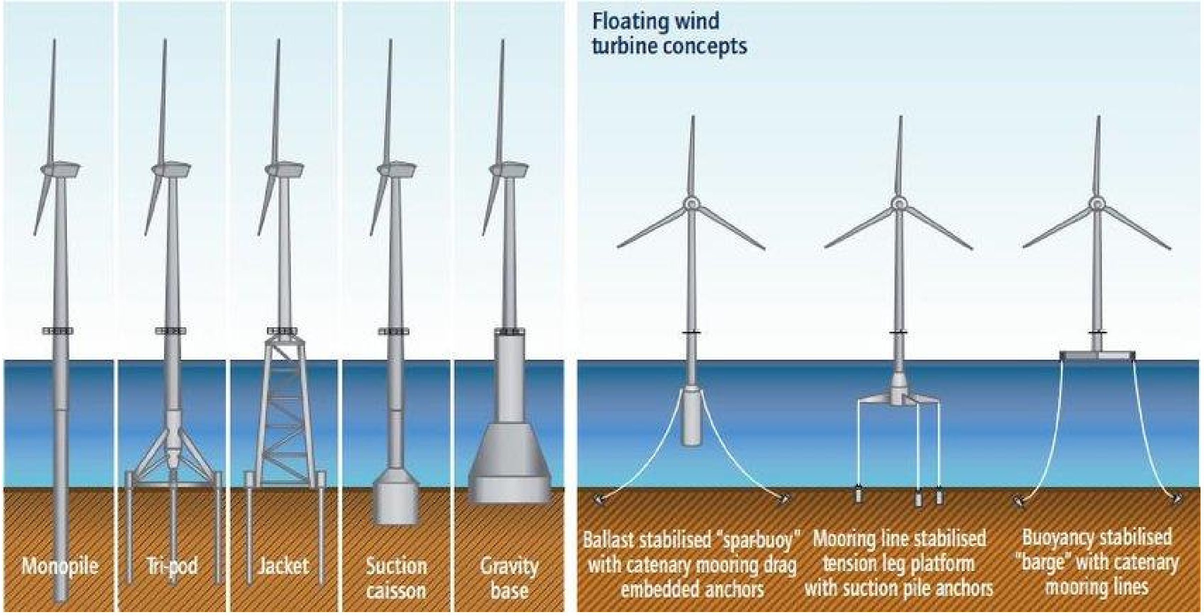


Figure 4. Fixed offshore wind turbines and floating offshore wind turbines (Wiser et al., 2011).

Bat Fatalities at Wind Energy Project Sites

Bat fatalities are predominantly caused by collision events from moving wind turbine blades. Between 2000 and 2011, an estimated 650,000 to 1.3 million bats were killed by wind turbines in the United States and Canada (Arnett & Baerwald, 2013). This level of fatality combined with the low reproductive potential of the species most at risk (i.e. hoary bats, *Lasiurus cinereus)* concerns stakeholders because of the possible population level impacts (Barclay & Harder, 2003; Frick et al., 2017). Bat fatalities tend to be highest during late-summer and early autumn coinciding with the migrating and mating season of bats (Arnett & Baerwald, 2013). The species composition reflects this pattern as most bat fatalities at North American LBW are migratory tree-roosting species, such as the eastern red bat (*L. borealis*), hoary bat, and silver-haired bat (*Lasionycteris noctivagans*) (Arnett et al., 2013a; Baerwald, Patterson, & Barclay, 2014; Cryan et al., 2014; Hatch, Connelly, Divoll, Stenhouse, & Williams, 2013; Hein, Gruver, & Arnett, 2013; Ontario Ministry of Natural Resources (OMNR), 2011). These species account for 78% of bat-wind mortalities north of Mexico (Arnett et al., 2013; Baerwald, Edworthy, Holder, & Barclay, 2009; Cullinan, Matzner, & Duberstein, 2015). In Europe, high-flying, long-distance migratory species are most at risk: Nathusius' pipistrelle (*Pipistrellus nathusii*), Parti-coloured bat (*Vespertilio murinus*), and the Common Noctule (*Nyctalus noctule*) (Limpens et al., 2017; Rydell et al., 2010; Scottish Govt., 2018).

Growing evidence suggests bats are drawn to wind turbines, yet the attractant(s) remain unknown (Kunz et al., 2007; Cryan & Barclay, 2009) and may vary by species, habitat, scale or interactions among these factors. Several hypotheses have been presented as to why bats approach and interact with wind turbines (Kunz et al., 2007; Cryan & Barclay, 2009). Visual observations using thermal cameras have documented bat behavior near wind turbines showing bats making multiple approaches or using the airspace around the structures (i.e., tower, nacelle, and blades) (Horn, Arnett, & Kunz, 2008; Cryan et al. 2014). Because LBW is usually placed in large open pasture, agricultural or prairie lands, or near forested lands (Baerwald et al., 2014; Bennett, Hale, & Williams, 2017; Hayes et al., 2019; OMNR, 2011; Wellig et al., 2018) bats may encounter these structures while searching for foraging or roosting opportunities. Moreover, the wind turbines themselves may attract bats or insects. For example, a subset of turbines uses white or red aviation lights at night which can attract insects, especially moths (Baerwald et al., 2009; Rydell & Wickman, 2015). However, Bennet and Hale (2014) found higher fatalities of red bats at turbines without aviation lighting and no difference in fatality for other species between turbines with or without aviation lighting. Turbine towers are usually painted a light color which may attract insects and in turn attract bats (Long, Flint, & Lepper, 2011; Bennett & Hale, 2018; Foo et al., 2017).

From a distance, wind turbines may be perceived as large trees; each has a main trunk and branch like projections. Bats have been seen approaching the leeward side of large trees, a behavior also observed at wind turbines (Allison et al., 2019; Bennett et al., 2017; Cryan et al., 2014). Ahlen, Bach, Baagoe and Pettersson (2007) describes an example of bats using wind turbines as a roost at Sweden’s Blekinge offshore wind facility. In the US, Bennett et al., (2017) found bat feces in numerous parts of the turbine structure such as gills and slats of the transformer, which could only have been present from bats physically roosting, not from air borne debris (Bennett et al., 2017). There is also an unpublished report of Mexican free-tailed bats showing startle response and exiting a turbine housing during a bat carcass survey (Hale, pers.comm., 2020).

Wind turbines may also represent a place for bats to congregate and interact with other individuals. Species such as Soprano pipistrelle (*Pipistrellus pygmaeus)* and Nathusius's pipistrelle (*Pipistrellus nathusii)* were acoustically recorded making territorial calls near turbines (Cryan et al. 2014). Understanding the behavioral component of bat interactions with wind turbines may help to mitigate the impacts. For example, if resident coastal bats are using the nearshore wind turbines as nightly foraging areas, determining maximum nightly flight distances may provide information on siting wind energy facilities away from land. For migrating bats, wind turbines may represent stopover roosts in an environment otherwise devoid of resources.

Migration and Behavior

In northern latitudes, many species of bats migrate in spring and autumn. Migratory routes and distances vary from hundreds to thousands of kilometers each season. Bats can migrate thousands of miles during early spring to more temperate climates and ample feeding grounds when they are gestating and return to winter roosts after the young become volant and leave the summer roosts. The autumn migration typically occurs from mid-July through early October with peaks in late August to mid-September (Ahlen et al., 2007; Cryan et al., 2014; Hatch et al., 2013; Hein, Schirmacher, Arnett, & Huso, 2011). Bat fatalities also appear to be highest during the late-summer and early autumn seasons (Arnett & Baerwald, 2013). Bat migration activity offshore resembles that of onshore. Peterson, Pelletier and Giovanni (2016) reported a multiannual review of bat activity peaking in August and September across the mid-Atlantic, Gulf of Maine and the Great Lakes region.

In the offshore environment, there is ongoing research in the North Sea to determine if the bat activity recorded at wind turbines are from migrating species or more local foraging activity. Limpens et al. (2017) theorize that most bats are purposefully using certain North Sea flyways during the autumn migrations. The bats are found mainly in calm winds, high barometric pressures and no precipitation which suggests bats were not blown out to sea but choosing to fly in favorable environmental conditions. Foraging noctule species use greater foraging ranges and are often observed at offshore sites in the Baltic and North Seas (Ahlen et al., 2007; Rydell & Wickman, 2015; Lagerveld et al., 2017).

In the United States, bats have been recorded using the Atlantic offshore environment as flight paths since the 1890s with individuals observed 40 km offshore (Hatch et al., 2013). Even though there are many studies looking at annual bat temporal movements, there is still a lack of information regarding bat migration, especially how they use the offshore environment (Baerwald et al., 2014; Lagervald et al., 2017; Peterson et al., 2016). There are modeling projects coupling acoustic bat activity to movement in attempts to determine if migration was a primary driver of coastal and offshore bat activity (Pelletier, Watrous, & Peterson, 2013; Peterson et al., 2016). Peterson et al. (2016) reported that bat migration patterns are comparable between coastal and offshore to other terrestrial studies with the same variables. This includes abiotic variables and seasonal timing. Determining bat behavior during autumn migration may help decipher why bats interact with wind turbines and how to mitigate collision events.

Abiotic Variables

Bats use environmental cues for activities such as migration, foraging, roosting and mating. Studies from pre- and post-construction monitoring of LBW projects show mixed results regarding predictive models of bat fatality using acoustic detectors for bat presence in the area (Arnett et al., 2013; Hein et al., 2013), but can help guide operations at wind energy projects and placement of specific turbines (Sinclair et al., 2018). The abiotic variables that appear to influence bat activity onshore and closely resembled atmospheric conditions that could have the greatest effect on bats in the offshore environment are temperature, barometric pressure and wind speed. While these variables can be significant factors when examining bat fatalities at land-based wind turbines, it is important to determine how these abiotic variables relate to bats and wind turbine interactions in the offshore environment. Modeling the relationship between abiotic variables and bat flight would allow managers may proactively predict seasonal bat activity.

Temperature. Bats use temperature cues for flight activity including nightly emergence for foraging and for the beginning of migration. Most land-based studies show a positive relationship between temperature and bat activity, although there are exceptions (Bender & Hartman, 2015; Smith & McWilliams, 2016). In Canada, silver-haired bat activity increased with warmer ambient temperature (Baerwald & Barclay, 2011). Temperature was a positively correlated variable up to ~12˚C when it comes to bat activity in the Gulf of Maine and mid-Atlantic coastal areas (Peterson et al., 2016). In contrast, Weaver

(2019) reported a negative relationship between temperature and bat activity at a site in south Texas. Temperatures at this site ranged between 16.6-35.6˚C, which may have exceeded thermoregulatory thresholds for bats or suppressed insect activity.

Land-based temperatures show greater daily and seasonal fluctuation relative to offshore. As temperature drops over land, water bodies will hold a constant temperature longer. This may influence how bats use the two different environments. For example, insect activity is also positively correlated with temperature (Bender & Hartman, 2015; Hein et al., 2011; Pelletier et al., 2013). Thus, insect abundance over water may remain more constant over a longer period offering a more stable food resource during periods of high stress such as migration (Pelletier et al., 2013).

Barometric pressure. Barometric pressure, or atmospheric pressure, is the pressure exerted on the earth's surface by the density of air molecules. Pressure changes are determined by temperature, humidity, air movement (wind) and altitude. Topography may also influence barometric pressure. The relationship between bat activity and barometric pressure is not fully understood. Some studies have shown that bats do not change flight or feeding behaviors based on nightly barometric changes (Sjollema, Gates, Hilderbrand, & Sherwell, 2014; Weaver 2019). Whereas, other studies have shown a correlation between bats and barometric pressure with bats responding to barometric pressure changes as an indicator of nightly activity (Bender & Hartman, 2015; Smith & McWilliams, 2016).

For migratory bat species, there may be a positive correlation between activity and barometric pressure (Bender & Hartman, 2015). One study found a positive relationship between hoary bat arrival at an island stopover point and low barometric pressure where bats predictably arrived under low wind conditions prior to an oncoming storm front (Cryan & Brown, 2007). Barometric pressure usually falls prior to a storm system that has stronger winds, precipitation and decreasing temperatures. During these events, bats may use these migratory stopover sites, including islands, for refuge or to rest during migration or wait out storms. Hatch et al. (2013) suggested that changes in barometric pressure might not initiate flight activity, but islands and offshore turbines might offer respite when bats are already migrating and experience drops in pressure during flight. In association with winds at higher altitudes, bats might be using areas of low pressure to help with flight energetics by using tailwinds (Hatch et al., 2013). High frequency bats showed a positive correlation to increasing barometric pressure prior to sunset, indicating these bats favor warmer temperatures and decreased wind speeds that accompany the passing of low-pressure fronts (Ahlen et al., 2007; Smith & McWilliams, 2016). Insect abundance also increases after the passing of low-pressure fronts. While changes in nightly barometric pressure might not show high correlation to bat activity, the passing of low-pressure fronts can show positive relationships to bat activity and insect movement.

Wind speed. Wind speed is an important abiotic variable considered when siting wind energy facilities. In general, bat activity tends to be higher when wind speeds are under 10.0 m/s (Ahlen et al., 2007; Cryan et al., 2014; Smith & McWilliams, 2016; Weaver, 2019). Several studies indicated that wind speed and bat activity are negatively correlated (Hein et al., 2011; Sjollema et al., 2014; Smith & McWilliams, 2016; Weaver, 2019).

Baerwald et al. (2009) showed a negative correlation between increased bat fatalities and lower wind speeds at a wind energy turbine facility in Canada. Wellig et al. (2018) showed a reduction in Savi's pipistrelle (*Hypsugo savii*) bats within 50–150 m above ground rotor swept zones (RSZ) with increasing wind speeds above 5.4 m/s. On land, nightly wind speeds can be highly variable, whereas offshore wind speeds tend to be more consistent and higher. Offshore wind also increases in the afternoons through sunset, when power demand is higher. Peterson et al. (2016) reported significance between wind speeds and bat activity in the coastal and nearshore areas where there was a negative correlation until wind peaked at ~10.0 m/s.

Other covariates may interact with bat activity and wind speed. Insect activity and abundance also changes with wind speed. In Cryan et al. (2014), bats exploited greater wind velocities to capture high-altitude insect swarms that were caught in airflows. Seasonality also may influence bat flight activity. A study looking at bat flight trends along the New England coast showed that wind speed had the strongest relationship with nightly bat activity during the autumn migratory period (Smith & McWilliams, 2016).

Species are influenced by wind speed and other variables based on their size and behavior. Arnett & Baerwald (2013) summarized the species composition of bat fatalities at wind energy facilities, and noted the majority are migratory species. Similar findings were reported in Europe (Rydell et al., 2010). Migratory species flying at higher altitudes may increase their likelihood of encountering the RSZ of wind turbines. These species are adapted for open-air foraging and are relatively less maneuverable when compared to species adapted to maneuver in more cluttered landscapes. The species composition, migratory behavior, and use of islands as stopover sites may influence how bats interact with wind turbines near coastal landscapes or farther offshore sites.

Information on how bats interact with LBW turbines, particularly the abiotic variables that may increase risk, is important for planning, siting, and potentially mitigating impacts at OBW. Although questions remain on the significance of how abiotic variables such as temperature, barometric pressure, and wind speed influence bat movement patterns on land, it is even less clear whether and to what extent these same factors effect bat activity offshore. More robust models are needed to establish relationships of migratory bat activity and abiotic variables at offshore wind turbines. While migration patterns can provide insight as to the seasonal timing of fatality events at wind energy facilities, understanding the abiotic variables under which these events occur is essential to developing cost-effective strategies to reduce impact.

Islands

Bats use coastal habitat for foraging, breeding, summering, migration routes and roosting (Baerwald et al., 2014; Cryan et al., 2014). Landscape features near the coast such as forests and freshwater bodies often support roosting and drinking opportunities for bats. Unique aspects to the coastal environment, such as wrack lines, may provide foraging opportunities (Peterson et al., 2016). Similarly, coastal islands may contain small areas of suitable resources or microhabitats that differ from their immediate surroundings. Small dense groupings of trees or plots of agriculture on islands may present bats with foraging and roosting options. Bat activity on or near islands has been recorded by visual observation and acoustic monitoring (Cryan & Brown, 2007; Pelletier et al., 2013). While it has been documented that bats use islands as stopover points during migration or near shore foraging spots, the primary reason for island bat activity is not clear, but it is most likely species and resource dependent (Cryan & Brown, 2007; Rydell & Wickman, 2015).

Stantec Consulting prepared a comprehensive report describing findings from a six-year bat monitoring study to determine bat activity off the mid-Atlantic Coast, New England Coast, and Great Lakes in preparation for offshore wind siting suggestions (Peterson et al., 2016). This project monitored 17 islands for spatial and temporal bat activity. Bats were detected up to 130 km offshore. Habitat type was an important factor, with greater bat activity recorded near forested areas and in the coastal or nearshore mainland areas (Pelletier et al., 2013; Peterson et al., 2016); however, this also pertained to island landscape and associated bat activity.

Bats have been recorded regularly using established flyways in the Dutch North Sea that overlapped with wind energy facilities (Lagervald et al., 2017). Rydell et al. (2015) observed seasonal bat activity across the Baltic Sea and southeastern North Sea coasts and islands between August and October during a 2013 study. Bockstigen Wind Park, based in the Baltic Sea near Gotland Island, Sweden, also recorded bat activity (Rydell & Wickman, 2015). Based on acoustic data, no foraging echolocation calls, or feeding buzzes, were observed. Thus, the Gotland Island site is believed to be a short stop over point during routine seasonal migratory pathways.

Siting of offshore turbines in relation to preferred habitat is an important component for proactive mitigation. Offshore turbines could be considered microhabitats if bats perceive these structures as a potential resource (i.e. roosting and foraging opportunity). Since insects have been recorded at offshore turbines, drawn there either by wind or seeking out shelter, bats may be drawn in as well. Bats are known to forage over water sources unsuitable for drinking. In a California study, Yuma (*Myotis yumanensis*) and Mexican free tailed (*Tadarida brasiliensis*) bats actively forage over salt marshes that support large insect populations (Brickley, 2012). If foraging opportunities present themselves offshore, this could potentially change availability of food sources and feeding habits offshore, particularly with wind turbine sited close to nearshore islands where bats have been monitored (Peterson et al., 2016). A determination of microhabitats at operational offshore turbines can help inform siting and operational decisions to mitigate risk to bats.

Bat and Odontocete Echolocation

Bats and odontocetes share the capability of producing echolocation. Though both species generate echolocation by physiologically different methods, they use echolocation in similar ways, such as prey detection and navigating vast spaces.

Bat Echolocation

Bats use biosonar, or echolocation for both prey capture and spatial awareness. Bats produce echolocation by either clicking their tongues or contracting their larynx. Variations in outer ear folds, shapes, and wrinkles help to receive echoes and direct sound to the specialized inner ear anatomy of highly sensitive receptor cells that are specifically tuned to frequency shifts (Au, 1997). Bats determine objects in their environment by analyzing the return time and frequency of an emitted tonal call (Schnitzler, Moss, & Denzinger, 2003).

Bats have two echolocation modes: constant frequency (CF) and frequency modulated (FM). Most bats do not exclusively use one or the other but use a complex mixture of both types of harmonics (Figure 5) (Au, 1997; Neuweiler, 2003; Masters & Harley, 2004). The CF mode is characterized by a constant tonal narrowband, longer duration frequency where bats alter their harmonics to match incoming echoes by shifting to lower frequency output (Commins, 2018). Constant frequency is used by bats that normally hunt in forested areas with increased spatial clutter (Moss & Sinha, 2003). Most bats do not use CF as a single frequency method but have a complex CF-FM signal. Some returning echoes may be outside of the bat's normal response ability, so by using the Doppler effect, a bat can better determine the position of a moving object in space and time. This is called Doppler Shift Compensation (Au, 1997; Schnitzler et al., 2003). The Doppler effect is the change in sound based on velocity and distance, or how frequency changes with movement (Commins, 2018). The main advantage of having a doppler shift ability is for the bat to keep a target within the preferred frequency sensitivity range for accurate detection. This is very effective for the changes in spectral variations from rapidly moving insect wing flutter (Moss & Sinha, 2003; Schnitzler et al., 2003; Commins, 2018).

Frequency modulated calls are short duration, broadband frequencies that determine distance by determining the time between emitted calls and their echo return (Neuweiler, 2003). Doppler shift compensation is not a part of this call regime because of the broader nature of the call, allowing for a larger range of sensitive frequencies. Bats that use FM to forage in less dense forested or cluttered areas, on fringes of forests or cities with open spaces, need strong three-dimensional targeting in relation to ground (Moss & Sinha, 2003).

The fundamental difference in CF and FM frequencies is bats use CF to determine location of a moving object whereas FM is better suited to orientating themselves in space in relation to stationary objects. The CF-FM combination is best to find moving objects while compensating for echo frequency increases while both bat and object are in motion (Moss & Sinha, 2003; Commins, 2018). The CF-FM doppler shift frequency method may be key in assessing how bats orient themselves to moving turbine blades (Long, Flint, & Lepper, 2010).

Bats also modulate their call frequency to prevent returning echoes masking new calls. By changing the frequency, bats can avoid missing targets by their own echoes hiding spatiotemporal cues. In an example of an evolutionary pathway, some species of moths have adapted a technique that sends a matched echo back to bats, essentially "jamming" the bat's signal (Corcoran, Barber, Hristov, & Conner, 2011; Wilson, Wahlberg, Surlykke, & Madsen,, 2013). Researchers found that Tiger moths (*Bertholdia trigona)* can completely mask incoming bat echolocation by matching the frequency and rendering themselves "invisible". Moths saturate airspace by clicking constantly to match or overpower echoes, allowing for complete coverage of the bat's call frequency. Corcoran et al. (2011) showed that bats respond slowly to jamming signals with an initial startle response, followed by habituation to mixed moth species. However, with *Bertholdia* moths, bats took longer to habituate to the high duty cycle jamming clicks in comparison to other moth low duty cycle click species. The high duty cycle appears to cause a neural latency in the bat, uncoupling precision of call timing and target position. While it is not clear if bats believe the clicks are from other conspecific bats, there is a 10-fold decrease in prey acquisition of *Bertholida* moths when jamming bat echolocation is noted (Corcoran et al., 2011). It is important to extrapolate this information from biological jamming to technological jamming using UADs.

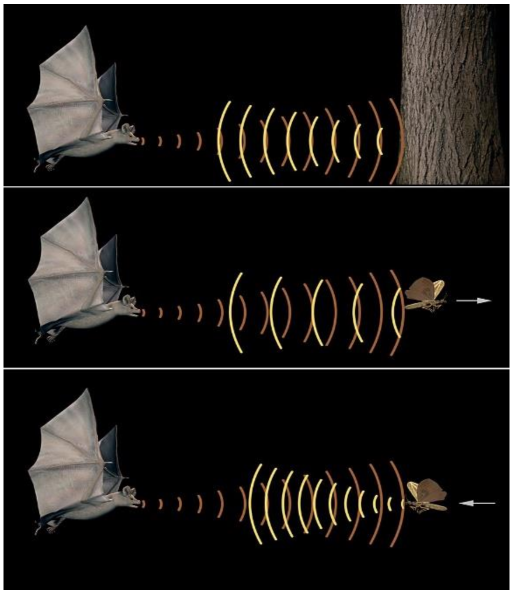


Figure 5. Simplified depiction of bats using different echolocation frequencies; constant frequency (CF), frequency modulated (FM) or a CF-FM combined call (Bonnetedbat, 2019).

Odontocete Echolocation

Anatomically different from bat echolocation, odontocetes produce biosonar by vibrating fat deposits in the melon located in the cranial portion of the head and concentrating the sound through similar fat deposits in their jaw, forming a “directional beam” (Au, 1997). This beam helps sound to attenuate through water and allows echoes to be received through the jaw’s “acoustic window”, into the middle ear and up to the melon and brain (Zainuddin Lubis, 2016) (Figure 6). An important aspect of this directionality is that odontocetes can determine shapes in three-dimensional space and minimize background noise interference to isolate one object in a multi-object environment (Au, 1997). Odontocetes do not use doppler shift compensation due to the nature of their echolocation, which is more comparable to FM bat calls. This is due to this mode of echolocation not paired with velocity of the target (Au, 1997). While there is a doppler effect in water, odontocetes do not possess the same breadth of frequency variation in their echolocation. Some of the larger, gregarious odontocete species such as Bottlenose dolphins (*Tursiops truncatus*) and Orca (*Orcinus orca*) use a broadband, short duration call. Smaller odontocetes such as porpoises use a narrow band, longer duration call. Odontocete echolocation does not seem to vary as much between species when compared to bat species. However, odontocetes and bats have evolved to share a convergent evolutionary trait (Liu, Cotton, Shen, Rossiter, & Zhang, 2010; Madsen & Surlykke, 2013; Kloepper & Branstetter, 2019).

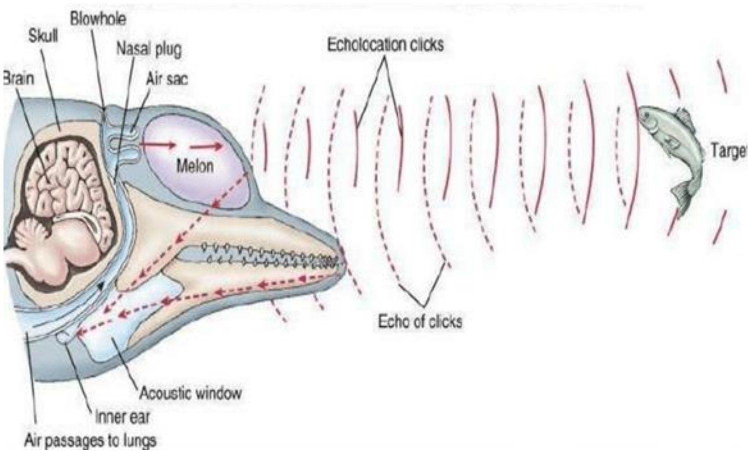


Figure 6. Anatomical depiction of odontocete echolocation signal (Zainuddin Lubis, 2016).

Convergent Evolution in Echolocation

Convergent evolution is the development of similar functional adaptations in completely different species (Madsen & Surlykke, 2013). In this case, echolocation for target detection developed in both odontocetes and bats. Researchers believe this adaptation evolved due to these species having to navigate and hunt in dark, murky large spaces such as night skies and deep water. Bats and odontocetes both echolocate at similar frequencies: Bats=20–200kHz and Odontocetes=20–150kHz (Madsen & Surlykke, 2013).

Genetic convergence, or phenotypic convergence has been seen in bat and dolphin (odontocete) phylogenetic trees (Parker et al., 2013). These parallel changes across independent genomes is based on natural selection (Liu et al., 2010). These adaptive similarities include many inner ear anatomical features that allow for processing ultrasonic frequency thresholds as well as emitting frequencies that differentiate shapes in space. Neural similarities include the understanding that with such complex processes as echolocation, a group of neurons instead of one specialized neuron are needed (Masters & Harley, 2004). Recent molecular biology research has isolated a hearing gene, Prestin, that seems to have evolved through natural selection in both odontocetes and CF bats (Li, Liu, Shi, & Zhang, 2010; Liu et al., 2010). Researchers believe this gene allows for high sensitivity and selectivity in the auditory system of echolocating mammals. If these types of gene types are present in odontocetes and bats that echolocate, then this shows an evolutionary convergence in mammals that use vast space niches (Madsen & Surlykke, 2014).

Odontocete and Bat Echolocation Differences

The molecular structure between air and water account for differences in bat and odontocete echolocation. The denser medium of water allows for a stronger vibrational wave, allowing sound to travel faster and further. Sound travels through water approximately five times faster and absorbs ultrasound less quickly. The acoustic absorption coefficient (Au, 1997) results in air absorbing ultrasound 100 times faster than in water. Thus, odontocetes have a larger "acoustic field of vision", 500 m compared to 2–10 m (Madsen & Surlykke, 2014).

This may also account for why odontocetes do not need to modulate their frequencies as habitually as CF bats do. Bats also have a higher diversity not only within their species but within a single individual's call (Masters & Harley, 2004). Odontocetes do not possess such diversification, possibly due to odontocetes not needing to interpret "background clutter" as much as bats. In essence, a target can "pop up" in a bat's echolocation field faster than with odontocetes, due to the density differences in water and air. Water allows for odontocetes to have a broader view of space from their echolocation.

Spectrograms for Bats and Odontocetes

Representative spectrograms of bats and odontocetes shows that bats have less time to detect an object. Bats use a pattern called a prey-capture sequence that consists of a search, approach and terminal call series that uses harmonic or frequency shifts (Figure 7) (Commins, 2018). The medium density determines how and when a terminal buzz sequence should be deployed from each species. A terminal buzz is a series of rapid succession pulses used for final target acquisition. If a bat uses a terminal buzz too soon, it will not have time to receive the object's echo and could miss or collide with the object. Conversely, odontocetes have more space and time to react due to the dense medium which allows for more time for echo relay. Bats possess a more elastic hunt sequence, showing frequency changes across the pattern more often than odontocetes (Figures 8 & 9). This could be attributed to both the acoustic differences in the mediums and the prey velocity changes that effect Doppler shifts for flying bats.

Because bats have a short window of detection due to ultrasonic absorption, it represents a disadvantage when trying to receive a visual on a large moving object. It serves better when detecting large, non-mobile obstacles like trees, but does not allow for the distinction between large slow-moving objects such as turbine blades. Because of the short-range nature of their echolocation, moving blades might either register as large solid objects, or open aerial space between the blades. Long et al., (2010) describes a Doppler shift-like reflection due to rotor position, from slow moving blades (~<6m/s), where a bat might have difficulty ascertaining the position of the blade in space, with ample time before collision.

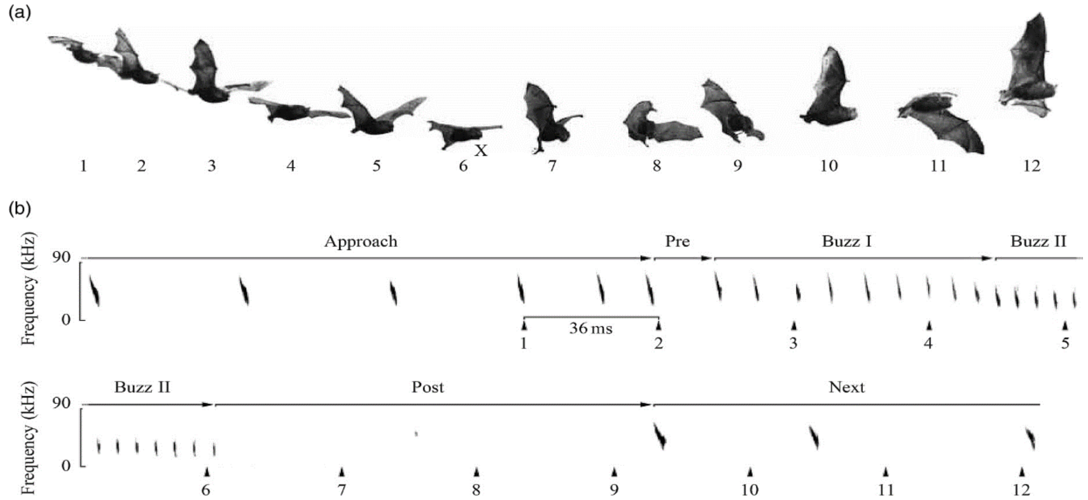


Figure 7. A sonogram of an FM typical bat species, Daubenton's bat (*Myotis daubentoniid)* showing multiple harmonic ranges for three pulse echolocation calls in the prey-capture sequence. (Commins, 2018).

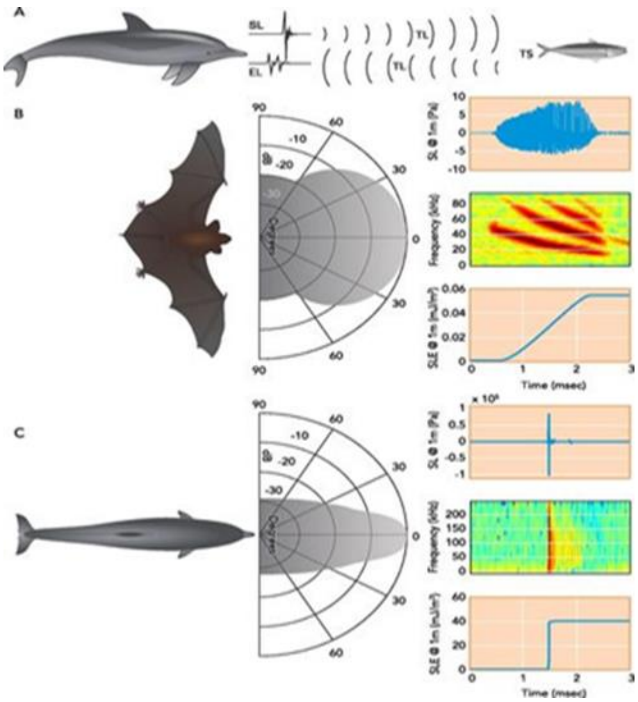


Figure 8: Comparison of echolocation spectrograms of bats and odontocetes (Johnson et al., 2006).

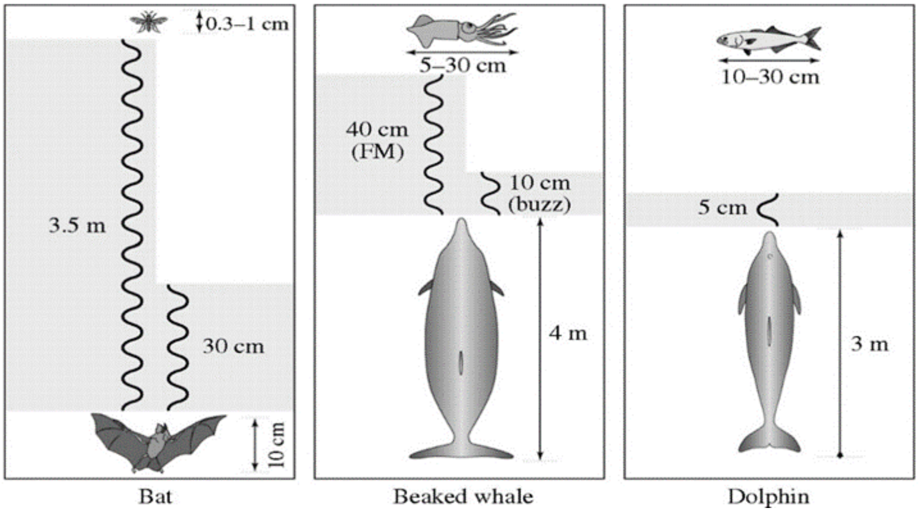


Figure 9. A schematic outline of the sonar equation comparing echolocating bat and odontocete species (Madsen & Surlykke, 2013).

Offshore Sound and Bats

Bats contend with reflective sound clutter when echolocating over water (Rydell, Miller & Jensen, 1999; Zsebok et al., 2013). Different foraging techniques will relay different echoes back to the bat when it is prey targeting over water. For example, Rydell et al. (1999) looked at how Daubenton's bats (*Myotis daubentonii)* use echolocation for foraging over small riverine streams in Sweden. Bats preferred to use calm sections of the stream system versus areas with visible ripples. He determined this behavior was due more to echolocation clutter and not insect abundance since insect abundance was more concentrated over the rippled areas. Trawling, or gleaning, bats will hunt directly over calm water, which helps distinguish insects from the smooth surface (Schnitzler et al., 2003; Suryan, Albertani, Polagye, & Oregon State Univ., 2016). Moreover, smooth surfaces allow sound to travel farther. Ripples or waves across the water surface refract and scatter the soundwaves making the returning echoes difficult to interpret.

In the offshore environment, undesired echo returned from ocean wave action that acts as an artificial target is referred to as sea clutter. Sea clutter and blade spin velocity can confuse echolocating bats by causing Doppler spread and or Doppler shift signatures, respectively (Jayaprakash, Reddy, & Prasad, 2016; Long et al., 2010). Doppler spread is the broadening over time of sound wave propagation frequencies caused by multiple disturbances in the pathway. This differs from Doppler shift where the frequency shift occurs in relation from the wave pathway to the observer. Visually it is akin to comparing Doppler spread to a sunburst and Doppler shift to a stepwise or oscillating pattern. Radar at sea must work through understanding desired targets by mitigating sea clutter (Jayaprakash et al., 2016). In a study looking at efficacy of a radar-based bird and bat detector, Merlin Bird and Bat Detector (DeTect Inc., Florida) in offshore field validations for bat collision rates, researchers employed filters that helped lessen effects of Doppler shift allowing them to determine fast flying objects. They also included a Sea Clutter filter that allows for better small object detection that would otherwise be obscured (Dirksen, 2017). Similarly, bats may account for sea clutter when active offshore. Sea clutter can disorient bats by changing reflective angles and timing of echolocation patterns. Different from looking for "glint patterns" from aerial prey signatures from returning echoes, bats may not be able to change direction fast enough from echo information when dealing with Doppler spread or shift extremes (Neuweiler, 2003; Schnitzler et al., 2003).

Moving turbine blades produce Doppler shift patterns that can confuse bats as to where blades are spatially. Moving blades, in reference to the rotor, can generate multiple Doppler shift patterns that can overwhelm returning echoes to bats. Long et al. (2010)

explains how findings of blade rotations eliciting Doppler shift patterns, dependent on angle of rotor and blade speed, can require bats to receive and interpret up to 50 echoes upon approach to wind turbines. Bats might not have time to interpret this many echoes, causing them to misinterpret blade speed and position leading to collisions. This seems to apply to FM bats more so than CF bats. FM bats do not utilize Doppler Shift Compensation tactics like the CF bats, so the constantly changing frequency echoes of the turbine blades seem to arrive quicker than expected, not allowing for echo completion and neural processing. FM bats also seem to compensate for Doppler shift by over-modulating their frequencies. This "masking" technique can cause them to disorient and over/undershoot distances to turbine blades (Long et al., 2010). Given the speed to which some bat species approach wind turbine RSZs, it would be extremely difficult for a bat to hover and ascertain how the Doppler shift is changing frequencies of the moving object in time before interacting with the blades.

Bats and Offshore Wind Energy Development

Offshore wind energy development has existed in Europe since the 1990s, but it is a relatively recent endeavor in North America. The United Kingdom, Scandinavia, the Netherlands and Germany have multiple offshore wind energy facilities that have established environmental impact statements and protocols. In a European Court of Justice case against Germany, there is prohibitive language stating that if bat collisions are possible, turbines must shut down (Ahlen et al., 2007). This language follows legislation that is generally outlined in reports compiled from Eurobats (UNEP/EUROBATS, 2020). Eurobats is a secretariat established through legislation called the Agreement on the Conservation of Populations of European Bats (1994) that protects bats through the United Nations Environment Programme (UNEP) (UNEP/EUROBATS, 2020). The verdict includes potential mitigation strategies such as operational minimization, establishing seasonal activity flyways, increased monitoring, and deterrent technology through other legislation such as the Bonn Convention (1979) and The Habitats Directive (1992). Eurobats offers a publication series for bat conservation. Publication No.6, Guidelines for Bats and Turbines (2014) outlines strategic best practices that brings awareness of potential detrimental impacts to bats from prospective wind energy projects (Rodrigues et al., 2015). There are guidelines such as monitoring methods at different areas around the wind turbine (nacelle height, base of tower), elimination of attractive features at the turbines (roosting areas, light sources that attract insects), and cumulative fatality estimation and outcomes. These types of publications can guide managers, stakeholders and governmental representatives in proactive environmental impact research to mitigate bat collision events at wind turbines.

The offshore environment presents challenges to studying bat activity and interactions with wind turbines. Observational and radar monitoring via ships and other vessels has been the standard for determining bat presence at offshore structures. Bats have been recorded moving across the North Sea from coast to coast, either on their seasonal migration route or following insect populations (Ahlen et al., 2007; Rydell & Wickman, 2015). New technology through infrared cameras, thermal cameras and acoustic technology has allowed for additional monitoring techniques that helped solidify seasonal and foraging bat activity offshore.

There are two leading theories as to why bats are observed at offshore wind energy facilities. The first is they are following insect swarms. Insects have been reported at offshore wind energy facilities in the Baltic Sea (Ahlen et al., 2007). The second is that bats migrate offshore, and wind turbines may be perceived as potential resting roosts. At Utgrunden off the coast of Sweden, bats were recorded flying <40m above water surface, however vessel observations noted bat flight altitudes were variable from only meters above sea surface to the height of the turbine (Ahlen et al., 2007). It was hypothesized that bats found at higher altitudes are migrating bats, as radar data indicated activity along a clear flight path coming from one direction. Conversely, bats showing high variably in their flight paths were thought to be foraging bats that returned to a land mass (Ahlen et al., 2007). At another offshore wind energy facility, Sweden's Yttre Stengrund, ships recorded spider webs catching many small insect species that are known bat prey (Ahlen et al., 2007). They also determined that bats were gleaning small crustaceans from the sea surface.

Bat Monitoring at Recent Offshore Wind Projects

Many offshore projects include bat monitoring as a part of their pre-construction plan. However, monitoring has been focused on establishing presence, instead of looking for mitigative methods if monitoring confirms high activity around proposed wind turbine sites. European examples of this are the anticipated Hywind Scotland Floating Wind Turbine Project and the Neart na Gaoithe site. Both sites are in the Scottish North Sea. However, when comparing the environmental statements of both projects, there are major differences in the way to which bats are addressed.

The Hywind project is a 30 MW fully commissioned project consisting of five floating turbines located 25 km offshore from Peterhead, Scotland in 350 feet of water (Staoil, 2015). Though the report stated that bats do use that area of the North Sea for foraging and migratory pathways, there is no language in the report on any sort for bat monitoring, either during the pilot project or the final ES. Platteeuw et al. (2017) reported bats 85 km offshore in the Dutch North Sea. Furthermore, hypothesized bat migratory pathways were mapped from the European mainland to the UK and showed that bats would encounter multiple offshore wind turbine sites (Figure 10) (Boshamer & Bekker, 2018). While arguably, a floating wind farm holds more impact on marine mammals due to the anchor cabling to the sea floor and entanglement issues, two offshore wind facilities approximately 240 km away from each other should discuss mitigative impact measures of the same caliber even if they are not observing bat activity presently. Per the Eurobats Pub. No. 6 (2014) and the Action Plan for the Conservation of All Bat Species in the European Union 2018–2024, co-authored by Eurobats and the European Commission, bats should be addressed for conservation impacts at wind energy project sites (Barova & Streit, 2018).

Neart na Gaoithe is a 105 km^2 footprint, 75-125 wind turbine site with a total power capacity of 450 MW located 16km east of Fife Ness, Scotland, UK (NNGOffshore, 2012). The project was permitted for commission in 2012. There is an extensive Environmental Statement that encompasses the Environmental Impact Assessment that discusses all aspects of environmental resources for project scoping. Significant in the report is a robust discussion of bat conservation which stated that even though the ship observers did not record any bat activity in the vicinity of the proposed site, they are still including a conservation plan to protect known high risk bats that have been observed in the surrounding areas; Noctule bat (*Nyctalus noctule*), Nauthsius's pipistrelle (*Pipistrellus nathusii*) and Liesler's bat (*Nyctalus leisleri*). The report stated there is no established pathway of the three most at risk species and therefore, most likely will be no impact from the turbines. They cite the Eurobats Guidelines Pub. No. 6 (2014) and the Scottish Natural Heritage Protected Bats document for impact considerations from known bat behavior and migratory movement. This differs from the Hywind site report because they included how to address bats, even though no bats were recorded during the pre-siting environmental impact assessment. They also mention the need to fill data gaps on bat movement in the offshore area.

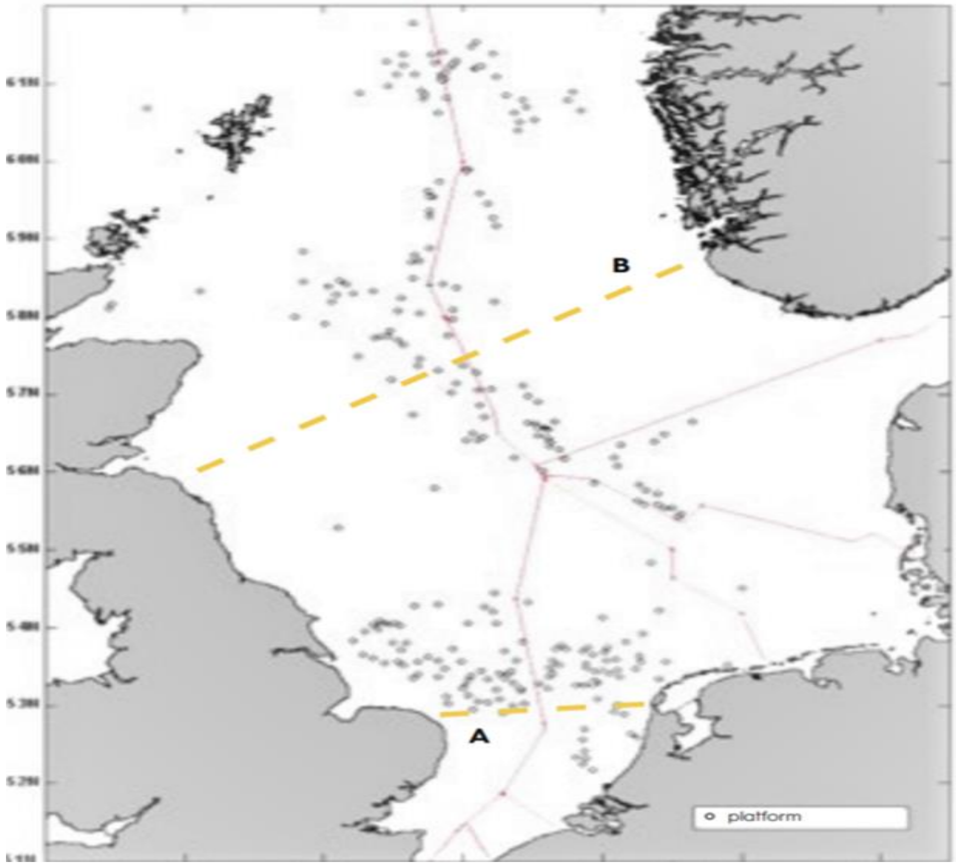


Figure 10. Hypothesized bat migratory pathways across the North Sea from the European mainland to the United Kingdom (dashed yellow lines) and offshore platforms (black dots) (Boshamer & Bekker, 2008).

The first North American offshore wind energy project was permitted in 2012 and became operational in late 2016. Block Island Wind Farm (Project) (BIWF or BIWP) is comprised of five wind turbines with a power capacity of 30 MW located 4.8 km off Block Island, Rhode Island in Narragansett Bay. BIWF hub height is 100-118 m from mean low water (MLW) with a blade clearance of 23-36 m MLW (USCAE, 2014). Three years of pre-construction bat surveys were completed and accepted by the United States Fish and Wildlife Service (USFWS) (USACE, 2014). Based on these findings, bat impact was determined to be low. According to the Rhode Island Wildlife Action Plan, under Species of Greatest Conservation Need Profiles, three species of bats are found on Block Island: Eastern red bat (*Lasiurus borealis*), Little brown bat (*Myotis lucifugus)*, and Big brown bat (*Eptesicus fuscus*) (RIDEM, 2020). Specifically, big brown bats are found crossing from the Rhode Island mainland to the larger islands of Narragansett Bay, such as Block Island. Though BIWF is located to the east of Block Island, if the managers are aware of these species using Block Island for foraging, roosting or hibernating, there should be specific language in the EA/EIS about mitigating possible collision events.

In 2014, the Bureau of Ocean Energy Management (BOEM) released a Finding on No Significant Impact (FONSI) for the BIWF. In it, there is mention of bat conservation via an avian and bat monitoring plan (Construction and Post Construction Avian and Bat Monitoring Plan) that was addressed in the Environmental Assessment (EA) (Tetra Tech, 2014). In this monitoring plan, it mentions bat acoustic monitoring during construction and three nonconsecutive years in the first five operational years post construction. Though it specifically mentioned bird monitoring in the post construction section, it does not specifically re-state bat acoustic monitoring, only bat occurrences. It does mention a goal of nocturnal migrant collision rate monitoring during post construction years 1,3,5, however it titles the goal as Nocturnal Bird Flight and Collision Monitoring. Although, the report states that certain methods such as side scanning radar and thermal cameras can decipher type of aerial target, such as bird or bat, there is no further discussion of specific bat monitoring post construction. In 2017, a BOEM funded project placed a tracking station on the most eastern wind turbine platform of BIWF to track previously micro-tagged birds and bats (BOEM, 2017). This study is a collaborative effort between USFWS, University of Rhode Island and the University of Massachusetts, Amherst. BOEM released OCS 2019-028 a report titled Field Observations During Wind Turbine Operations at the Block Island Wind Farm, Rhode Island (HDR, 2019). Even though the EA and FONSI reports mention bat monitoring, OCS 2019-028 lacks any mention of bat monitoring. This report specifically pertains to environmental monitoring surveys performed at BIWF during turbine operations. Future wind turbine siting should prioritize bat monitoring technology and techniques, both pre-and post-construction.

Acoustic and Observational Monitoring

Acoustic monitoring is the listening and recording of animal sounds. Acoustic monitoring can further be defined by either passive or active monitoring. Passive monitoring is automated sound recording and pre-determined placement of a microphone in space and time. Active monitoring involves tracking an animal's movement while recording its activities. Acoustic monitoring is often used to identify species and establish presence of bats. It is also important in relating bat activity patterns to landscape and abiotic weather factors. This method is commonly used in pre-construction siting and post construction environmental monitoring. Microphones and ultrasonic detectors are often attached to MET (meteorological towers), turbine nacelles, or on the ground near wind turbines. Offshore, acoustic monitoring has been used in North America for projects in the Gulf of Maine, mid-Atlantic and Great Lakes regions (Allison et al., 2019; Pelletier et al., 2013; Peterson et al., 2016). In an acoustic monitoring project off the New Jersey coast, ship-based acoustics detected bats 130 km offshore (Peterson et al., 2016). It has also been used extensively in the North Sea and the United Kingdom on lighthouses and ships (Ahlen et al., 2007; Lagervald et al., 2017; Limpens et al., 2017; Rydell & Wickman, 2015). At a small offshore wind turbine site in the Baltic Sea off the coast of Sweden, ultrasonic detectors consistently recorded sharp tones from calling bats. This is an important finding in that they determined the sharper the call, the flatter the water surface (Rydell & Wickman, 2015).

Infrared cameras, thermal cameras, radar and LiDar are also techniques to monitor bat movement around wind turbines. Alone, these monitoring methods do not establish robust patterns of bat movements, however when used in concert, acoustic monitoring and cameras can find trends in bat activity and species presence around pre and post sited wind turbines. When working with the harsher offshore environment, acoustic monitoring and camera use is more complicated. There are white noise issues with acoustic monitoring and salt corrosion on equipment. The advent of LiDar (short wave light waves) is giving more accurate size and shape results than traditional radar (long wave radio waves). However, radar and LiDar still lack the ability to acoustical record bat calls which provides information on species-specific activity. Thermal imaging is used offshore with acoustic monitoring to determine bat flight paths. Lagervald et al.

(2017) used stereoscopic thermal cameras and acoustic detectors mounted on a turbine to record 3D flight paths of bats off the coast of the Netherlands in the southern North Sea. As more offshore projects come online, robust monitoring and modeling will be essential. Since carcasses from collision events cannot be retrieved, combining several technologies can assist in evaluating activity and potential collisions at OBW.

Odontocete Stranding Monitoring

Less directly related to bats is an acoustic technology used to prevent marine mammal strandings. International Fund for Animal Welfare's (IFAW) Marine Mammal Rescue Response is the primary organization that focuses on marine mammal stranding response and rescue in the Cape Cod area. Cape Cod is one of the main marine mammal stranding "hotspots' in the world due to its prolific prey opportunities in the summer and geography of a "hooked" spit of land from the end of the landform. Marine mammals especially Long-finned pilot whales (*Globicephala melas*), Atlantic white-sided dolphins (*Lagenorhynchus acutus*) and Short-beaked common dolphins (*Delphinus delphis*) frequent these waters. These species are found in the Odontocete parvorder, or toothed whales, and possess biosonar, or echolocation.

The IFAW's Marine Mammal Rescue Response team has data where pingers were deployed in stranding events. A stranding event is where animals were in distress from beaching (on land) or found in lagoons during low tide or storm events (milling events) where human intervention was warranted (Brownell, Yao, Lee, & Wang, 2009; Sharp, 2017). Mass stranding events are not uncommon on Cape Cod's inner beaches. Though researchers are unsure of why whales and dolphins mass strand, leading theories include severe weather events, health issues from a lead animal, following prey or predator avoidance, or disorientation from mid-level anthropogenic sonar. These animals are herd animals and highly social: if one animal enters a dangerous zone, the others can follow. To help mitigate actual stranding events, pingers have been suggested and implemented.

Mitigating Bat Mortality at Wind Energy Facilities

The extent and magnitude of bat fatalities at wind energy facilities is a concern among the wind energy and wildlife stakeholder community. Mitigation techniques are still new to the field. Novel technology is still in testing phases for LBW. However, understanding where the nexus of monitoring and mitigation come together for reduced bat mortalities is proving challenging.

Turbine Curtailment, Cut-in Speed and Feathering

Based on the relatively narrow timing and weather conditions when bats are most at risk (i.e., late-summer and under low wind speed conditions), preventing turbine blades from spinning at high rpms may reduce bat fatalities. This is commonly referred to as curtailment and involves feathering turbine blades and raising the cut- in speed. Arnett et al. (2013) defines curtailment, cut-in speed, and feathering as follows:

- Curtailment is the act of limiting the supply of electricity to the grid during conditions when it would normally be supplied.

- Cut-in speed is the wind speed at which the generator connects to the grid and begins producing electricity. The manufacturer's cut-in speed for most contemporary turbines is between 3.0 and 4.0 m/s.
- Feathering is the process of adjusting the angle of the rotor blade parallel to the wind, or turning the whole unit out of the wind, to slow or stop blade rotation.

Although curtailment has been successful in reducing bat fatalities, it results in loss of renewable energy generation (Arnett, Johnson, Erickson, & Hein, 2013b). Moreover, as wind energy development moves into lower wind regimes and turbine technology allows for lower cut-in speeds, curtailment will become more difficult to implement. Thus, additional impact reduction strategies are necessary to offer a suite of options that meet both conservation and energy production goals.

Ultrasonic Acoustic Deterrents

Ultrasonic acoustic deterrents (UAD) are technological devices that emit sonic wave patterns at various frequencies above human hearing, 20–120 kHz. The intent is to create a disorienting environment for echolocating bats and reduce their activity in the airspace ensonified by the devices (Arnett et al., 2013a; Arnett et al., 2013b; BCI, 2018). Deterrent technologies are in various stages of development and testing. Several nacelle-mounted technologies are commercially available, whereas blade-mounted devices are in earlier stages of R&D. Sound transmission varies by technology, with some using piezoelectric transducers or a pneumatic system to emit ultrasound. Although UADs can reduce bat activity and fatality at wind turbines, results are inconsistent across species (Arnett et al., 2013; Romano et al., 2019; Bat Conservation International, 2020). This may be in part due to the physics of sound propagation. Sound attenuates in the atmosphere with higher frequency sounds dissipating faster than lower frequencies. As a result, generating ultrasound to ensonify the entire RSZ, particularly for devices mounted on the nacelle, remains challenging.

Efforts to improve UAD technology include assessing different signal patterns and placement options and combining UADs with other minimization strategies. There are new research goals, mentioned in Environmental Impact Reports or Assessments (EIR/EIAs) for new wind projects, that will employ bat UADs proactively (Pelletier et al., 2013; Peterson et al., 2016; Staoil, 2013). This information is based on detection of bats in the offshore area from field studies. Using comparisons studies from LBW research and applying it to OBW can guide policy requiring UAD technology to conserve bat populations.

The first generation NRG Bat Deterrent System (NRG Systems, Hinesburg, Vermont) uses piezoelectric transducers to generate high intensity ultrasound within the frequency range of most bats in North America (Hein, pers.comm, 2019). Each device consists of 6 sub-arrays, or speakers, each with its own resonant frequency (Figure 11). In total, the frequency range of the device is 20-50 kHz (Weaver, 2019). The UADs are installed on the nacelle of the wind turbines and can be oriented in any direction, depending on the desired acoustic effect (Figure 12).

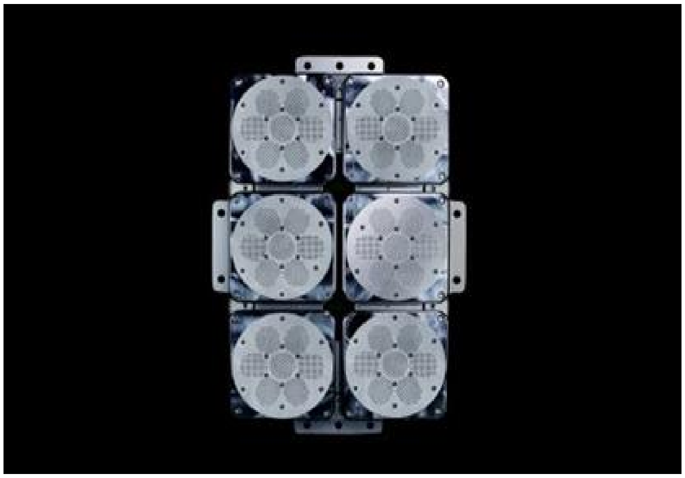


Figure 11. NRG Systems first generation UAD Array (NRG Systems, 2019).

Figure 12. Two installed acoustic deterrents on top of a wind turbine nacelle at Duke Energy’s Los Vientos facility. Image by Will Ramirez (2019).

The effectiveness of nacelle-mounted deterrents may depend on the size of wind turbines. Blade lengths continue to increase for LBW and OBW turbines. On average, land-based turbine blades measure approximately 35–50 m compared to offshore blades at 80–100 m (Figure 13). The new 12 MW GE Haliade-X will be the largest turbine is existence with blade lengths of 107 m with a 38,000 m^2 RSZ (GE, 2020). Longer blades exacerbate the difficulties of ensonifying the entire RSZ. Research to improve the technology (i.e., generate higher intensity signals, optimize placement and orientation on the nacelle) at LBW may prove useful when adapting the technology for the much larger OBW turbines. Moreover, pairing of nacelle- and blade-mounted deterrents, or combining UADs and smart curtailment, may mitigate potential risks to bats at OBW.

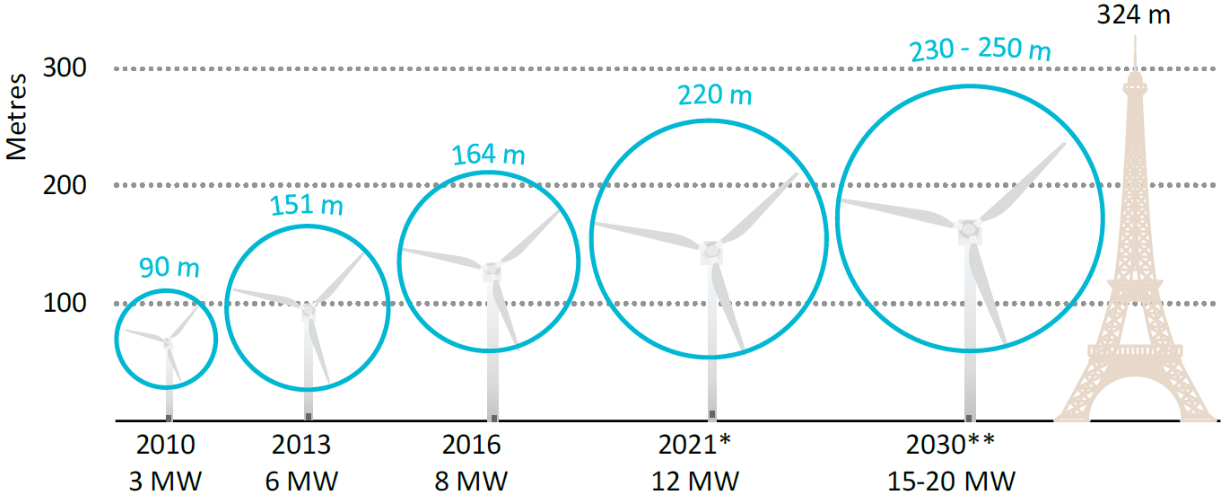


Figure 13. Comparison of RSZ and height of onshore and offshore wind turbines (IEA, 2019).

Aquatic Acoustic Deterrents

Acoustic deterrent devices (ADDs) are devices used to dissuade odontocetes from approaching objects or areas that may cause harm. Aquatic acoustic deterrents (ADDs) or pingers are different from UADs in that they are made to be submerged, are battery powered and in the case of the models used in this study, not manually programmable. They were designed to be placed on fishing gear to deter predation of commercial fish species. Similar to the aerial UADs, they broadcast ultrasound within the range of 20–160 kHz depending on model of pinger.

ADDs have been used to deter odontocetes away from pile driving activity (near field injury) while installing new offshore turbines in the North Sea. Both the ADD and the pile driving noise has caused species displacement (Graham et al., 2019). For example, with ADD use, Harbor porpoise (*Phocoena phocoena*) response increased 30-50% with near field distance activity versus no ADD (Graham et al., 2019). Furthermore, ADD use was a significant covariate during the 12-hour response but diminished in effect in the 24-hour responses and beyond.

There are similar in-field examples of using ADDs with odontocetes to deter them from mouths of bays, shallow lagoons, high episodic tidal marshes and mudflats to mitigate mass stranding events (Coram, Gordan, Thompson, & Northridge, 2014). Odontocetes also have established feeding and migration patterns, though these patterns are not as seasonally defined as mysticetes, or baleen whales. Cold fronts and storms change water column patterns of diet items, such as schooling fish. Individuals or pods of odontocetes will hunt by following erratic movements of schooling fish, and this can lead them into shallow bays, lagoons or even estuarine systems. With high tidal fluctuations in some of these systems, odontocetes will become trapped, and possibly strand.

While not many published documents highlight stranding event mitigation using ADDs, there are a few studies out of Taiwan and Australia where rescue groups and biologists have used ADDDs, also called “acoustic pingers” or “seal scarrers”, with some success (Brownell et al., 2009). The basis for using these ADDs to mitigate odontocete stranding events was taken from research used by the commercial fishing industry and several governmental agencies such as National Oceanic and Atmospheric Agency (NOAA) and National Marine Fisheries Service (NMFS) in attempt to reduce bycatch and predation upon desired fish stocks (Long et al., 2015; Fishtek, 2019). These devices are not used with regularity due to mixed results in past deployments and the problematic ability to predict when an odontocete stranding event might occur. Despite organizations not deploying ADDs at every event, deterrence successes have been noted (Sharp, 2017).

To avoid deleterious near-field effects to marine mammal hearing thresholds, agencies have required deterrents during underwater construction, such as pile driving for offshore turbine installation (Long et al., 2015; Graham et al., 2019). This is in comparison to trawl, longline and pot fishing techniques where pingers were not an overall successful deterrent for odontocetes over time (Hamilton & Baker, 2019). In more neophobic species, such as harbor porpoises, pingers are more effective in deterrence, but not for more gregarious species such as bottlenose dolphins (Dawson, Northridge, Waples, & Read, 2013; Long et al., 2015; Hamilton & Baker, 2019). North Sea Harbor porpoise individual response to offshore turbine noise seems to peak at near field (within 20 km); however, species population level effects were still evident at 20–50 km far-field from primary noise source (Graham et al., 2019). Graham et al. (2019) used Germany as an example of ADD deployment, where it is mandatory to deploy pingers at least 30 minutes before piling to mitigate the risk of physical injury. However, they also noted that it is difficult to determine what causes response, whether it is from the ADD, pile driving, construction vessel noise, or a cumulative effect.

Many studies found large exclusion zones around pingers (Culik, Koschinski, Tregenza, & Ellis, 2001; Graham et al., 2019). This could be attributed to noise in water traveling faster than air. Culik et al. (2001) describe that porpoises can be alerted by the pinger, investigate the ensonified area with echolocation and from that information, identify the net and pingers and be able to navigate around the area. There might be multiple factors why the harbor porpoises avoided the ensonified pinger areas in the study. One factor might be prey redistribution and another might be alerting. While startling was also a factor, most startle responses have an acute threshold, and animals will enter the area again after desensitization (Coram et al., 2014; Graham et al., 2019). Prey redistribution was mentioned by various studies where herring (Clupea harnagus), a preferred prey item will also respond to ultrasonic sound and move out of the area (Culik et al., 2001; Hamilton & Baker, 2019). There are also opportunities for animals to move in acoustic "shadows" where there are smaller ensonifed areas, maybe from a single pinger, and the animals will still enter a danger zone (Coram et al., 2014). This is important to note for differences between odonotcetes and bats entering deterrent ensonified areas. Odontocetes can identify a stationary object such as a driftnet lined with pingers. Conversely, bats need to identify moving turbine blades in a deterrent-ensonified area using echoes that change with blade movement and placement in space for collision avoidance

As with bats, it remains unclear how odontocetes are affected or respond long term to deployment of deterrents. A 2015 National Oceanic and Atmospheric

Administration (NOAA) report recognizes numerous research gaps regarding acoustic deterrent effectiveness with repeated uses in marine mammals (Long et al., 2015). The NOAA report also mentions species displacement at a population level from ensonified areas a concern and called for further research to help fill knowledge gaps.

Bat and Wind Energy Working Groups

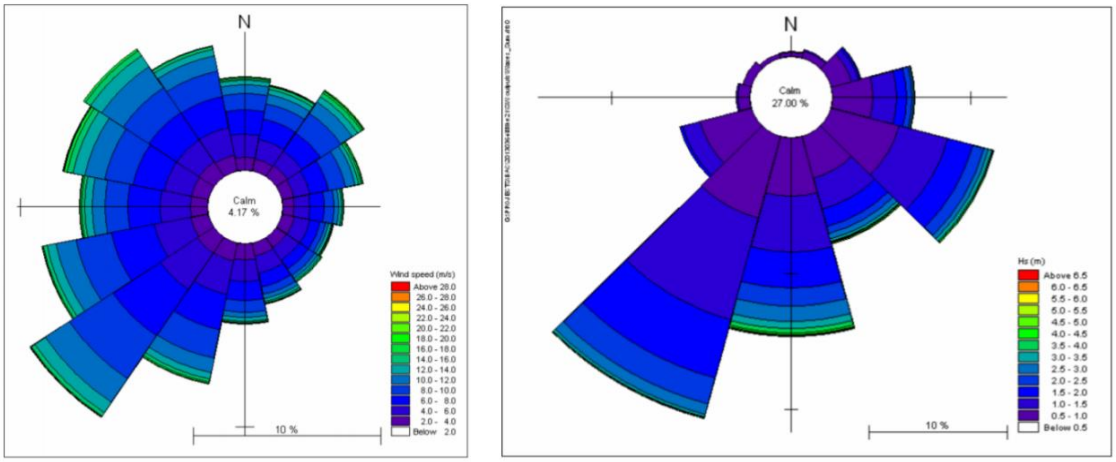
Bat conservation is increasingly becoming an important aspect of the renewable energy sector. Collaborative teams have organized to address this, and other environmental issues associated with wind energy, such as the Bats and Wind Energy Cooperative (BWEC) and Working Together for Resolving Environmental Effects of Wind Energy (WREN). BWEC was formed in 2003 by Bat Conservation International (BCI), the US Fish and Wildlife Service (USFWS), the American Wind and Energy Association (AWEA) and the US Department of Energy's National Renewable Energy Laboratory (NREL) to develop and disseminate solutions to reduce bat fatalities at wind energy facilities (BWEC, 2020). Members of other organizations such as US Geologic Survey, several universities, wind energy company representatives and NGOs form committees that focus on feasibility of BWEC objectives, scientific guidance for BWEC sponsored research and general oversight of BWEC's implementation goals.

WREN or, the IEA Wind Technical Collaborative Program Task 34, was formed in 2012 (IEA, 2018). Task 34 recognizes the need to protect wildlife as the growth of wind energy facilities are expanding globally. WREN tasks include supporting wind-wildlife mitigative strategies, wind siting, deployment of technology for policy decisions and habitat level research. WREN is supported by the US Department of Energy's Wind

Energy Technology Office (WETO) and operated by NREL. Tethys (http://tethys.pnnl.gov) an interactive platform website, managed by the Pacific Northwest National Laboratory (PNNL) curates international marine and wildlife collaboration and outreach and hosts WREN as another portal for information dissemination on wildlife and wind energy (Tethys, 2020).

Importance of Mitigative Action at OBW

Since offshore wind is a relatively new renewable energy source, there are opportunities to conduct research and proactively identify data gaps prior to broadscale development. Studies show bats use the offshore areas where new OBW projects will be sited (Pelletier et al., 2013; Peterson et al., 2016). Data gathered from LBW can be used to extrapolate how cumulative effects from wind energy may impact bats offshore. This could prompt proactive mitigative responses prior to construction. Many physical, environmental, and biological variables used to predict suitable wind project siting can be compared directly from LBW to OBW. The same variables can be collected pre-construction for onboarding new OBW sites (Figure 14). The deployment of UADs at OBW can benefit from multi-year studies at LBW to reduce bat mortality rates from wind turbine blade collisions (Arnett et al., 2013; Weaver, 2019).



Wind and Wave Distributions

Figure 14. Wind and Wave Rosette Graphics for Block Island Wind Project Site Assessment (Muuss, 2018).

A cumulative effects assessment (CEA) is a complex methodology of identifying net impact estimates on an environmental aspect, in this case, a targeted species population, based on the precautionary principle and knowledge decision making processes (Allison et al., 2019; Goodale & Milman, 2019; Platteeuw et al., 2017). A six-step assessment process was established to simplify CEAs and address specific issues, identify relevant causes and plan monitoring and mitigation options through adaptive measures (Platteeuw et al., 2017). The EU believed cumulative effects to be important enough of an issue that language was included in two legislative directives: the EU Birds Directive (1979) and the EU Habitats Directive (1982).

In a five-year period, 12 new OBW permits were received by the Dutch government (Platteeuw et al., 2017). Four of the 12 applications were required to produce an environmental monitoring program based on CEA guidelines to fill knowledge gaps regarding how OBW siting could affect specific species. Harbor porpoises are a species of concern in the North Sea as OBW construction has shown habitat and prey patch displacement from pile driving towers. Migratory bats use the North Sea as flyways. Assuming OBW will continue to grow globally, especially around North America and the EU, mitigative action for bat and odontocete detrimental activities or fatalities with offshore wind siting should include proactive use of a suite of monitoring and deterrent technology to quantify and potentially reduce adverse impacts to these species. Feasibility studies supporting permit decisions using a cumulative effect model to reduce these negative effects can be a tool in mitigative species protection.

Echolocating bat and odontocete regulatory action could be suggested using the outcome of UAD successes or failures. Multi-sensor arrays for bat strike detection could be coupled with deterrents to form multi-dimensional results (Suryan et al., 2016). A Wind Turbine Sensor Unit for Monitoring of Avian & Bat Collisions (WindTechnology Ref. # OSU-15-21) was introduced by Suryan et al. (2016). This sensor offers wireless collision event-based data to determine what species is connecting with wind turbine blades. This technology is applicable to both LBW and OBW and can be fitted post construction or proactively installed on pre-operational wind turbines. It consists of accelerometers, visual and IR cameras and sensors that can decipher species. Suryan et al. (2016) suggested the deployment of an integrated impact detection system could help validate the efficacy of deterrent or operational measures that are employed to mitigate species impacts.

Arnett & Baerwald (2013) recommended that impacts from the first several offshore wind energy facilities proposed and built in North America, including those on inland waters such as the Great Lakes, be evaluated extensively both for fatality and displacement effects (Peterson et al., 2016). Furthermore, predicting fatalities at existing and planned wind energy facilities offshore will be required to understand impacts and develop mitigation strategies. Ground-truth testing UADs for wind turbine placement is a favorable economic choice. OBW risk assessment algorithms can be applicable across ecoregions and species assemblages such as *Myotis* species in sea caves, not just migratory tree-roosting bat species (Hayes et al., 2019).

Proactive pre-construction monitoring using modular technologies, such as acoustic detection and imaging can guide population or species level-based effect permitting. UADs and other proactive mitigative techniques could be included in a CEA or ES/EIA to guide conservation regulations for OBW. Siting decisions should include MET data, seasonality of at-risk species and best practices for either landscape or seascape management. Adaptive management through siting, acoustic deterrents, smart curtailment and post construction long term monitoring programs can be strategies for strong economic and conservation strategies for OBW.

Research Hypotheses, Questions and Specific Aims

My primary research question was: if data show high bat activity during certain times of the year, can strategic UAD deployment reduce seasonal bat fatalities at wind project sites versus where no UADs are present? Therefore, my primary hypothesis was that UAD presence on wind turbines during times of increased bat activity reduces bat fatalities at wind energy facilities.

A secondary research question was: do abiotic variables have significant effects on bat activity that could lead to increased bat fatality events at wind energy facilities?

The corresponding secondary hypothesis was that high winds, low barometric pressure and low temperatures reduce bat activity and thus reduce bat fatality at wind energy facilities.

A tertiary research question using odontocete stranding event data as a proxy for bats was: if odontocete and bat echolocation frequencies are similar, will the same UAD technology work on both, regardless of medium (air versus water)? If there is no correlation, why not? Theoretically, the same deterrent technology would be successful for mitigating bat fatalities at offshore wind energy facilities when compared to archived successfully averted odontocete stranding data (IFAW archives). The hypothesis related to this was: since odontocetes and bats echolocate in the same frequency band, both groups of species will respond similarly to UADs, regardless of medium.

Specific Aims

To meet my research objectives, this study:

1. Analyzed temperature, barometric pressure, and wind speed to determine the most significant abiotic, or environmental variables to guide bat fatality mitigation at OBW.
2. Identified UAD successes from *in situ* LBW research and if extrapolation to OBW was feasible.
3. Addressed applicability using a multi-variate approach, and comparisons and contrasts made through modeling for multi-locational bat data.
4. Compared UAD deployment during odontocete stranding events to determine if they could be a proxy parallel to bat mitigation at wind energy sites.

5. Applied positive outcomes from data analysis that shows how to suggest OBW policy language to protect bat populations by reducing blade related fatalities using UADs.

Chapter II

Methods

Data were obtained with permission from three different land-based wind energy facilities in Canada and two in the United States for a total of five sites. I used all five wind energy facilities as a singular combined dataset that totaled 2,318 turbine data points. I renamed the five facilities Site A through Site E to provide anonymity of the operators. Site specific factors were omitted from the statistical analysis. Sites differed by turbine manufacturer, turbine dimensions, and facility capacity (Table 1). Each site varied in study duration. Therefore, I chose a subset of the data (30 July 2017–1 October 2017) that overlapped among sites. This date range reflects the majority of the fall migration season and potential highest period of risk (Arnett & Baerwald, 2013; Lagerveld et al., 2017; Limpens et al., 2017; Sjollema et al., 2014).

Deterrent Specifications

Each project had selected a random subset of turbines for UAD placement. Treatments were implemented on a randomized schedule, such that control (UAD off) and treatment (UAD on) rotated on a nightly basis. This was to prevent spatiotemporal bias. Each site employed first generation UAD Bat Deterrent Systems manufactured by NRG Systems (Hinesburg, VT). All five sites used a 6-array deterrent configuration on their treatment turbines. These arrays produced a continuous signal with a frequency range between 20–50 kHz (Weaver, 2019). Most bats known to these regions echolocate in this frequency range. Although there are species with lower frequencies within range of these sites, these species are not known to interact with wind turbines. All five sites used the configuration of four UADs on the top of the turbine. However, placement under the nacelle differed among projects (Hein, pers. comm, 2020). Deterrent placement under the nacelle differed among sites to assess whether bats approach from different directions (Arnett et al., 2013a; Arnett et al., 2013b; Baerwald et al., 2014; Hein et al., 2013; Weaver, 2019). Comparisons among the different UAD configurations are not included in this study.

Table 1. Wind project site specifications for comparisons and similarities.

Site	**Generation Capacity**	**Turbine Type**	**Nacelle Height**	**Blade Length**
A	304 MW	152 Gamesa G90, 2.0 MW	100m	44m
B	149 MW	92 GE, 1.6MW	80m	49m
C	102 MW	1 GE ESS, 1.5MW; 62 GE ESS, 1.6 MW	80m	49m
D	60 MW	37 GE, 1.6 MW	80m	49m
E	510 MW	225 Vestas V-110, 2.0 MW	95m	54m

Variables Analyzed

I analyzed abiotic variables that influence bat activity and mortality at land-based wind turbines. These variables can be easily obtained from MET tower data, as most projects collect these variables opportunistically. These variables may also influence bat and wind turbine interactions in the offshore environment. The offshore environment usually is a steadier state regarding temperature and barometry fluxes due to large water bodies cooling and warming at a slower rate compared to land (Bender & Hartman, 2015; Smith & McWilliams, 2016).

Effectiveness of the treatment turbines, or turbines with operational UADs, was determined by overall bat carcass count and count of individual species. Carcass counts were determined by on-ground observational bat surveys around the turbines of each site throughout their study period. Some species that were identified in the studies include: Mexican free-tailed bat *(Tadarida brasiliensis*), Northern yellow bat *(Lasiurus* [*Dasypterus*] *intermedius),* Hoary bat (*Lasiurus cinereus*), Southern yellow bat *(Lasiurus [Dasypterus] ega/xanthinus),* Evening bat *(Nycticeius humeralis),* Eastern/ Western red bat (*Lasiurus borealis/blossevillii*), and Cave myotis *(Myotis velifer*). Seasonality, geographic site location and species will be static, or controlled variables, and not used as individual statistical variables in the models.

I reviewed the Massachusetts based International Fund for Animal Welfare's (IFAW) Marine Mammal Rescue and Research Program's archived stranding records from 1999 to 2012. These records consisted of individual real time stranding reports that were completed on site during stranding events and compiled summaries post-stranding events. There is also a Protocol for Mass Stranding Prevention through Acoustic Deterrence and Physical Herding document that has pingers as a part of the decision tree for stranding events. The stranding reports included information such as location, observer name, species and number of animal(s) in the event, time, weather, substrate and other variables. If herding behavior or deterrent methods were deployed during stranding events, they were recorded on these stranding sheets, or post-event on herding or stranding event summary sheets. I reviewed summaries, stranding and herding event sheets, and compiled datasheets for incidences of herding with pingers. All species were of the parvorder Odontocete. The species most encountered were; Atlantic White-Sided

Dolphin (*Lagenorhynchus acutus*), Long-finned pilot whale (*Globicephala melas*), Short-finned pilot whale (*Globicephala macrorhynchus*), Common dolphin (*Delphinus delphis*), Risso's Dolphin (*Grampus griseus*), Harbor porpoise (*Phocoena phocoena*) and Bottlenose dolphin (*Tursiops truncatus*).

Data collected included each event that included deploying submersible pingers and the successive behavior changes in the odontocete(s). The two submersible acoustic pingers used were the: 1) AQUAmark 200 (Aquatec Group, Hampshire, United Kingdom), and 2) Dukane NetMark 1000 (Dukane KVT, Illinois). These pingers have acoustic ranges from 5-160 kHz harmonic frequencies. This acoustic range is comparable to the UADs used on the turbines for bats (Table 2). Pingers are deployed often with more than one used in harmony along trailing edges of nets or pots. The rescue team used them as single, or up to six pingers at a time to redirect odontocetes from entering shallow areas where stranding events could occur or had already occurred. Team members used deterrents sparingly, and usually with other deterring tactics such as engine revving and banging on boat sides. Pingers were placed in the water shoreward of the animals, allowing for access to open, deeper water (Figure 15). The pingers come pre-programmed to emit pulsed sounds within their frequency range at a set rate in a randomized cycle. Both types of pingers had ensonification ranges between 100–200 m. The pingers were used sparingly and not at each stranding event.

Table 2. Comparison of three Ultrasonic Acoustic Deterrents.

Deterrent	Manufacturer	Application	Purpose	Harmonics Range	Sound Range
Bat Deterrent System	NRG Systems	Aerial	Deter bats from wind turbines	20-50kHz	122dB
NetMark 1000	Dukane KVT	Submersible	Deter marine mammals from fishing gear, stranding events	10-12Khz, <100kHz	132dB
AQUAMark 200	Aquatec	Submersible	Deter marine mammals from fishing gear, stranding events	5-160kHz	145dB

*Sound pressure range=dB re.1µPa@1m

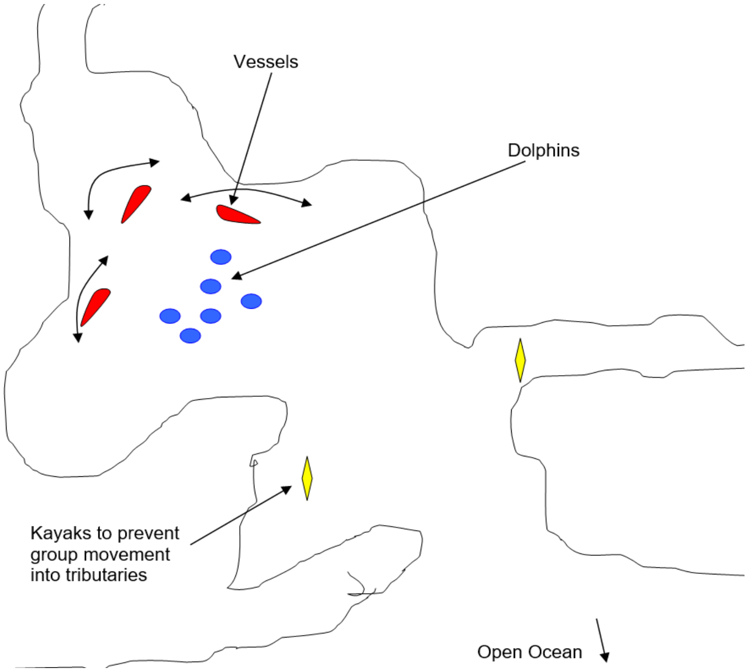


Figure 15. Diagram from IFAW Protocol for Mass Stranding Prevention through Acoustic Deterrence and Physical Herding illustrating proper pinger deployment in a possible stranding event (IFAW, 2011).

Data Analysis

I established three different statistical models: 1) UAD efficacy, 2) abiotic variables on treatment turbines, and 3) abiotic variables on control turbines. These were applied to all five wind project sites. Model 1 was run to determine if UADs on turbines significantly reduced bat fatalities relative to control turbines. In Model 2, the three abiotic variables and treatment turbines were assessed to determine if any environmental variable influenced bat fatalities, even when a UAD was operating. Model 3 examined the three abiotic variables and control turbines. Bat carcass counts were the response variable for all three models. Carcass data were grouped into one overall carcass count ("Ct.Carc.") category, and not by individual bat species. This was done to simplify the model and to account for some datasets that did not survey due to events such as inclement weather or could not differentiate species due to predation or degradation of carcasses.

The models' predicator variables were the all the abiotic variables pertaining to meteorological data such as temperature (˚C), wind speed (m/s) and absolute barometric pressure (mbar). All data were collected from MET towers in the vicinity of each site. Each abiotic variable was averaged across the night. An average night was usually categorized as dusk through dawn. Averaging the data assisted in filling in missing data and avoiding gaps in the model.

As output of the three statistical models, beta coefficients were calculated. Beta coefficients are valuable in determining the strength of the independent variable effect on the dependent variable. In the case of my models, these represented the effectiveness of UADs on deterring bats (Model 1), or the strength of the abiotic variables on the carcass counts for Models 2 and 3. Ninety-five percent confidence intervals were calculated for the beta coefficients by multiplying the standard error (SE) by 1.96 (Weaver, 2019). If the interval crossed zero, then the beta coefficient was considered non-significant.

Statistical Model Code

I used generalized linear mixed model (GLMM) for all three models. I conducted the analysis using R version 3.6.1 (The R Foundation for Statistical Computing, 2019) and package “glmmTMB” due to its ability to fit Poisson distributions and negative binomial error distributions, which were run for the three models (Weaver, 2019). For the first model, turbine was coded as a random effect and deterrent was coded as fixed effect. For the second model, turbine was a random effect, treatment turbines were fixed effects, and abiotic variables were predicator variables, or covariates. For the third model, turbine was a random effect, control turbines were fixed effect and abiotic variables were predicator variables, or covariates. I looked at the combined data sites as random effects due to differences in physical location and opted for no spatial analysis. This was to account for locational anomalies of each site and to disallow any one site to influence the model or the fixed effect calculations.

Chapter III

Results

The best fit model for all three models was a type 2 negative binomial (nbinom2) based on the Akaike Information Criterion (AIC) (Table 3). Presence of operational UADs on turbines was the most significant effect when attempting to reduce bat collision events from wind turbines (p <0.001). Overall, there is an established effective outcome from deploying UADs on turbines when compared to control turbines without UADs.

Table 3. R Model results from poisson formula data output.

Variable	AIC	BIC	LogLik	Dev.	df resid.
Deterrent	2425.4	2454.1	-1207.7	2415.4	2303
Abio.Deterrent	1079.6	1114.9	-532.8	1065.6	1139
Abio.Control	2410	2450.2	-1198	2396	2301

AIC=Akaike Information Criterion; BIC=Bayesian Information Criterion; LogLik=logistic liklihood; Dev.=deviance; df resid. =degrees of freedom

Model 1: UAD Efficacy

Model 1 shows that when UADs are operational, there is a statistically significant reduction in bat fatalities when compared to control turbines (p=0.013, Table 4).

Table 4. Model 1: Statistical results of UAD efficacy on treatment turbines versus control turbines.

Variable	Estimate	SE	*Z* Value	*P* Value
Intercept	-1.64	0.17	-9.69	(<0.001)
Treatment	-0.31	0.12	-2.49	**0.013**

Model 2: Abiotic Variables and Treated Turbines

Average carcass counts among sites varied across the study period and with abiotic variables (Figures 16, 17 & 18). However, none of the three abiotic variables were statistically significant in reducing bat fatalities at treatment turbines (p >0.05, Table 5).

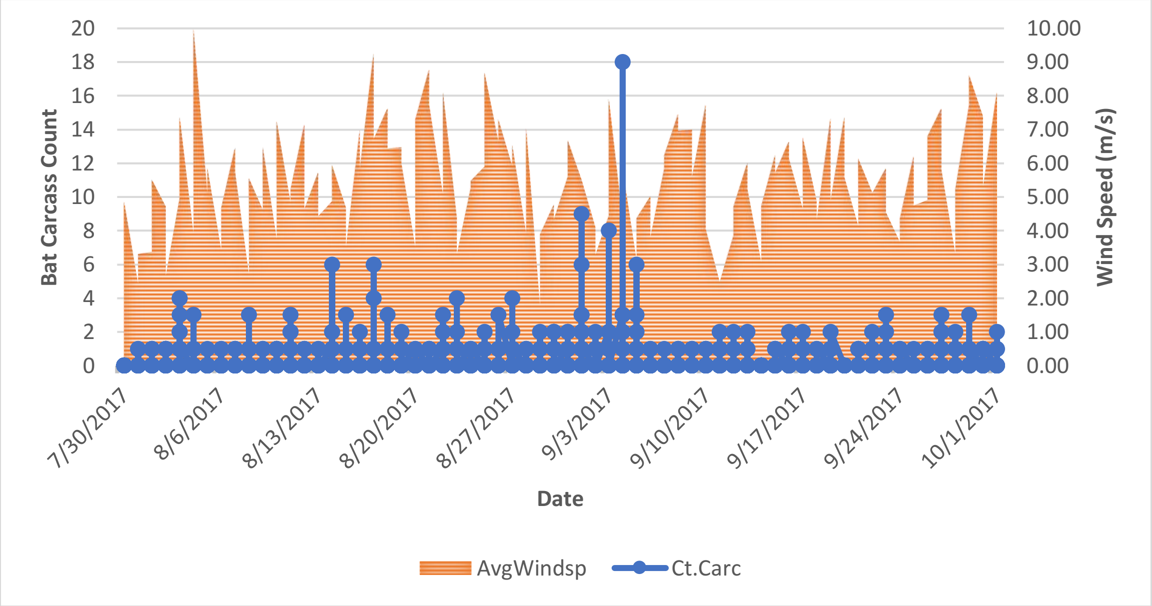


Figure 16. Relationship between averaged nightly wind speed (AvgWindsp; m/s) and numbers of observed bat carcasses (Ct.Carc.) between 30 July and 1 October 2017 across five sites in North America.

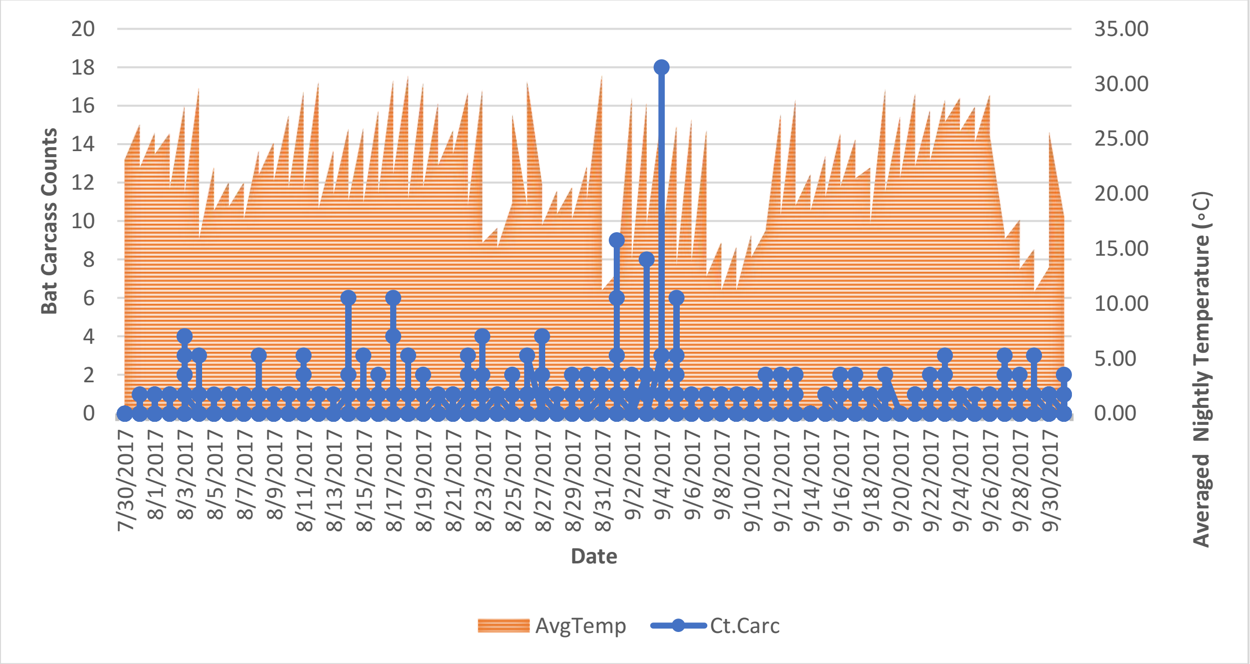


Figure17. Relationship between averaged nightly temperature (AvgTemp; ˚C) and number of observed bat carcasses (Ct.Carc) between 30 July and 1 October 2017 across five sites in North America.

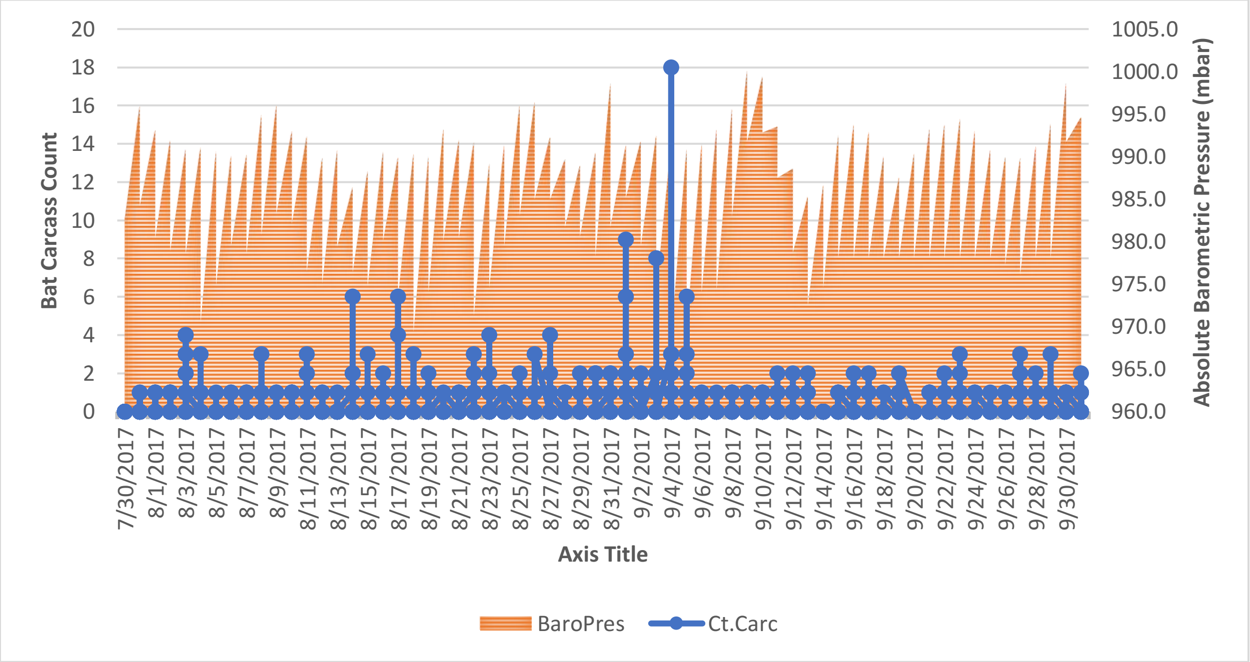


Figure 18. Relationship between averaged nightly absolute barometric pressure (BaroPres; mbar) and numbers of observed bat carcasses (Ct.Carc) between 30 July and 1 October 2017 across five sites in North America.

Table 5. Model 2: Relationship between abiotic variables and treatment turbines.

Variable	Estimate	SE	*Z* Value	*P* Value
Intercept	-1.89	0.12	-15.55	(<0.001)
AvgTemp	0.06	0.12	0.54	0.59
AvgWindSp	-0.16	0.1	-1.61	0.11
AvgBaroPres	-0.05	0.11	-0.48	0.63

Model 3: Abiotic Variables and Control Turbines

The average nightly wind speed was statistically significant for the abiotic variables and control turbines model (p<0.001, Table 6). Site E exhibited the highest maximum wind speeds across all five sites. However, no site reported an average wind speed higher than 10 m/s wind speeds during the selected study period.

Table 6. Model 3: Relationship between abiotic variables and control turbines.

Variable	Estimate	SE	*Z* Value	*P* Value
Intercept	-1.77	0.18	-9.69	(<0.001)
AvgTemp	0.11	0.15	0.71	0.48
AvgWindSp	-0.33	0.69	-4.74	**(<0.001)**
AvgBaroPres	0.02	0.86	0.21	0.83

Beta Coefficient Value Graphs

Based on beta coefficients, I found a higher incidence of bat fatalities at control turbines (Figure 19). Operational UADs have a significant reduction effect on bat carcass counts as the beta value does not cross zero (Figure 20). For the abiotic variables and treatment turbines, the beta coefficient values showed no statistical significance (Figure 21). Wind speed was the only statistically significant beta coefficient for the control turbine abiotic model (Figure 22).

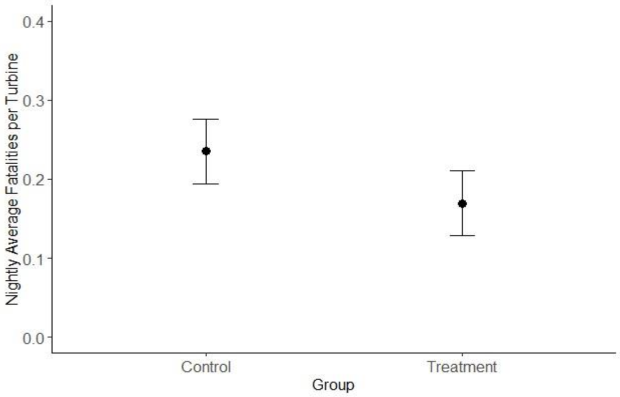


Figure 19. Mean and 95% confidence intervals for nightly bat fatalities at control (no deterrents) vs. treatment (deterrents on) turbines between 30 July and 1 October 2017 across five sites in North America.

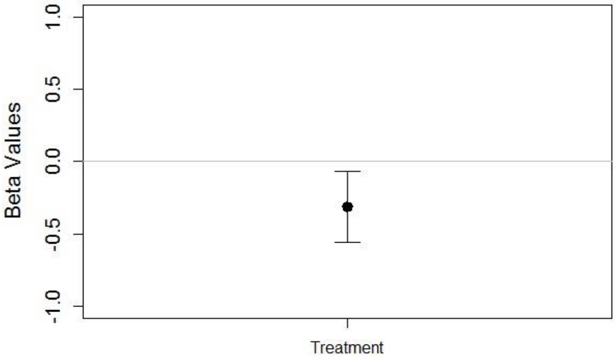


Figure 20. Mean and 95% confidence intervals for treatment turbines (deterrents on) between 30 July and 1 October 2017 across five sites in North America.

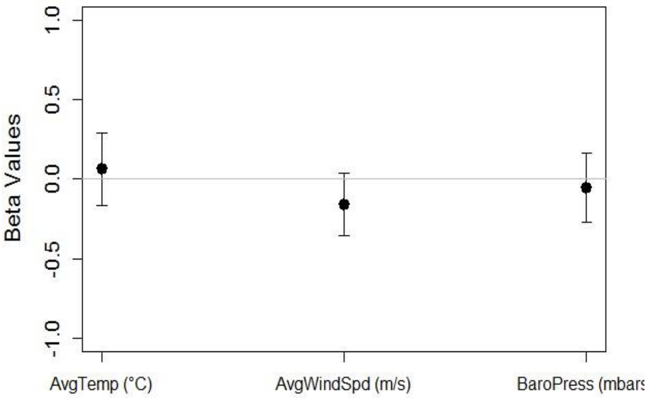


Figure 21. Mean and 95% confidence intervals for abiotic variables and treatment turbines (deterrents on) between 30 July and 1 October 2017 across five sites in North America.

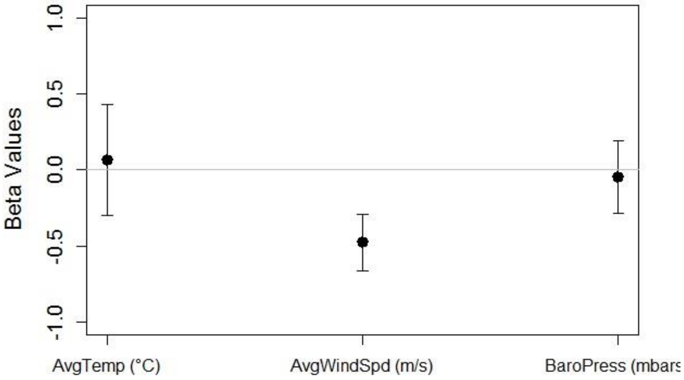


Figure 22. Mean and 95% confidence intervals for abiotic variables and control turbines (no deterrents) between 30 July and 1 October 2017 across five sites in North America.

Odontocete Stranding and Pingers

Over the14 years of data, there were eight stranding events recorded where pingers were used. Of these eight stranding reports, pingers were reported as effective for four. Two of these four reports used pingers as the solitary deterrent method with positive but mixed results. Two reports noted that most likely other deterrence techniques were more effective than the pingers. One report noted that animals were attracted to the pingers. Overall, due to small vessels only allowing a small number of personnel, the IFAW team stated they did not use the pingers regularly. Thus, there were insufficient data to make comparisons among species, locations or between the two pinger types (Patchett, pers.comm. 2019). Pinger deployment has mixed effects at being effective for reducing odontocete stranding events in this area.

Chapter IV

Discussion

Based on the data used for this analysis, I found a reduction in bat collision events at wind turbines with operating UADs. In addition, I found that wind speed was a significant abiotic variable related to bat fatalities at control turbines. I was unable to collect sufficient field data related to odontocete stranding events and the use of pingers. Therefore, relative to my initial hypotheses:

- Hypothesis 1 was accepted.
- Hypothesis 2 was partially accepted with wind speed being the only abiotic variable showing a significant relationship.
- Hypothesis 3 was not accepted as a result of insufficient data.

Deterrent technology has the potential to reduce bat fatalities regardless of wind speed and does not result in changes to normal wind turbine operations (Arnett et al., 2013; Romano et al., 2019; Weaver, 2019; Bat Conservation International, 2020). My results indicated a higher incidence of bat carcasses at control wind turbines, showing that treatment wind turbines with operational UADs were effective at mitigating bat fatalities. Although two nacelle-mounted technologies are commercially available, additional research on UADs is warranted to improve their performance for a broader range of species and adapt the devices to the offshore environment.

For the wind abiotic variable, there was a negative relationship between average nightly wind speed and carcass count. This is consistent with studies showing suppressed bat activity and mortality at relatively high wind speeds (Ahlen et al., 2007; Baerwald et al., 2009; Weaver, 2019). The relationship between wind speed and bat mortality at wind turbines led to investigations studying the effectiveness of curtailment in reducing bat mortality (Baerwald et al., 2009; Arnett, Huso, Schirmacher & Hayes, 2011; Arnett et al., 2013). However, given the loss of power generation and revenue associated with curtailment, other mitigation strategies are preferred. Thus, the effort to develop a robust UAD. There was not a significant relationship between mortality and average nightly temperature or average nightly barometric pressure.

There is a lack of US East Coast odontocete stranding events with data either from raw stranding reports or personal communication with the marine mammal stranding organizations. While pingers have shown some positive response on deterring odontocetes when used in the commercial fishing industry, there are no definitive results of pingers effectively deterring odontocetes from potential stranding events. At this point, this parameter cannot be used as a true indicator of UAD success for these species. Further results with repeated use of pingers during stranding events might yield more definitive results in the future.

Ultrasonic Acoustic Deterrents

In a 2019 press release, NRG Systems sold their first commercially available Bat Deterrent System to Kawailoa Wind, Hawaii's largest wind company (NRG, 2019). The system will be installed on an existing LBW turbine project on Oahu consisting of 30 wind turbines. The intent is to reduce fatalities of the Hawaiian hoary bat (*L.c. semotus*), a federally endangered subspecies. Given the echolocation range of the Hawaiian hoary bat and the success of reducing bat fatalities on the mainland, (Weaver, 2019), NRG and Kawailoa Wind anticipate UADs successfully reducing bat fatalities on Oahu. Vestas Wind Systems recently signed a strategic contract with NRG Systems to install their UADs on existing LBW turbines (Bates, 2019). Vestas is a large global wind solutions company with thousands of wind energy turbines. While the NRG System is only currently available commercially in North America, the agreement includes all Vestas wind turbines.

Although nacelle-mounted UADS are commercially available, they do have limitations. Sound attenuation remains a challenge for UADs and existing wind turbine designs. Current UAD manufacturers, including the NRG Systems, are not confident that frequencies at the higher end of the emission (i.e. 50 kHz) are ensonifying the entire RSZ at the intensity level necessary to deter bats at LBW turbines (Figure 23). Therefore, nacelle-mounted UADs may not, in and of themselves, be adequate. However, it remains unclear as to whether deterrents need to ensonify the entire RSZ to be effective. Assessing the effectiveness of UADs at wind turbines with various blade lengths and combining validation studies with thermal video monitoring may provide insight as to how bats are responding to this mitigation strategy.

As monitoring and mitigation technologies advance to commercialization, wind turbine manufacturers could incorporate proactive installation of these technologies when designing future turbine models. In addition to NRG Systems' Bat Deterrent System, General Electric has developed and tested a nacelle-mounted deterrent technology (Romano et al., 2019) and other organizations are designing blade-mounted systems. Advanced monitoring systems that combine multiple sensors such as acoustics, thermal, and collision detection, for example dtBat, remains an important component of research to assess collision risk and avoidance models, particularly for OBW (Liquen Consultoría Ambiental,S.L, 2020). Integrated monitoring systems used in concert with mitigation technologies may offer a more comprehensive assessment of risk and risk management.

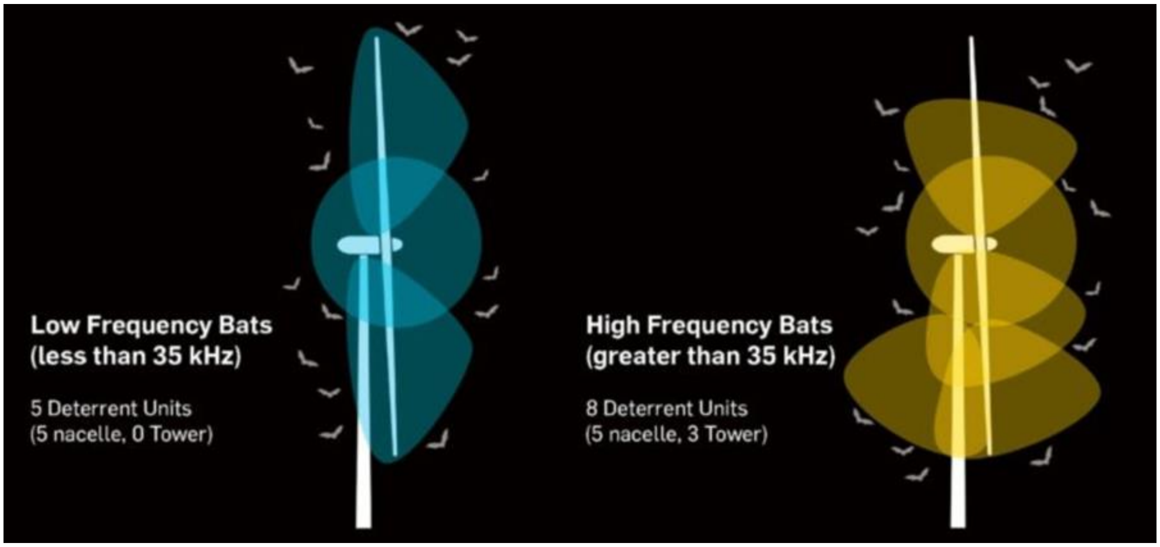


Figure 23. An illustration showing different configurations of the NRG Bat Deterrent System on a wind turbine, depending on the frequencies of the echolocation pulses emitted by bats in the area. (NRG Systems, 2019).

Technology providers need to consider environmental differences associated with offshore development when establishing monitoring and mitigating solutions. Equipment must be weatherized for a harsher environment that includes salt, wave inundation and higher wind speeds. Moreover, technologies must be able to operate for longer periods of time between maintenance checks or replacement. Travel to and from OBW is time consuming and expensive. Operation and maintenance require a cost benefit component and life cycle analysis (LCA) to help convince stakeholders and managers that a technology can be robust and effective, both environmentally and economically. The question of whether a UAD can handle the marine environment with minimal operational maintenance to make it cost effective enough for an operational mitigation tool is a necessary next step.

Future Offshore Wind Energy and Bat Protection

As of the first quarter in 2020, the installed capacity for wind energy in the US exceeded 100 GW (AWEA, 2020). With the exception of 30 MW from the Block Island Wind Project, current installed capacity comes from LBW. The U.S. Department of Energy (2015) estimated that by 2030 wind power generation would reach 224 GW, with 22 GW from OBW (USDOE, 2015). To reach the 35% wind energy by 2050 goals, installed capacity is expected to reach 404 GW, with 86 GW from offshore. The Offshore Wind Outlook (2019) report states that as OBW expands during this time, it is projected to become a $1 trillion industry (IEA, 2019). With approximately 80% of power demand originating from coastal states, OBW has the potential to more than double the power capacity available for US residents (Gilman et al., 2016). With current global electricity demand at approximately 23,000 TWh, OBW wind could offer 36,000 TWh from turbines sited in less than 60-meter water depth and within 60 km of shore distance (IEA, 2019).

Offshore wind turbines are being sited farther from near coastal areas due to the public opinion of sight lines and the increasing size of turbines (NYSERDA, 2017). As offshore turbines are sited farther from shore, this may decrease the likelihood of bats encountering them. Furthermore, larger wind turbines, with higher rated capacity, may result in fewer installations. However, these structures are getting taller with longer blades, perhaps making them more visible to bats. If bats do perceive these structures as potential resources, even if they are farther offshore, bats will still interact with operational wind energy facilities, particularly during migration. Because there remains a paucity of information about how bats use the offshore environment, it is difficult to make siting decisions that reduce risk. Understanding their migratory movement patterns should remain a priority as OBW continues to expand. A network of offshore structures (buoys, meteorological towers, decommissioned oil and gas platforms, lighthouses) can be employed for constant monitoring to help understand bat movement patterns offshore.

Relating bat activity and mortality at LBW to habitat and landscape features may inform siting decisions for OBW in the coastal zones. For example, heavily wooded areas in coastal zones can offer habitat for migratory tree-roosting bat species. This can also pertain to islands where wind turbines are located, such as the Block Island Wind Project (HDR, 2019). Levels of observed offshore activity were comparable between migratory and non-migratory species, and migratory bats were about equally likely to be recorded offshore as at coastal or inland sites. In contrast, non-migratory bats were less likely to be recorded at offshore sites relative to observed levels of activity at coastal and inland sites in the US (Pelletier et al. 2013).

High biodiversity and biomass of insects can attract multiple species of bats to wind energy sites. Insect abundance and availability are a factor that cannot be easily mitigated, so with floating offshore wind turbines sited farther from the shoreline, the presence of insects will presumably decrease, thus decreasing bat foraging activity. Flyways and migratory corridors should be one of the major contributing factors in wind energy project siting for both fixed and floating wind turbine sites.

Monitoring data from the past 6-8 years for established seasonal migration patterns, especially fall, has formed a baseline for locations such as the North Eastern Atlantic, the North Sea and mid Pacific California Coastal plains. Resources are being allocated into forming novel and efficient monitoring programs. Global web-based platforms offer siting and research outcomes, such as the Tethys supported "Environmental Effects of Wind and Marine Renewable Energy" portal or NOAA and BOEM supported MarineCadastre.gov (http://marinecadastre.gov) that offers OBW siting tools. While more baseline parameters need to be established, there is growing consensus that the time to begin mitigative efforts is now while OBW installed capacity is still relatively low (E. Arnett, pers. comm., 2019). While there are still data gaps that need identifying, active mitigative policy needs to be placed to have future and present wind projects held accountable for wildlife fatalities. Artificial intelligence (AI) technology (algorithms) connecting visual and acoustic detection is a first step in identifying bats in the area. However, after multiple seasons of research using this type of technology, it can be assumed a migratory flyway or feeding behavior spatial pattern is established and focus can turn to how to mitigate potential collision events through management plans involving industry and scientists. Baseline population and cumulative effects research can be ongoing for establishing local and regional databases; however, this can occur in concert with proactive mitigation policy for wind project siting.

Spatial monitoring is an important component for identifying and understanding population cumulative effects between bats and offshore wind. Policy cannot be successful if the overarching language does not encompass the population of each species encountering each OBW site. It is complicated to enact policy when unsure of the status and trends of populations, how bats are interacting with the OBW sites, and how to regionally enact laws across multiple countries and international waters. Therefore, project site policy should include language for spatial planning:

- Understand the migratory species in the area.
- If sites placed near islands or inlets, understand habitat use of mainland species.
- Quantify wind potential in area.
- Install proactive detection and deterrent technology that modularly work to recognize and mitigate bat activity around wind energy turbines.

Conclusions

Bats are valuable natural resource components, acting as natural predators for night-flying insects, pollinators, seed dispersers, and fertilizers (Jones et al., 2009). Protection of the more than 1,300 recognized global bat species is important for protection of larger natural resources. With anticipated growth of the wind industry combined with human and natural stressors, there is an increased possibility for population effects for many bat species. Bats are currently contending with multiple natural and anthropogenic issues. Cave hibernating bat populations are in decline from White Nose Syndrome (Frick et al., 2010). With climate shifts expanding species ranges, some bat species are moving northward. This could impact species moving up the coastal ranges of both the US West and East coasts, as potential wind energy sites have been proposed in the offshore areas of the Northeastern States (i.e. New York, New Jersey, and Massachusetts) (AWWI, 2018) and on the West Coast near the Channel Islands, Humboldt Bay in California, and north up the coast to Oregon (AWEA, 2019). As global

OBW expands, lessons learned from wildlife monitoring and mitigation studies at LBW may provide guidance for addressing impacts at OBW.

Overall, one mitigative strategy or technology may not be applicable in all scenarios. A mixture of smart curtailment, AI image recognition, acoustic detection, UADs-both nacelle-and blade-mounted, and working with industry to allow for construction modulation to wind turbines for the addition of external deterrent and monitoring equipment could be introduced to pre-construction EIA/ES permitting language. Pre-construction monitoring and EIA should be a requirement for each specific project including siting, habitat, seasonal and migratory corridors, species type, and prey availability for each species. Risk assessment language based on CEA, resilience indices, and species vulnerability on an ecosystem level is a new systems-thinking process that could prove effective in reducing bat fatalities at wind energy sites (Koppel, 2017; Platteeuw et al., 2017). This could apply to both bats and odontocetes as both species have shown behavioral changes by OBW.

New pinger research that may parallel aerial UAD research could help in protecting odontocetes and bats from OBW affects. As offshore wind expands, especially proposed floating turbine designs, marine mammals will face new obstacles such as cables and teethers. Pinger technology growth could aid in deterring migrating odontocetes from entanglement events.

Most of the research, including this study, are showing that UADs can reduce bat fatalities. With new UAD technology being developed and tested, and with the global expansion of wind energy, funding and industry resources should focus on how to make these deterrents as practical and applicable as possible. To enhance their success, continued monitoring at a global scale is necessary to ensure wind energy development is sustainable and wildlife compatible.

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