Multi-sensor Arrays Provide Complementary Information on Bat Presence and Activity in the Offshore Environment

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Survey Methods for Monitoring Bat Populations
2025 *Journal of North American Bat Research* Special Issue 1:75–88

Multi-sensor Arrays Provide Complementary Information on Bat Presence and Activity in the Offshore Environment

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Abstract - Two Acoustic and Thermographic Offshore Monitoring (ATOM) systems were deployed on wind turbines 42 km offshore to monitor bat activity throughout the year and around-the-clock, using thermal imagery, ambient-light video, and acoustic detectors. We documented a strong seasonal pattern, with 89% of bat detections occurring during late summer and early autumn. We recorded 31–38% of bat detections during daytime. Bats were present while turbine blades were spinning (64% of video detections), and although we occasionally documented altered flight paths, we never recorded a collision. Our results highlight the need for increased monitoring, using innovative and complementary methods, to understand bat presence and behavior in the offshore environment.

Introduction

The accelerated development of global offshore wind-energy production, with 64.3 GW in operation and another 380 GW expected in the next decade (Williams and Zhao 2023), and its potential impact on bats and birds, is highlighting a knowledge gap about presence and behavior in this harsh environment. Insights into bat presence and behavior offshore can increase understanding of the collision risk and species displacement in these areas. Bat occurrence offshore has been documented extensively in Europe (Ahlén et al. 2009, Lagerveld et al. 2021, Solick and Newman 2021), although research is limited in North America (Dowling et al. 2017, Willmott et al. 2023). Despite data on bat occurrence, there is little information on bat behavior offshore, and more specifically, bat interactions with offshore wind turbines (SEER 2022).

The limited data on offshore bat activity is understandable. Most bats depend on terrestrial food and are not expected to be offshore, except a few species, such as *Myotis vivesi* Menegaux (Fish-eating Bats) and *Noctilio leporinus* (Linnaeus) (Greater Bulldog Bats) (Bloedel 1955, Egert-Berg et al. 2018). Nocturnal habits and small size impede anecdotal observations of bats from vessels or offshore structures, and few surveys have been aimed at documenting bats away from the coast. Although acoustic techniques are commonly used for large-scale surveys, these methods are challenging, since platforms for stationary surveys are lacking, boat-based transects are expensive, and ambient noise offshore is considerable, which complicates acoustic analyses. Finally, the harsh marine environment can damage sensitive electronics, and retrieving data from remote recorders that do survive may be difficult.

The potential for bat exposure to wind turbines has forced regulators to address the existing knowledge gap. In Europe, potential impacts on bats from offshore wind-energy development have been recognized, based on both anecdotal and systematic observations (Ahlén 1997; Ahlén et al. 2007, 2009; Boshamer and Bekker 2008; Lagerveld et al. 2017, 2019; Poerink et al. 2013; Rydell et al. 2014), and pre-construction survey guidelines have been developed by specific countries and on a continental level (Rodrigues et al. 2015). In North America, most targeted bat assessments have occurred in the western Atlantic Ocean, off the coast of the United States, and have included acoustic surveys performed from

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Associate Editor: Aaron J. Corcoran, University of Colorado

buoys, islands, boats, oil rigs, and wind turbines (Normandeau Associates and Ocean Tech Services 2023, Peterson et al. 2016).

While acoustic surveys are standard, considerable uncertainty exists as to how representative acoustic records are of real bat presence, density, and species richness (Appel et al. 2021, Gibb et al. 2019, Torrez et al. 2017). This issue becomes more prominent when bat presence and density are low and occurrence is irregular, such as in the offshore environment. Due to the rarity of bats, any missed record (e.g., false negative) will cause a disproportionately large underestimate of bat presence (Appel et al. 2021). On land, this problem can be mitigated by physical surveys; for example, harp trapping or mist netting in addition to acoustic surveys can dramatically boost the number of species recorded (e.g., Appel et al. 2021), but these techniques are not possible offshore. Given that few terrestrial approaches are applicable over the open ocean, new methods and technologies are needed to expand opportunities in this space. One option is to use a multi-sensor, remote-sensing array. By relying on multiple sensor types, biologists can achieve both complementary documentation of bat presence and approximate the scale of false negatives for each sensor.

To improve the capability of detecting bats (and birds) in the offshore environment, we developed the Acoustic and Thermographic Offshore Monitoring (ATOM) system. ATOM is designed to be deployed on offshore wind turbines and uses ultrasound bat recorders to record echolocation calls, thermal cameras and ambient-light video cameras to detect and classify flying objects, and a very-high-frequency (VHF) receiver designed to detect Motus-tagged (https://motus.org/) birds and bats flying nearby. With these sensors, ATOM can operate autonomously 24 hours per day and 365 days per year in all weather conditions. ATOM can be accessed remotely via satellite modem for system health information and basic troubleshooting. Each sensor has its own drawbacks, but when operating together, a multi-sensor platform has fewer limitations than each sensor operating independently (Robinson Willmott et al. 2015, Willmott et al. 2023). The objectives of the study are to quantify bat activity around wind turbines in the offshore environment, characterize bat behavior at wind turbines, including avoidance behavior and collisions, and ultimately understand how bat activity correlates with multiple weather parameters. The current paper addresses the first 2 objectives.

Field-site description

The Coastal Virginia Offshore Wind Pilot Project (Dominion Energy 2024) is in federal waters, 43 km off the coast of Virginia (Fig. 1). The project consists of 2, 6-MW wind-turbine generators 1 km apart and a 34.5-kv transmission cable extending to shore through state and federal waters. The turbine nacelle (and monopole height) was 110 m above lowest astronomical tide (LAT), and blade length was 79 m. The lowest point of the rotor-swept zone was 33 m above LAT and 8 m above the "transition piece" (a platform at the base of the monopole that allows access to the turbine and houses additional turbine-related machinery and hardware). The transition piece was 12-m square and located 24 m above LAT, with the monopole passing through its center. The ATOM systems were installed on the transition piece of each turbine.

Methods

Study period

Although 2 ATOMs were deployed (1 on each turbine), the system placed on turbine 2 was removed during the second year due to logistical issues at the facility. Consequently, the data presented here are from turbine 1, years 1 and 2. In year 1, we deployed ATOM during 3 seasons: spring (1 April–15 June 2021), late summer and fall (15 August–31 October 2021), and winter (15 January–15 March 2022), during which uptime was 92%, 94%, and 75%, respectively. Downtime, in most cases, was a result of power outages at the turbine, except during a brief period in winter 2022 when damage to the satellite modem prevented remote login and correction. During this 15-day period (26 January–9 February 2022), ATOM recorded data, but they were not saved. In year 2, we deployed ATOM continuously for a full year (16 March 2022 to 15 March 2023), during which the uptime was 92%; any downtime was attributed to turbine maintenance. We performed bi-monthly data-retrieval trips to collect data from the sensors, provide fresh storage drives, and check equipment functionality and system health that could not be done remotely.

Data collection

Each ATOM combines 4 types of sensors that function concurrently (Fig. 2). To monitor animals by sound, ATOM uses 2 full-spectrum audible sound detectors for bird vocalizations and 2 full-spectrum ultrasonic detectors for bat vocalizations (SM4 and SM4Bat, respectively, Wildlife Acoustics, Maynard, MA). Acoustic data also provide some species-specific identifications for targets detected with thermal cameras that cannot otherwise be identified. While ATOM includes bird and bat acoustic sensors, only bat acoustic data are presented in this paper.

Two thermal cameras (Teledyne Tau 2, FLIR, Middletown, NY) provide data to quantify passage rates during low visibility, or when individuals are using reduced forms of echolocation or not vocalizing (Corcoran and Weller 2018, Corcoran et al. 2021). The 2 cameras, operating in stereo, permit calculation of flight heights. The thermal cameras record at 30 frames per second (fps), with a resolution of 640-by-512 pixels, using a 9-mm f1.4 lens. Preliminary tests showed that we can detect a tennis-ball-sized object, 6.5–6.9 cm in diameter, at 144 m.

An ambient-light camera (Q1808-LE, Axis Communications, Chelmsford, MA) permits some species identification, depending on the size and flight altitude of the target. This camera also allows detailed collection of behavioral data. The ambient-light camera records at 20 fps, with a resolution of 3712-by-2784 pixels. The videos from both thermal and ambient-light cameras are saved on a central processing unit (CPU), which is also the interface for setting recording parameters and for remote access via satellite modem.

The last instrument is a VHF receiver (SRX800-D1, Lotek Wireless, Newmarket, ON, Canada) that detects radio transmitters carried by flying animals as part of the Motus network (https://motus.org). We installed omnidirectional antennas on opposite sides of the turbine monopole to limit interference caused by the structure itself. We can detect transmitters that pass within 2 km of the turbine platform with this system.

We used custom-fabricated weatherproof containers to house the ATOM computer, power supply, networking components, and stereo-paired thermal cameras that form the core of the ATOM system. We mounted the weatherproof containers along with the ambient-light camera on a custom metal chassis attached to the turbine platform. We mounted the ultrasonic acoustic detectors and VHF antennas 2 m from the chassis to prevent obstruction within the camera viewshed. We used 2 ultrasonic detectors for redundancy, and both detectors sampled the same airspace. The location of the chassis on the platform was critical to allow thermal and visible-light cameras to encompass as much of the rotor swept zone as possible. Based on the available locations, we selected the position that provided the most comprehensive view of the rotor-swept zone, while still permitting turbine maintenance operations without constraints. The view of the rotor-swept zone is a ~50° cone with its

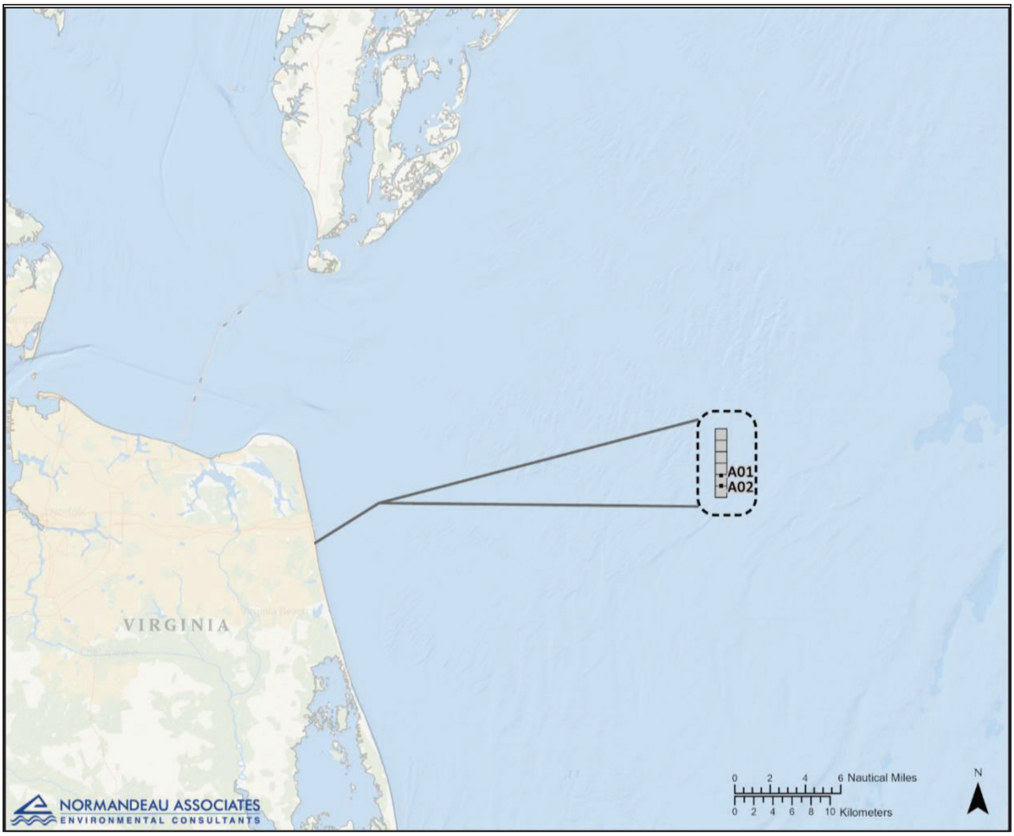

Figure 1. Location of the Coastal Virginia Offshore Wind Pilot Project and turbines.

Figure 2. ATOM acoustic sensors and Motus antennas (left) and the main ATOM control box with video cameras and VHF receiver (right).

base beginning about 1 m above the transition piece and covering the monopole and the blades. Since the nacelle and blades rotate to be perpendicular to the wind, the portion of the rotor-swept zone visible in the cameras is constantly changing and cannot be accurately estimated.

Video data from both cameras were stored on solid state media drives inside the weatherproof box. Data from the bird and bat acoustic detectors were preserved on SD cards within the detectors, and data from the Motus VHF receiver were saved on the receivers' internal storage. During bi-monthly data retrieval trips, the solid-state drives and SD cards were exchanged with empty ones, and Motus data were downloaded to a portable thumb drive.

Data processing

Before video review, we cataloged all data to note any gaps due to power outages, system malfunctions, or corrupted files. To analyze thermal video, we generated 10-second composites, which are aggregations of 10 seconds of video into single still images; the changing position of an object over 10 seconds generates a "track" on the composite image, thus making targets more visible. We manually reviewed all composites with tracks using ReMOTe (Remote Marine and Onshore Technology), a data portal and analysis tool (Normandeau Associates 2024) that allows simultaneous review of thermal and ambient-light video, along with the composites for the periods with known targets. Human analysts determined the type of target (e.g., bird, bat, insect, airplane, cloud, rain drop, turbine blade) present, and their observations were saved automatically into a central database. Videos and images that contained birds or bats were sent to taxonomic experts (>10 years of experience), who made identifications to the lowest taxonomic level possible. During identification, various behaviors (Table 1) and movement of the turbine blades were noted.

Table 1. Description of various behaviors noted during identification of targets.

Behavior	**Description**
Altered flight path: change of speed	Change of **speed** (blade interactions when blades are moving). In this behavior the bat adjusts its speed before crossing the plane of the rotating blades (e.g., slows down before crossing). This is possibly a microavoidance behavior (avoiding the blade, in contrast to mesoavoidance – avoiding the turbine, or macroavoidance – avoiding the wind farm).
Altered flight path: change of direction	Change of **direction** (blade interactions when blades are moving). In this behavior the bat adjusts its direction before crossing the plane of the rotating blades (e.g., flies parallel to the rotating plane before turning to cross it). This is possibly a microavoidance behavior.
Blade interaction	When blades are moving, the bat clearly interacts with the blades, but no clear avoidance behavior.
Aerial foraging-like behavior	Prolonged continuous circuitous flight that suggests capturing prey items.
Low straight flight	Direct flight below the rotor swept zone.
High straight flight	Direct flight within or above the rotor swept zone.
Flyover	Very high flight visible above turbine, usually large birds for detection reasons.
Monopole interaction	This behavior looks very similar to gleaning (taking insects off the monopole); however, since we cannot confirm actual predation, we use the term interaction.

We processed acoustic recordings of bats using 2 automatic classifying programs––SonoBat (https://sonobat.com) and Kaleidoscope Pro (https://www.wildlifeacoustics.com/products/kaleidoscope-pro). Using 2 programs was a way to minimize the chances of false negatives (actual bat classified as noise). We used full-spectrum .wav files and geographically appropriate species lists for both software tools. All bat calls (recordings that were classified by the programs as originating from a bat) were manually vetted by a bat specialist with >10 years of experience performing acoustic analysis. Identification was done to the species level when possible and classified as "unknown" when species identification was not possible. Note that echolocation calls in the offshore environment may not always be typical for the species; since the offshore environment is free of clutter, bats tend to emit lower frequency content and longer durations than in most terrestrial settings. When available, we corroborated acoustic identification (ID) with visual observation, but when this was not possible and acoustic ID was ambiguous, the call was classified as "unknown". See the video in Supplemental File 1 (available at http://www.eaglehill.us/NABRonline/suppl-files/nabr-010k-Amichai-s1.mp4) and the acoustic ID in Supplemental File 2 (available at http://www.eaglehill.us/NABRonline/suppl-files/nabr-010k-Amichai-s2.wav), for an example of multi-sensor identification of 2 bat species observed together.

We uploaded the tag data from the VHF receivers to the Motus website (motus.org). These data are processed on the Motus webserver, and identifications are determined by matching any tags detected to the Motus database. Since all the detected tags were identified as birds, the results are not further described in this manuscript.

Data analysis

A common challenge for analysis of bat echolocation is the uncertainty of whether a series of calls or call sequences represents 1 or more individuals. This challenge is increased when 2 sequences are separated by a short time span (e.g., 30 seconds); during these brief periods, it is possible for 2 individuals to pass 1 after the other, or for the 1 individual to be recorded, followed by a short time when it is silent or otherwise not detected and then reappears. The same challenge is present when analyzing video, if an animal exits the camera's field of view and another or the same individual appears. To address the ambiguity, we used an arbitrary rule, both for visual and acoustic observations. We regarded call sequences or visual observations that were separated from preceding or following calls or observations by >5 minutes as distinct, independent events. However, calls or observations that were separated from preceding or following calls or observations by ≤5 minutes were regarded as 1 event, as long as the same species was identified.

To analyze annual activity patterns, we divided each year into 2-week bins. For daily activity patterns, we divided each day into periods in relation to sunrise (sunrise time at the 7th day of the 2-week period), midday (12:00), sunset (sunset time at the 7th day of the 2-week period), and midnight (00:00) (first, second, third, and fourth periods, respectively). According to this system, if a bat was observed after sunrise at 07:00, it would be scored as active during the first period of the day.

For behavioral classification (Table 1), only visual observations were used. For this analysis, we did not use the 5-minute rule to define independent observations, since a bat may be engaged in more than 1 behavior at any time. It was therefore possible for 1 observation to have more than 1 behavioral classification. Consequently, the total number of behaviors observed is greater than the number of independent observations.

Results

The study presented here represents a subset of the bat portion of post-construction monitoring, the results of the analysis of the data collected during years 1 and 2 (2021–2023) from turbine 1. Only bat-related data are presented. Avian data from the first year were published previously (Willmott et al. 2023), and analysis of subsequent years for both birds and bats is ongoing.

Although no tagged bats were detected by the Motus receivers, we documented 346 distinct bat observations (112 in year 1, and 234 in year 2), with 303 observations identified to species and 43 unidentified (Table 2). All visual observations were detected with the thermal cameras; 28.8% (15 of 52) were also classified using the ambient light camera. 15.4% (8 of 52) visual observations did not have a corresponding acoustic detection. Bats were identified to 3 species (by acoustic, visual, or both): *Lasiurus borealis* (Müller) (Eastern Red Bat), *Lasiurus cinereus* (Palisot de Beauvois) (Hoary Bat), and *Lasionycteris noctivagans* (Le Conte) (Silver-haired Bat). Since the Eastern Red Bat is acoustically indistinguishable from *Lasiurus seminolus* (Rhoads) (Seminole Bat) and is visually very similar, some identifications attributed to Eastern Red Bats may have been Seminole Bats. However, for this study, we consider all to be Eastern Red Bats.

Activity around the offshore turbine had a strong seasonal pattern (Figs. 3–4), with 88.7% of all bat observations, acoustic or visual, occurring between 15 August and 15 October (Fig. 3). This pattern held both in year 1 (91.1%) and year 2 (87.6%). This peak is probably associated with fall migration. While mating (and reproductive swarms) also occur at this time, we did not observe behaviors suggesting reproductive activity, nor did we record large groups of bats that might suggest swarming. Only Eastern Red Bats were documented during spring, while all 3 species were observed during summer and fall (Fig. 4). This seasonal pattern may result from the low sample size and more data are needed to lend power to our analysis.

As expected, most activity was nocturnal and occurred between sunset and sunrise (Fig. 5). However, we also documented activity during daytime, primarily during the first period of the day between sunrise and midday. In year 1, 37.5% of all observations (acoustic and visual) occurred during daytime, as did 31.2% of all observations in year 2.

We documented bats engaging in 6 of the 8 defined behaviors (Table 1, Fig. 6). Most (82.7%) behaviors appeared related to foraging (i.e., aerial foraging-like behavior or

Table 2. Number of detections per sensor type in each year. All visual observations were detected using thermal cameras. Daytime visual observations (15 of 52) were further classified using the ambient-light camera.

Species	Acoustic, Year 1	Visual, Year 1	Acoustic, Year 2	Visual, Year 2	Total observations
Eastern Red Bat	43	1	110	3	157
Hoary Bat	21	0	27	5	53
Silver-haired Bat	31	0	54	8	93
Unidentified	8	8	0	27	43
Total	103	9	191	43	346

monopole interaction). However, 12.6% included an interaction with moving blades (i.e., undefined blade interaction and the 2 types of flight path alteration—adjustment of speed or direction).

During the 2 years, we did not observe any collisions between bats and moving blades. This was true for both turbines, even though data from only 1 turbine are presented (unpublished data). Most (64.3%) visual observations occurred when the blades were rotating. Although we could see the blades turning in the video, blade state information is not available for acoustic observation, as we do not have access to direct turbine data. During the 2 years, we documented 3 events of apparent "air displacement", which occurs when a bat abruptly changes position as a blade passes nearby, seemingly recovers from the disturbance, and then resumes normal flight. All raw and cleaned data used in this manuscript are available in Supplemental File 3 (available at http://www.eaglehill.us/NABRonline/suppl-files/nabr-010k-Amichai-s3.xlsx).

Discussion

Our data from a single turbine suggest that bat activity offshore, even at long distances from land, may not be rare. We documented bats of 3 species, 42 km from the coast, engaging in various behaviors and following similar seasonal patterns in both years of our study.

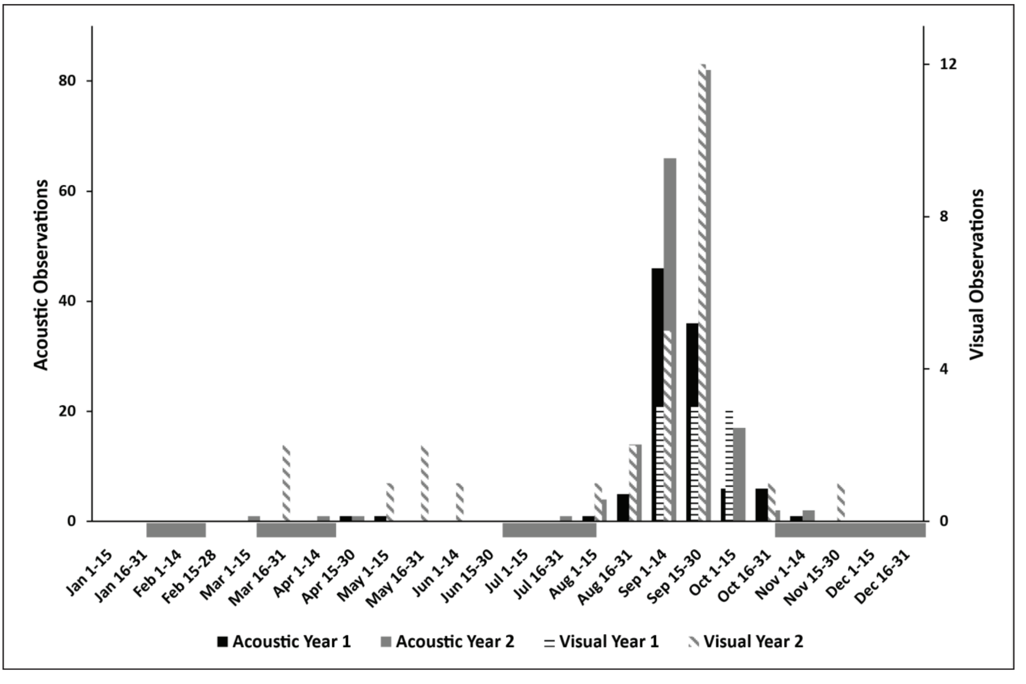

Figure 3. Annual activity pattern of all bats combined, divided into 2-week bins. During each year, activity peaked during late summer and fall (88.7% of observations between 15 August and 15 October). The number of independent acoustic observations is plotted against the left y-axis, whereas the number of independent visual observations is plotted against the right y-axis. Acoustic observations are depicted as solid lines, and visual observations are shown as dotted lines. Years are differentiated by color, with black for year 1 and gray for year 2. The gray bars under the x-axis represent the period during which the system did not collect data in year 1; data collection occurred throughout year 2.

These 3 species—Eastern Red Bat, Silver-haired Bat, and Hoary Bat—are often referred to as migratory tree-roosting bats. These bats are strong flyers that tend to forage in open spaces, travel long distances daily and seasonally, and are therefore more likely to be present offshore than other species (Hatch et al. 2013, McGuire et al. 2012, Morningstar and Sandilands 2019, True et al. 2023, Weller et al. 2016).

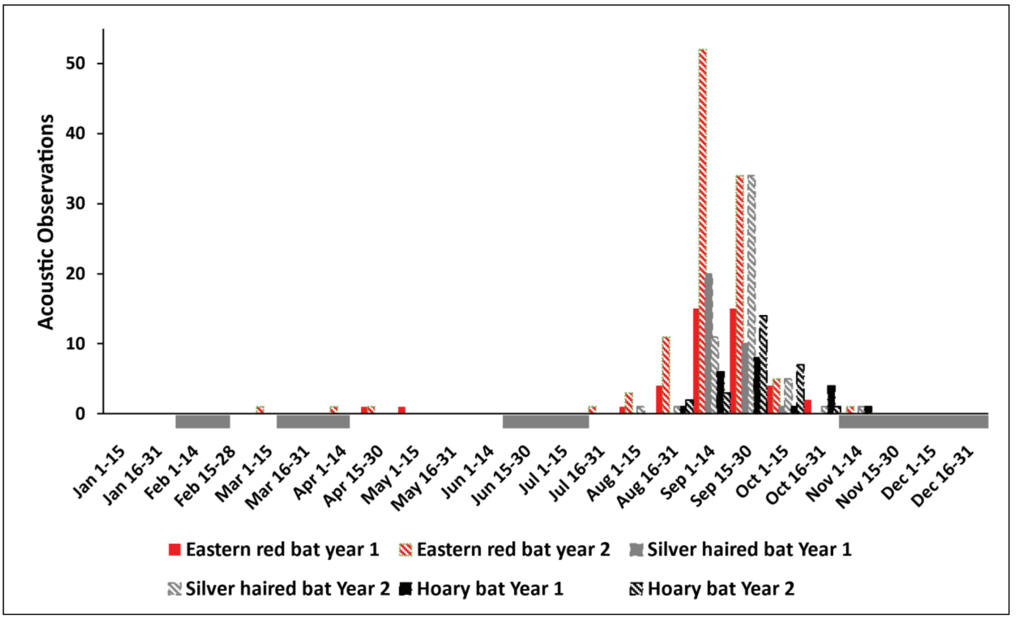

Figure 4. Annual activity pattern by species, divided into 2-week bins. Each year, activity peaked during late summer or fall for all species. Due to the low number of visual observations that were identified to the species level, only acoustic observations are depicted. The different species are marked by different bar colors, and years are differentiated by pattern, with solid lines for year 1 and diagonal lines for year 2). The gray bars under the x-axis represent the period during which the system did not collect data in year 1; data collection occurred throughout year 2.

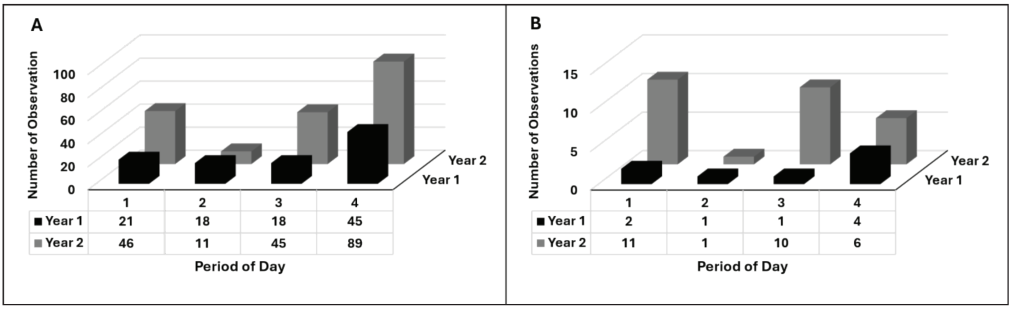

Figure 5. Daily activity patterns. The number of independent observations (all species, n = 329) in each period of the day (first period: sunrise-to-midday, second period: midday-to-sunset, third period: sunset-to-midnight, fourth period: midnight-to-sunrise). Daytime activity was documented in both years (year 1 – black columns, year 2 – gray columns), and through both sensor types – acoustic (A) and visual (B).

High level of bat activity offshore during late summer and autumn suggests that the presence of bats near the turbine is associated with migratory movements. Although fall migration is also associated with reproductive activities, such as swarming or mating (e.g., Burns and Broders 2015), we did not observe enough bats to suggest the former, nor did we document any acts of the latter. With the exception of pteropodids (Sapir et al. 2014), most studies of bat migration use VHF radio transmitters, either with active (manual) receivers or with automated receiving stations, such as Motus (True et al. 2023). However, these instruments can only detect bats over a few kilometers. Although GPS technology is rapidly improving and the number of studies employing heavy GPS transmitters to track bats is increasing swiftly (e.g., Cvikel et al. 2015a, b), insectivorous bats are generally too small to be tagged with current GPS transmitters, and, consequently, little is known about migration routes of most species (but see Weller et al. 2016).

Bats are not typically active during the day, and most surveys and monitoring programs only sample during the night, a procedure that is recommended by regulatory and conservation agencies (e.g., U.S. Fish and Wildlife Service 2024). Although bats have been recorded over the ocean during daytime (e.g., a single Hoary Bat recently was spotted over the Pacific Ocean (Kennerley et al. 2024) and several Eastern Red Bats were spotted over the Atlantic Ocean (Hatch et al. 2013)), our study is the first to show that a large proportion (>30% of all observations) of offshore activity occurs during daylight—a pattern that was repeated during both years and documented by both sensor types. Diurnal activity over the open ocean should not be surprising, especially if the bats were migrating. First, there were no natural roosts offshore, and even the newly erected turbines provided little or no appropriate shelter for a resting bat. Second, a factor that may make diurnal flight by bats offshore more common is the lower density of birds in the ocean environment compared to over land, which may lessen potential predation (Rydell and Speakman 1995). Given that

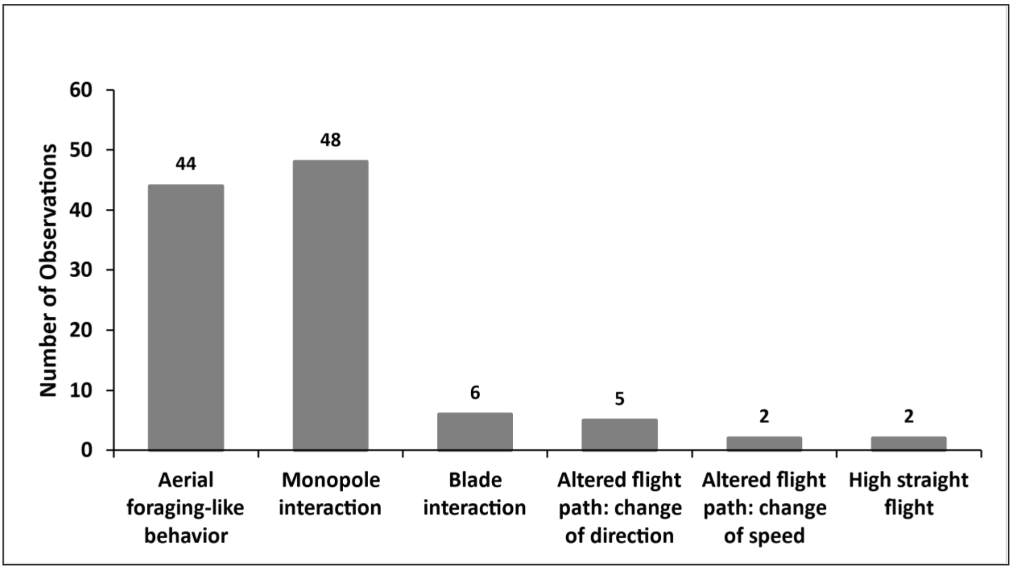

Figure 6. The number of different behaviors observed during both years combined, including behaviors by unidentified bats. The total number of classified behaviors (107) sum to more than the number of independent observations (52), since a bat can be engaged in more than 1 behavior at a time.

bats lacked roosts and were far from shore (43 km), the only alternative to daytime flight was that bats consistently travel out to sea for migration every morning and back to shore for roosting every evening, an energetically expensive and unlikely scenario. Whatever the cause of this diurnal flight, we recommend that offshore monitoring include an around-the-clock sampling regime.

Most behavior we documented at the turbine appeared to be associated with foraging, either aerial hawking or gleaning off the monopole (see video in Supplementary File 1 for an example of daytime foraging-like activity of an Eastern Red Bat and a Silver-haired Bat. The echolocation calls of these individuals corroborate the visual ID, see Supplementary File 2). We assumed foraging activity based on observing bats and insects in the video data, although they were not observed simultaneously. An abundance of insects has been documented around offshore and terrestrial turbines (Rydell et al. 2010, 2016; Willmott et al. 2023), showing this is a possible resource for foraging bats (and birds). Insects may be attracted to offshore turbines for the same (not entirely understood) reasons that insects are attracted to terrestrial turbines, such as temperature, monopole or blade color, and hilling behavior (insects congregating at the top of an elevated landscape) (Jansson et al. 2020; Long et al. 2011; Rydell et al. 2010, 2016; Voigt 2021). Although bats may be attracted to the turbines directly, as may be suggested by repeated flights to and from the monopole and blades, we believe insect presence may play a part in this attraction, and that it is important to understand why insects are attracted to offshore turbines (Long et al. 2011) and to explore ways to decrease this attraction. Given that our data are from a single turbine, we do not know whether these data are representative of broader oceanic trends.

Bats are frequently struck by spinning turbine blades at terrestrial wind farms. However, we did not detect any collisions at the offshore site. We do not know whether the lack of collisions was due to ATOM's incomplete coverage of the rotor-swept zone, low levels of bat activity, or a real lower collision rate offshore compared to terrestrial wind facilities. However, the bats often seemed aware of the moving blades. This was evident when the bats altered their flight path; in addition, when the blades were moving, the bats tended to fly parallel to the plane of rotation and generally refrained from crossing it.

Our results underscore the advantages of employing several sensor types to monitor bats, especially in the challenging offshore environment. Using thermal imagery, we were able to detect bats in all weather and light conditions; and using ambient-light imagery, we were able to identify many detected bats to species. Both types of visual sensor allowed us to classify bat behavior with a finer resolution than would be possible using acoustic methods or direct observations alone (Willmott et al. 2023). Acoustic sensors provided documentation of bats that were not flying within the cameras' field of view. Video sensors also documented bats that either were not acoustically recorded or did not echolocate, as evidenced by a lack of corresponding acoustic identifications during video observations. The different sensor types thus provided both verification and complementary information, increasing our detection and classification abilities and improving our understanding of bats' presence and behavior offshore.

Currently most bat monitoring (onshore and offshore) is done acoustically (Solick and Newman 2021). Although ATOM was originally designed to operate offshore, using this system (or the concept of multiple sensor types) onshore presumably will confer similar benefits. We encourage researchers and regulators to employ multi-sensor monitoring whenever possible, to obtain a more complete understanding of bat presence and behavior in the sampled area.

Acknowledgments

We thank the Dominion Energy team and the CVOW Pilot Project, particularly Scott Lawton, Casey Seelig, and Matt Overton for their continuing support of this research. We also thank SGRE, particularly Adam Cross and Francis Ackerman for coordinating site visits, and Charlie Donadio and his team from Fast Ferry for safe travel to the turbines. We thank BOEM for supporting the initial development of the first ATOM system and our Normandeau team, including our hardware and software engineers, for moving this research forward.

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