New insights into the influence of turbines on the behaviour of migrant birds: implications for predicting impacts of offshore wind developments on wildlife

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Abstract. Knowledge of the movement and behaviour of birds and bats around turbines in the offshore marine environment is critical for assessing the environmental impacts of offshore wind developments in the eastern USA. To address the problem of gathering high-quality, long-term data on these species in this remote environment, we designed a multi-sensor system that was recently deployed for 6 months in 2021 and 2022. Two Acoustic and Thermographic Offshore Monitoring (ATOM™) systems were deployed on wind turbines 23 nautical miles off the coast of Virginia, USA. The systems were operational during the day and night and recorded 1,581 detections of birds and bats, with 99% of detections occurring in the fall. Most detections were of birds, including 5 shorebird species, 3 gull species, 1 tern species, 3 raptor species, 1 woodpecker species, and 18 passerine species. Skuas, corvids, and swallows were also observed. There were 521 detections of bats. Differences between species detected and identified in each sensor confirms that a multi-sensor approach for monitoring is beneficial. There were no observed collisions; two individuals (1 bird and 1 bat) suffered air displacement, causing them to fall, but they recovered and continued flying. ATOM also collected novel data on insects, tracking over 7,000 insects around the turbine rotor swept zone and revealed foraging behaviour in 596 of the 1,581 bird and bat detections. Offshore wind turbines thus provide potential sites for perching and foraging. Although these turbine sites provide a new opportunity to feed, which may be beneficial for insectivores and omnivores in enabling them to reach migration destinations in better condition, the consequences of a potentially delayed arrival are unknown (positive, negative, or neutral). Overall, our approach produced the first detailed insights into terrestrial land bird and bat activity around offshore turbines, providing novel information on changes in behaviour when turbine blades are moving and during higher wind speeds. Moreover, our data show that foraging activity appears to be conducted with an awareness of the moving blades and in safe zones close but parallel to blade movements. We recorded 113 observations of activity within 10 m of the moving blades and 70 observations where interactions with moving turbine blades were within 1 m; we call these latter avoidance measures nanoavoidance. No collisions were observed.

1. Introduction

The offshore wind industry in the USA has a goal of 30 gigawatts (GW) of deployed offshore wind by 2030 [1], with a currently predicted capacity of 86 GW expected by 2050 [2]. The principal areas of development include the eastern seaboard from Maine to North Carolina, the central and western Gulf of Mexico, and several areas along the Pacific coast and Hawaii.

As part of the National Environmental Policy Act (NEPA) process, the US Fish and Wildlife Service (USFWS) and Bureau of Ocean Energy Management (BOEM) are responsible for evaluating and determining how proposed offshore wind energy development in federal waters could impact species listed under the Endangered Species Act and Migratory Bird Treaty Act through completion of a Biological Assessment. During the permitting process, agencies request developers to complete research on wildlife within the area of development to fill knowledge gaps and assess risk.

In terms of species diversity and abundance, birds and bats constitute two groups of potential concern in the offshore environment. Broadly, birds include diurnal and nocturnal migrants, moving to and from overwintering and breeding sites, and resident seabirds. Migrant shorebird and songbird species are of particular interest because they are small and often migrate nocturnally, and little is known of their movements and use of offshore environments. Few datasets exist for understanding the movements of terrestrial land birds offshore. A dataset collected 29 miles offshore North Carolina, USA, in 2012–2013 is one of few publicly available reports and contains detections of 26 species of terrestrial land birds [3]. This study shows seasonality, weather, and wind speeds as being the main drivers of bird activity. Otherwise, there are limited data on migrant land bird individuals from gps- and vhf-tagged birds on movebank.org and motus.org. None of these datasets contain data on bird and bat behaviours around operational turbines. Similarly, although bats are known to be found offshore and the drivers of activity appear to be similar to those of birds (such as seasonality, weather, and wind speeds [4], [5], [6], [7]), activity and behaviour at operational offshore turbines is under-studied.

During both construction and operation, offshore wind developments may impact bird populations directly through mortality from collisions and indirectly through displacement or attraction, which may affect population fitness [8], [9], [10], [11], [12], [13]. Bird collisions with offshore wind turbines appear to be rare [14], [15], [16], but relevant studies are very limited due to logistical difficulties, and, in particular, very little is known about collision impacts on small bird species. More broadly, there is a strong need to better understand how birds interact with and are influenced by wind turbines daily and at small scales. The goal of this study was to provide the most detailed data to date on bird movements in the vicinity of offshore wind turbines and document bird behaviour around turbine blades (and possible collisions with turbines) using a novel multi-sensor system.

2. Approach

We designed a system with multiple sensors to collect information about bird and bat activity in the rotor-swept zone (RSZ) of offshore turbines. The Acoustic and Thermographic Offshore Monitoring (ATOM™) system combines four types of wildlife sensors analysed in combination: thermal cameras operating in stereo, a visible-light camera to allow species identification during the day, acoustic detectors for birds and bats, and a VHF receiver to detect birds fitted with VHF radio tags. The system is deployed on platforms underneath offshore wind turbines and continually collects data within the RSZ and the vicinity of the wind turbine during the monitoring period. The core ATOM components are mounted to a chassis attached to the turbine platform, the location of which is optimised for the best available view of the RSZ without constraining turbine maintenance operations. Acoustic detectors and VHF antennas are mounted away from the chassis (Figure 1).

Two ATOM systems were deployed on two adjacent turbines in the Dominion Energy Research lease area 23 nautical miles off the Virginia coast (Figure 2). The systems were deployed from 1 April to 15 June 2021, 15 August to 31 October 2021, and 15 January to 15 March 2022. Despite a remote connection via satellite modem, the connection speed and data transfer limits precluded us from remotely transferring data; nevertheless, the satellite connection was used to monitor system functionality and institute remote repairs when required. Data retrieval was done manually by swapping drive boxes and data storage cards every few months.

Figure 1. ATOM systems deployed on offshore turbines showing camera box (left) and acoustic sensors (right).

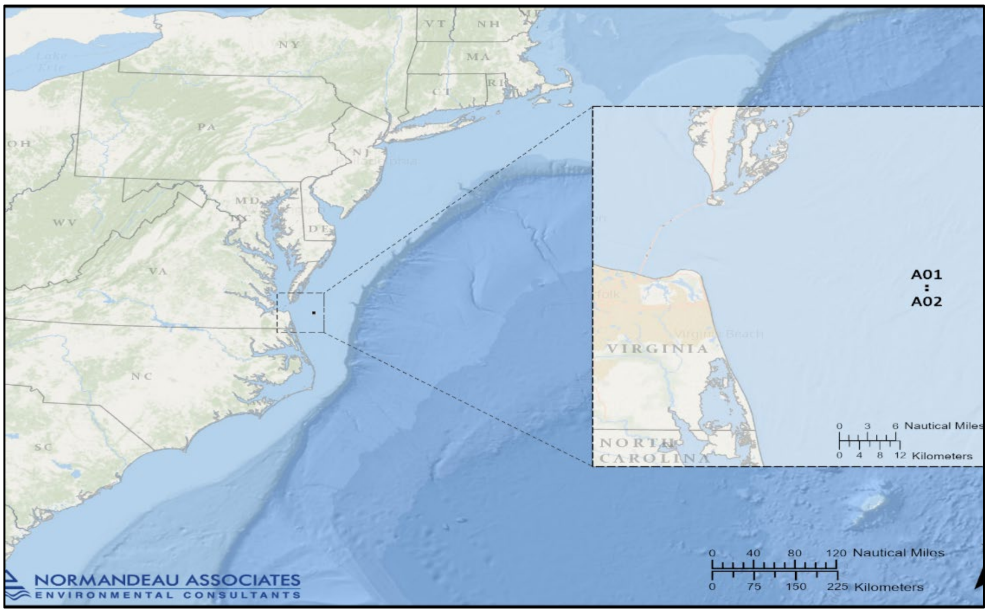

Figure 2. Location of the two Dominion Energy wind turbines off the coast of Virginia.

We reviewed 100% of video data using a combination of automatic target detection software and manual review of potential targets using our online data portal and analysis tool (ReMOTe). Using ReMOTe, analysts simultaneously reviewed both thermal and visible-light video. Determinations of target-type and behaviour were saved automatically into a central database. Birds and bats were sent to taxonomic experts (>10 years of experience) for identification when individuals were detected by both the thermographic and the visible-light video. Identifications were made to the lowest taxonomic level possible. Birds and bats marked as unidentified were those that were only recorded in the thermographic cameras or those for which key morphological characteristics needed for identification were not clear in the visible-light camera. During identification, it was also noted whether the turbine blades were moving and behavioural observations were noted as the following: Attraction (individual comes to check-out turbine then continues); Hawking (sallies from perch on short flights to capture flying insects); Aerial foraging (prolonged continuous flight capturing prey items); Monopole gleaning (taking insects off the turbine monopole); Microavoidance (blade interactions when blades are moving); Low patrol (direct flight below the RSZ); High patrol (direct flight within or above the RSZ); Flyover (very high flight visible above turbine, usually large birds for detection reasons); Thermaling (no flapping); and Perching.

Flight height and speed calculations were based on a track detection and particle analysis process within the stereo-thermographic video. Once tracks from the left and right cameras were paired, the distance of the object from the cameras was determined from the relative position of the object in each camera. Object velocities were determined by comparing location in sequential video frames. It was not possible to calculate distance and speed if targets were detected in only one camera in the stereo pair.

Insect detections were quantified along with bat and bird activity for the monitoring period. We examined relationships of insect detections with bird and bat detections by using Spearman's rank correlations.

Bird and bat acoustic data were reviewed by expert acousticians, and calls were ascribed to the lowest taxonomic level possible. Tag information from the VHF receivers were uploaded to the Motus website (Motus Wildlife Tracking System; motus.org) and were processed on motus.org.

To relate bat and bird activity to weather variables, we used modeled wind speed, wind direction, temperature, and sea level pressure data from StormGeo [17]. Weather variables were related to the bird and bat data by matching the animal detection timestamps to the closest value found in the weather data.

3. Results

The system was reliable throughout deployment with a few notable challenges: during the spring, there was a system short that caused 3 weeks of lost data on ATOM 2 (A02), and during the winter, a satellite modem was damaged by water intrusion preventing remote repair of a disk storage issue on ATOM 1 (A01), causing 15 days of lost data. Minor issues such as software bugs could be fixed remotely via satellite modem. Other periods of downtime were small and could mostly be attributed to power outages at the turbine, during which time the blades were not spinning.

Across all ATOM sensors and the entire monitoring period, there were 1,581 detections of birds and bat detections (521 bats, 1,011 birds, and 49 bird/bat) and over 7,000 insect detections. Bird detections included 5 shorebird species, 3 gull species, 1 tern species, 3 raptor species, 1 woodpecker species, and 18 passerine species. Skuas, corvids, and swallows were also identified but no individuals were identified to species (see Table A1). Of the bird detections, 522 occurred at turbine A01 and 489 occurred at A02 and most occurred during the fall, with only 9 birds observed in the spring and 5 during the winter. Only 2 bat detections occurred in spring and the remaining 519 detections occurred in fall; no bats were detected in winter. Bat detections include three species: Silver-haired Bat (*Lasionycteris noctivagans*), Hoary Bat (*Lasiurus cinereus*), and Eastern Red Bat (*Lasiurus borealis*) (see Table A1). Insects included many butterflies and moths (Lepidoptera) and dragonflies (Odonata), although only a few detections were identified to species. Insect detections occurred during all monitoring periods.

Most detections were recorded by video sensors (n=1,085; 70.9%) followed by acoustic detections (n=443, 28.9%) with only 0.2% made by the Motus receivers (n=3) (see Table A1). Ninety-one percent of bird detections and 45% of bat detections were during the day (Figure 3). Birds were active at lower median wind speeds compared to bats and insects, while insects were active at a higher median wind speed and a wider range of wind speeds than birds or bats (Figure 4). Bird activity dropped sharply at wind speeds above 5 m/s (Figure 5) and was minimal above 8 m/s, while bat activity dropped sharply above 6 m/s and was minimal above 10 m/s (Figure 6). Bird, bat, and insect activity occurred within similar temperature ranges (Figure 7). Birds were primarily active in air temperatures of 19–22°C (Figure 8), while bats were primarily active between 20 and 24°C (Figure 9).

Boxplots (Figure 4 and Figure 7) show the distribution of data among the animal types. The dark horizontal line is the median wind speed, and the box represents the middle 50% of data values. The lines above and below the box represent the data points that are within 1.5 times the length of the box above or below the box. Data beyond this range are shown as individual points.

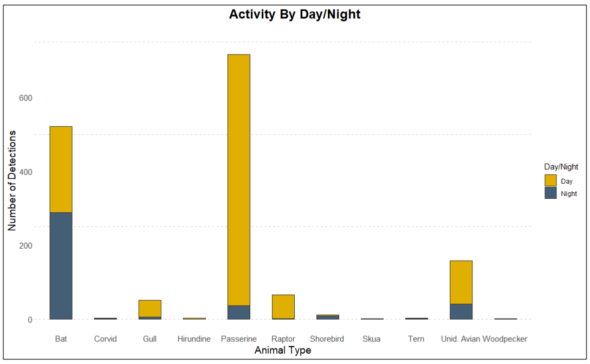

Figure 3. Day and night activity by bird and bat species groups.

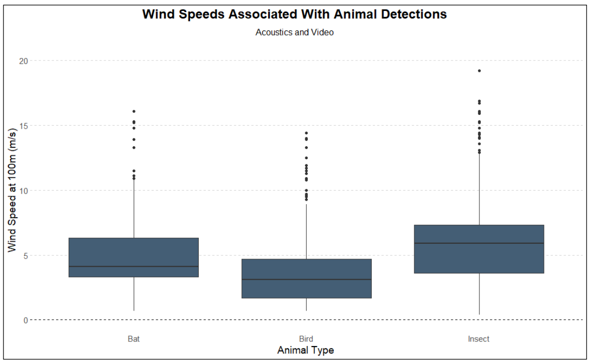

Figure 4. Bird, bat, and insect activity in relation to wind speed at 100 m above sea level.

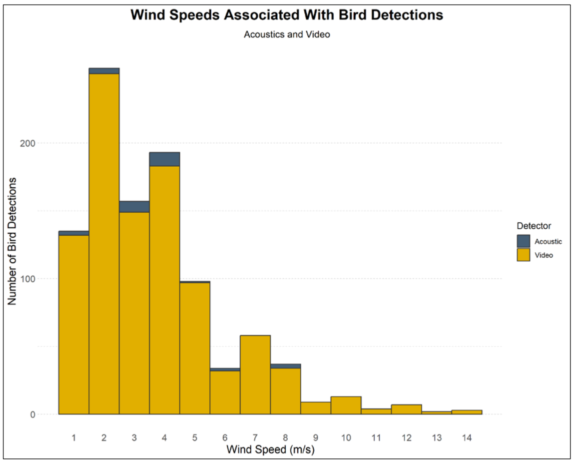

Figure 5. Number of bird detections at various wind speeds at the Coastal Virginia Offshore Wind Pilot Project.

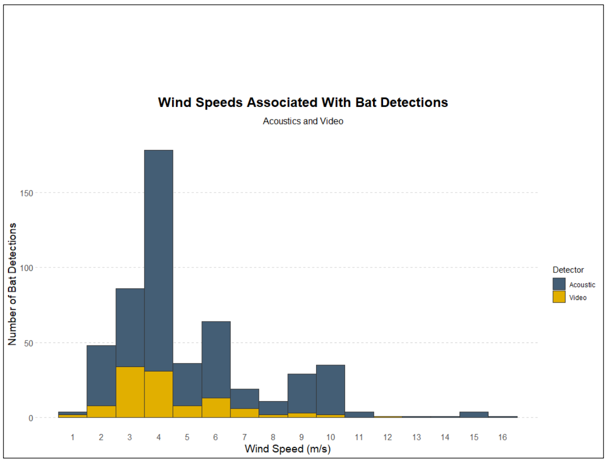

Figure 6. Number of bat detections at various wind speeds at the Coastal Virginia Offshore Wind Pilot Project.

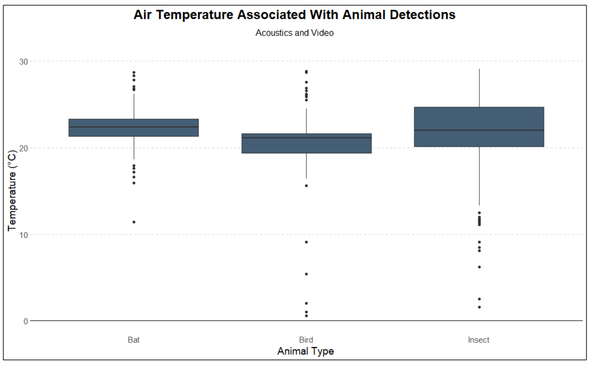

Figure 7. Bird, bat, and insect activity in relation to ambient air temperature.

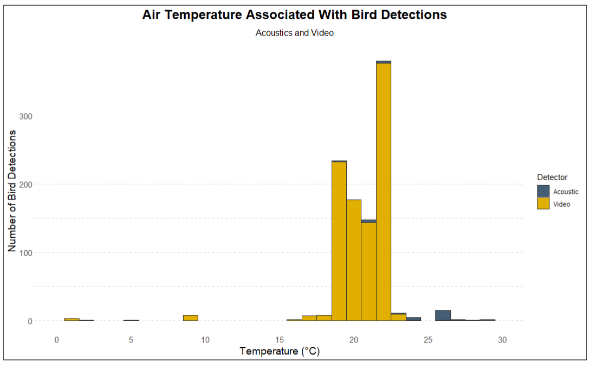

Figure 8. Number of bird detections at various air temperatures at the Coastal Virginia Offshore Wind Pilot Project.

Foraging in general was the most frequently observed behaviour (n=596 detections), executed by 21 bird species/groups and 2 bat species/group (Table 1). Aerial foraging (n=463) was the most frequently observed, followed by hawking (n=104) and monopole gleaning (n=29). Perching was sometimes associated with hawking or, in the case of Peregrine Falcons (*Falco peregrinus*), with resting and plucking prey. Feathers were observed drifting across the camera when a Peregrine Falcon was staying at the turbine, and remains of a freshly plucked corpse of a Dickcissel (*Spiza americana*) was found at the turbine the following day. Peregrine Falcons were seen patrolling the turbines (Figure 11). For both birds and bats detected by video, most foraging was associated with non-moving blades (n=483; 81%) (Figure 10; Figure 12) despite the blades spinning an estimated 81% of the time based on review of wind regime data and a cut-in speed of 5.0 m/s for the turbines. Foraging behaviours on Figure 10 include aerial foraging, hawking, and monopole gleaning.

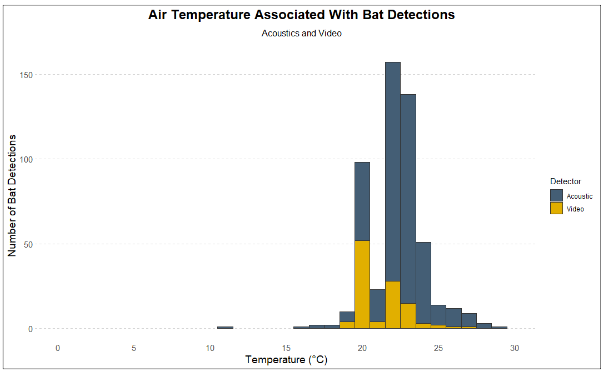

Figure 9. Number of bat detections at various air temperatures at the Coastal Virginia Offshore Wind Pilot Project.

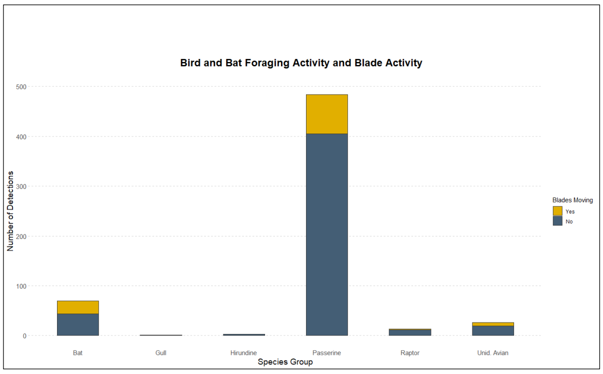

Figure 10. Number of foraging observations of bird and bat species groups when the blades were and were not moving.

Table 1. List of species and species groups seen foraging in video.

Common Name	Scientific Name
Peregrine Falcon	*Falco peregrinus*
Hirundine species	
Brown Creeper	*Certhia americana*
Winter Wren	*Troglodytes hiemalis*
Wren species	
American Robin	*Turdus migratorius*
Blue-winged Warbler	*Vermivora cyanoptera*
Black-and-white Warbler	*Mniotilta varia*
American Redstart	*Setophaga ruticilla*
Cape May Warbler	*Setophaga tigrina*
Magnolia Warbler	*Setophaga magnolia*
Bay-breasted Warbler	*Setophaga castanea*
Blackburnian Warbler	*Setophaga fusca*
Palm Warbler	*Setophaga palmarum*
Pine Warbler	*Setophaga pinus*
Yellow-rumped Warbler	*Setophaga coronata*
Setophaga species	
Parulidae species	
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Passerine species	
Unidentified bird species	
Eastern Red Bat	*Lasiurus borealis*
Bat species	

There were 70 observations of microavoidance from 18 species or species group (Table 2), where activity involved avoiding moving turbine blades. Microavoidance has been defined as a "bird behavioural responses to single blade(s) within the RSZ (including a 10-m buffer); it is considered as the bird's 'last-second' action taken to avoid collision" [16]. In our study, these 70 observations were individuals that manoeuvred around the turbine blades using similar behaviours as defined in Skov et al. [16]. These include an adjustment of direction where the bird or bat flies parallel to the rotor (n=39; bat=14, bird=25) (Figure 15), non-visible-adjustment where the bird or bat moves through the moving blades (n=19; bat=6, bird=13) (Figure 14), or avoidance involving an adjustment of speed where the bird or bat stalls flight with only slight adjustment of direction while waiting for the blade to pass (n=12;

bat=6, bird=6) (Figure 13). With avoidance involving adjustments in speed and direction, the bird or bat would afterwards either go through the blades or fly away from the turbine. Of the 113 foraging flights involving manoeuvring while the blades were moving, 6 were gleaning at RSZ height (within 10 m of the blades), 24 were hawking at RSZ height, again at times within 10 m of the blades, and the remaining 83 observations were of aerial foraging at various heights. All behaviours were angled such that they avoided directly interacting with the rotating blades, and these behaviours could also be defined as microavoidance. Hereon, we consider the submeter avoidance as nanoavoidance.

Figure 11. Peregrine Falcon patrolling at the turbine (blades were not moving).

Figure 12. Cape May Warbler chasing a moth (blades were not moving).

Table 2. Species or species groups observed showing nanoavoidance with moving blades.

Common Name	Scientific Name	#
Shorebird species		1
Great Black-backed Gull	*Larus marinus*	1
Peregrine Falcon	*Falco peregrinus*	5
Corvid species		1
Brown Creeper	*Certhia americana*	3
Winter Wren	*Troglodytes hiemalis*	2
Wren species		1
American Pipit	*Anthus rubescens*	1
American Redstart	*Setophaga ruticilla*	1
Cape May Warbler	*Setophaga tigrina*	1
Bay-breasted Warbler	*Setophaga castanea*	1
Palm Warbler	*Setophaga palmarum*	1
Setophaga species		3
Passerine species		13
Bird species		9
Silver-haired Bat	*Lasionycteris noctivagans*	1
Hoary Bat	*Lasiurus cinereus*	1
Bat species		24
TOTAL		70

Gulls were seen to approach the turbine then turn away. On 7 occasions, a gull approached the nacelle to perch and, on all occasions, the blades were not moving. There were 15 instances of gulls making a high flyover above the RSZ most (n=9) of which were when the blades were moving. There were 32 instances where gulls were seen within reach of the RSZ of which 28 were when blades were not moving. Great Black-backed Gull (*Larus marinus*) was also observed successfully navigating moving blades (nanoavoidance) although it was buffeted by the air draught.

Besides gulls, there were 9 other species or species groups observed approaching the turbine to perch (Table 3) including a woodpecker species and an Osprey (*Pandion haliaetus*).

No bird or bat collisions were observed. When the turbine blades were moving, all observed birds and bats avoided collisions while foraging within the RSZ. Two individuals (1 bird and 1 bat) appeared to be pushed off course from the turbine blade by the force of air movement. Both individuals recovered and continued flying. The bat revisited the blades before leaving the turbine.

Flight heights and flight velocities were generated for 33 species/species groups (see Table B1). Sample sizes are small, but, unsurprisingly, because the system was monitoring the RSZ, most flight heights generated were at rotor height.

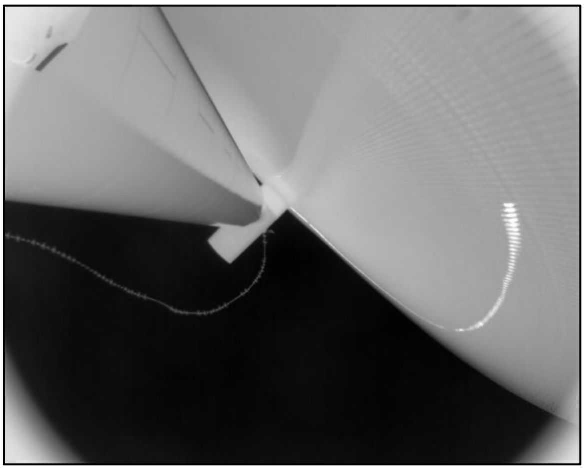

Figure 13. Nanoavoidance using adjustment of direction—the track goes parallel to the moving blades until the animal goes through the rotor swept area (image generated by a composite of thermographic images).

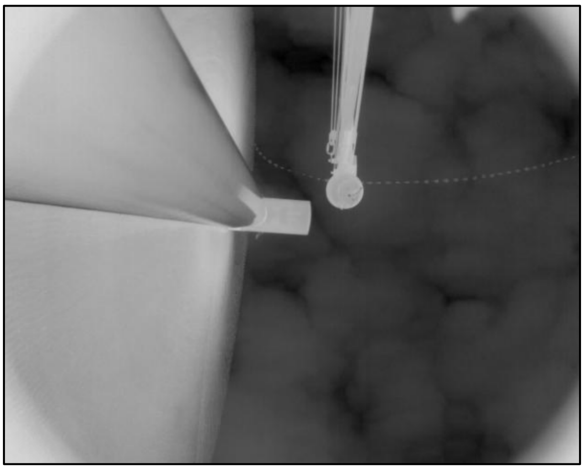

Figure 14. Nonvisible nanoavoidance (image generated by a composite of thermographic images).

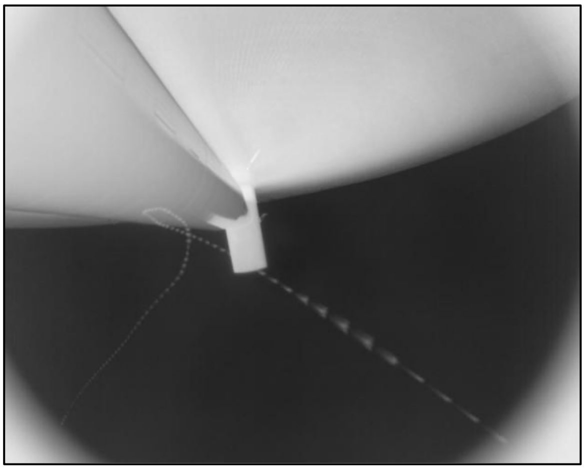

Figure 15. Nanoavoidance using adjustment of speed (image generated by a composite of thermographic images).

Table 3. Species or species groups observed perching.

Common Name	Scientific name	#
Laughing Gull	*Leucophaeus atricilla*	1
Large Gull species		2
Small Gull species		1
Osprey	*Pandion haliaetus*	8
Peregrine Falcon	*Falco peregrinus*	17
Raptor species		2
Northern Flicker	*Colaptes auratus*	1
Cape May Warbler	*Setophaga tigrina*	4
Pine Warbler	*Setophaga pinus*	5
Yellow-rumped Warbler	*Setophaga coronata*	1
Setophaga species		25
Passerine species		117
Bird species		28

4. Discussion

In this study we successfully used a novel multi-sensor system for monitoring bird and bat movement in the offshore environment. This approach provided unprecedented detail on bird movement offshore and provided new and surprising observations of land bird species using turbines to rest or forage. Such species included Northern Flicker and Brown Creeper (*Certhia americana*), neither of which have been recorded this far from shore (23 nautical miles) in the USA. There were other migrant passerines that might not be expected to be found so far from shore, such as American Robin (*Turdus migratorius*), but the shape of the coastline might encourage such species to make a shortcut when traveling between northern US states such as Massachusetts and Rhode Island to Virginia and North Carolina. In addition, the system provided new insights into bird behavior around turbines—we documented a high abundance of insects around the turbines, which provided a potentially important food source for birds and bats. At the same time, birds showed a high degree of avoidance of turbines with no recorded instances of collision in the study. These results have important implications for assessing exposure and collision risk in this remote and poorly studied environment.

Across bats and birds and all sensor types, video recorded 1,133 (72%) detections (see Table A1). For birds, terns were only recorded by the acoustic sensors and were not in the video viewshed, which is smaller than the reach of the acoustic sensors. All behaviours observed in gulls suggest that gull species can navigate safely around wind turbines, are seemingly more likely to approach turbines when the blades are not moving, and are more likely to keep above the RSZ when the blades are moving. These demonstrations of avoidance and apparent low collision rates for gulls are supported by other research [18], [19], [20], [21], [22], [23].

The presence of insects in the vicinity of turbines is assumed to be at least partially responsible for bird and bat activity around turbines [6], [24]. Nevertheless, we are unaware of studies that have documented insects and their possible influence on birds and bats around offshore turbines. Here, we recorded an unexpectedly high number of insect observations (>7,000) along with a high frequency of foraging behaviours associated directly or indirectly with this insect biomass. Long-distance migrations over the ocean have been documented in a number of insect species, especially among relatively large species in the orders Lepidoptera, Orthoptera, and Odonata [25], [26], [27]. Nevertheless, because of the obvious logistical challenges of recording insects in the offshore environment, very little is known about the precise routes, timing, and ecology of these migrations. Furthermore, surveys show that these larger insects comprise only a tiny fraction, perhaps less than 5%, of aerial insects in offshore waters, with smaller species of Diptera, Hymenoptera, and Homoptera being dominant [25]. Therefore, overall insect abundance around the turbines was clearly much higher than documented by our study and further research on the insect community composition, source, and seasonality could be valuable in understanding how the presence of this food source impacts bird and bat species around offshore turbines.

We recorded 113 observations of activity within 10 m of the moving blades and 70 observations where interactions with moving turbine blades were within 1 m. We call these avoidance measures within 1 m of the blade nanoavoidance. As research continues over the next 2 years and with continuous coverage, a significant number of new observations are anticipated, and a closer scrutiny of foraging and avoidance behaviours should be feasible.

Migrant songbirds and shorebirds, which would otherwise fly directly to their wintering sites, now encounter potential sites for perching and foraging. Although these turbine sites provide a novel opportunity to feed, which may benefit insectivores and omnivores by enabling them to reach migration destinations in better fitness, the consequences of a potentially delayed arrival are unknown (positive, negative, or neutral). As such, more work is needed to determine how these interactions with turbines impact the overall fitness of individual birds and bird populations. Our results suggest a high level of micro- and nanoavoidance of turbine blades by birds, which has potential implications when assessing risk. These turbine platforms are continuously lit at night as required by 33 CFR 67.05-15 which states "Obstruction lights shall be displayed at all times between the hours of sunset and sunrise". These lights appear to be flashing amber lights. Without doubt, the drivers of insect activity at offshore wind turbines deserve further investigation.

5. Conclusions

This initial study comprised only 6 active monitoring months. However, these unique data already provide key information on the timing and location of bird migrations, attraction, and foraging activities in the vicinity of wind turbines and the species involved. The results increase both our knowledge of bird ecology and our understanding of which bird species might be sensitive to future developments in offshore wind. Thus far this short study, which spanned the main period for fall migratory movements offshore along the eastern US Atlantic coast, has shown high avoidance by migratory songbirds of moving turbine blades and is the first study to incorporate a camera resolution sufficient to record small songbird activity around offshore turbines.

Appendix A

Table A1. Bird and bat detections by sensor recorded and by day or night (highlighted species were observed foraging)

Common Name	Scientific Name	Acoustic	MOTUS	Video	Total		
					Day	Night	Total
BIRD							
Semipalmated Plover	*Charadrius semipalmatus*		2		0	2	2
Semipalmated Sandpiper	*Calidris pusilla*		1		0	1	1
Spotted Sandpiper	*Actitis macularius*	1			0	1	1
Solitary Sandpiper	*Tringa solitaria*	1			0	1	1
Upland Sandpiper	*Bartramia longicauda*	3			1	2	3
Shorebird species				3	3	0	3
Skua species				1	1	0	1
Laughing Gull	*Leucophaeus atricilla*			10	9	1	10
Herring Gull	*Larus argentatus*	1		8	9	0	9
Great Black-backed Gull	*Larus marinus*			3	3	0	3
Large Gull species				16	14	2	16
Small Gull species				3	2	1	3
Gull species				10	9	1	10
Royal Tern	*Thalasseus maximus*	1			0	1	1
Osprey	*Pandion haliaetus*			8	8	0	8
Merlin	*Falco columbarius*			1	1	0	1
Peregrine Falcon	*Falco peregrinus*			53	52	1	53
Raptor species				3	3	0	3
Northern Flicker	*Colaptes auratus*			1	1	0	1
Corvid species				2	1	1	2
Hirundine species				3	3	0	3
Brown Creeper	*Certhia americana*			10	10	0	10
Winter Wren	*Troglodytes hiemalis*			17	17	0	17
Wren species				1	1	0	1
American Robin	*Turdus migratorius*	2		2	4	0	4
American Pipit	*Anthus rubescens*			1	1	0	1
Northern Waterthrush	*Parkesia noveboracensis*	1			1	0	1
Blue-winged Warbler	*Vermivora cyanoptera*			1	1	0	1
Black-and-white Warbler	*Mniotilta varia*	2		13	13	2	15
American Redstart	*Setophaga ruticilla*	1		3	3	1	4
Cape May Warbler	*Setophaga tigrina*			112	110	2	112
Northern Parula	*Setophaga americana*	2		1	2	1	3
Magnolia Warbler	*Setophaga magnolia*	1		4	4	1	5
Bay-breasted Warbler	*Setophaga castanea*	2		7	7	2	9
Blackburnian Warbler	*Setophaga fusca*			5	5	0	5
Palm Warbler	*Setophaga palmarum*	1		13	14	0	14
Pine Warbler	*Setophaga pinus*			27	27	0	27
Yellow-rumped Warbler	*Setophaga coronata*			16	16	0	16
Kirtland's Warbler	*Setophaga kirtlandii*			1	1	0	1
Setophaga species				171	167	4	171
Parulidae species				6	6	0	6
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	12		10	21	1	22
Passerine species				271	249	22	271
Unidentified bird species				158	120	38	158
BAT							
Silver-haired bat	*Lasionycteris noctivagans*	233		1	155	79	234
Hoary bat	*Lasiurus cinereus*	80		2	9	73	82
Eastern Red bat	*Lasiurus borealis*	86		4	49	41	90
Unknown low frequency species		13			6	7	13
Bat species				103	15	88	103
TOTAL		443	3	1085	1154	377	1531
Percent of TOTAL		28.9%	0.2%	70.9%	75.4%	24.6%	

Appendix B

Table B2. Summary of flight heights and velocities

Subtype	Common Name	N	No. Null Values	No. with Value	Height (m above sea level)			Velocity (m/s)		
					Median	Min	Max	Median	Min	Max
Shorebird	Shorebird species	2	1	1	35.1	35.1	35.1	5.0	5.0	5.0
Skua	Skua species	1	0	1	107.9	107.9	107.9	32.1	32.1	32.1
Gull	Laughing Gull	5	3	2	100.0	86.7	113.4	30.5	19.3	41.7
Gull	Herring Gull	7	3	4	100.2	91.9	151.0	34.9	22.9	61.2
Gull	Great Black-backed Gull	3	2	1	106.4	106.4	106.4	58.3	58.3	58.3
Gull	Large Gull species	8	3	5	131.0	78.7	174.0	36.9	16.8	71.7
Gull	Gull species	6	3	3	86.9	85.8	174.0	25.8	17.4	28.1
Raptor	Merlin	1	1	0						
Raptor	Peregrine Falcon	24	10	14	74.4	33.0	114.2	21.6	4.0	35.8
Corvid	Corvid species	1	0	1	59.9	59.9	59.9	12.2	12.2	12.2
Hirundine	Hirundine species	2	0	2	46.8	45.4	48.1	6.7	6.3	7.1
Passerine	Brown Creeper	8	3	5	32.0	28.0	78.8	9.8	4.8	35.1
Passerine	Winter Wren	6	3	3	27.2	27.1	28.6	3.5	3.0	5.6
Passerine	Wren species	1	0	1	31.0	31.0	31.0	9.1	9.1	9.1
Passerine	American Robin	1	1	0						
Passerine	American Pipit	1	1	0						
Passerine	Blue-winged Warbler	1	1	0						
Passerine	Black-and-white Warbler	12	8	4	32.3	26.9	39.0	3.6	2.3	6.7
Passerine	American Redstart	3	1	2	44.8	40.4	49.2	20.8	11.5	30.0
Passerine	Cape May Warbler	34	22	12	29.9	26.7	35.7	5.7	3.8	8.2
Passerine	Magnolia Warbler	4	4	0						
Passerine	Bay-breasted Warbler	7	2	5	31.1	28.2	37.7	4.8	3.3	11.4
Passerine	Blackburnian Warbler	4	2	2	29.1	26.7	31.5	7.0	6.4	7.6
Passerine	Palm Warbler	10	7	3	28.6	28.5	29.3	4.5	4.2	6.9
Passerine	Pine Warbler	3	1	2	27.3	27.0	27.6	3.6	3.0	4.2
Passerine	Yellow-rumped Warbler	11	8	3	37.7	28.8	41.9	5.9	4.0	6.7
Passerine	Setophaga species	37	25	12	37.2	27.5	55.3	7.4	2.7	11.4
Passerine	Parulidae species	6	3	3	33.4	31.4	46.9	6.1	5.0	6.6
Passerine	Rose-breasted Grosbeak	9	4	5	32.4	26.8	48.3	5.4	3.4	8.3
Passerine	Passerine species	59	33	26	37.8	24.0	110.0	7.9	0.1	49.1
Unid. Avian	Unidentified bird species	42	15	27	50.5	25.5	127.4	10.1	1.0	53.2
Bat	Bat species	36	10	26	97.8	39.7	130.4	29.2	5.8	50.0

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