POST-CONSTRUCTION AVIAN AND BAT IMPACT ASSESSMENT OF THE UNIVERSITY OF DELAWARE WIND TURBINE IN LEWES, DE:

Interim report

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In May 2010, a Gamesa G90 2.0 megawatt wind turbine was erected in Lewes, DE through a collaborative effort between The University of Delaware, Gamesa Technology Corporation, Inc., and Sustainable Energy Developments, Inc. The turbine was commissioned and began generating electricity in June 2010. The turbine has a tower height of 78.03 m (256 feet) above ground with a three-blade rotor diameter of 90 m (295 feet), thus a rotor swept area of 6,362 m^2. The blades can turn up to 19 RPM, giving it a top rotational speed of 89.54 m/s (200.28 mph) at the blade tips.

The University of Delaware received federal funds in support of the wind project. As a result, an Environmental Assessment (EA) was conducted pursuant to the National Environmental Policy Act by the US Department of Energy (DOE). Based on the EA, DOE issued a Finding of No Significant Impact (FONSI), but required the University of Delaware to conduct a post-construction assessment of wildlife impacts, specifically to determine collision risk and mortality of birds and bats.

There have been many studies documenting mortality of bats and birds colliding with wind turbines (reviewed by Erickson et al. 2001, Arnett et al. 2008). Until recently, passerine birds were among the most frequently reported wildlife fatalities at wind-energy facilities in the United States. They accounted for 78% of carcasses found at wind-energy facilities outside of

California among a review of 31 studies (Erickson et al. 2001). Approximately half of these birds were of nocturnally migrating species. Based on weather radar observations (Buler unpublished data), night-migrating birds concentrate in relatively high densities within coastal habitats along the Delaware coast during spring and fall migration, including areas adjacent to the Lewes wind turbine. However, in general, daily stopover density and flight activity of migrating birds can be highly variable due to local weather (Richardson 1978). Raptors are also at risk. In particular, raptors that are protected or of conservation concern, including Bald Eagle (*Haliaeetus leucocephalus*), Northern Harrier (*Circus cyaneus*), and Sharp-shinned Hawk (*Accipiter striatus*) have been documented in the vicinity of the Lewes turbine (Kerlinger and Guarnaccia 2010).

More recent studies have documented that considerably more bats have been killed than expected based on early monitoring studies where birds have been the focus (NRC 2007). Migratory, foliage- and tree-roosting lasiurine bat species (e.g., hoary bat *Lasiurus cinereus*) are the dominant types of bats killed by turbines based on a review of 21 post-construction fatality studies (Arnett et al. 2008). Bat fatalities, although highly variable and periodic, consistently peak in late summer and fall, coinciding with nocturnal migration of lasiurines and other species. Although bat activity along the Delaware coast is less than that reported at Appalachian mountain ridges (A. Sjollema pers. comm.), bat mortality has been documented at a nearby wind energy facility on the New Jersey coast (D. Mizrahi pers. comm.).

To provide accurate and robust fatality estimates, three main sources of bias must be accounted for; 1) carcass removal by scavengers, 2) search area and frequency, and 3) searcher efficiency (Anderson et al. 1999, Morrison 2002, Kunz et al. 2007a). Carcass removal rates can be estimated using fresh or frozen carcasses placed on the ground and monitored by researchers. Bird carcasses have been used surrogates for bats when estimating scavenging rates, and evidence indicates that bat carcasses have similar or lower scavenging rates relative to birds (Kerns et al. 2005). Because fatalities occur in a temporally-clustered distribution, often attributed to poor weather conditions that force birds to fly at low altitudes and/or reduce visibility of wind turbines, and infrequent search intervals can lead to underestimation of the total number of fatalities due to removal by scavengers, search frequency should be maximized (Kerns et al. 2005). Finally, searcher efficiency, or carcass detection rate, depends on several factors such as physical characteristics of the search strata, observer skill and distance of the carcass from the observer. The probability that a searcher will locate a carcass decreases rapidly with increased vegetation height and density and increasing distance from the observer; declining significantly beyond three meters (Kerns et al. 2005).

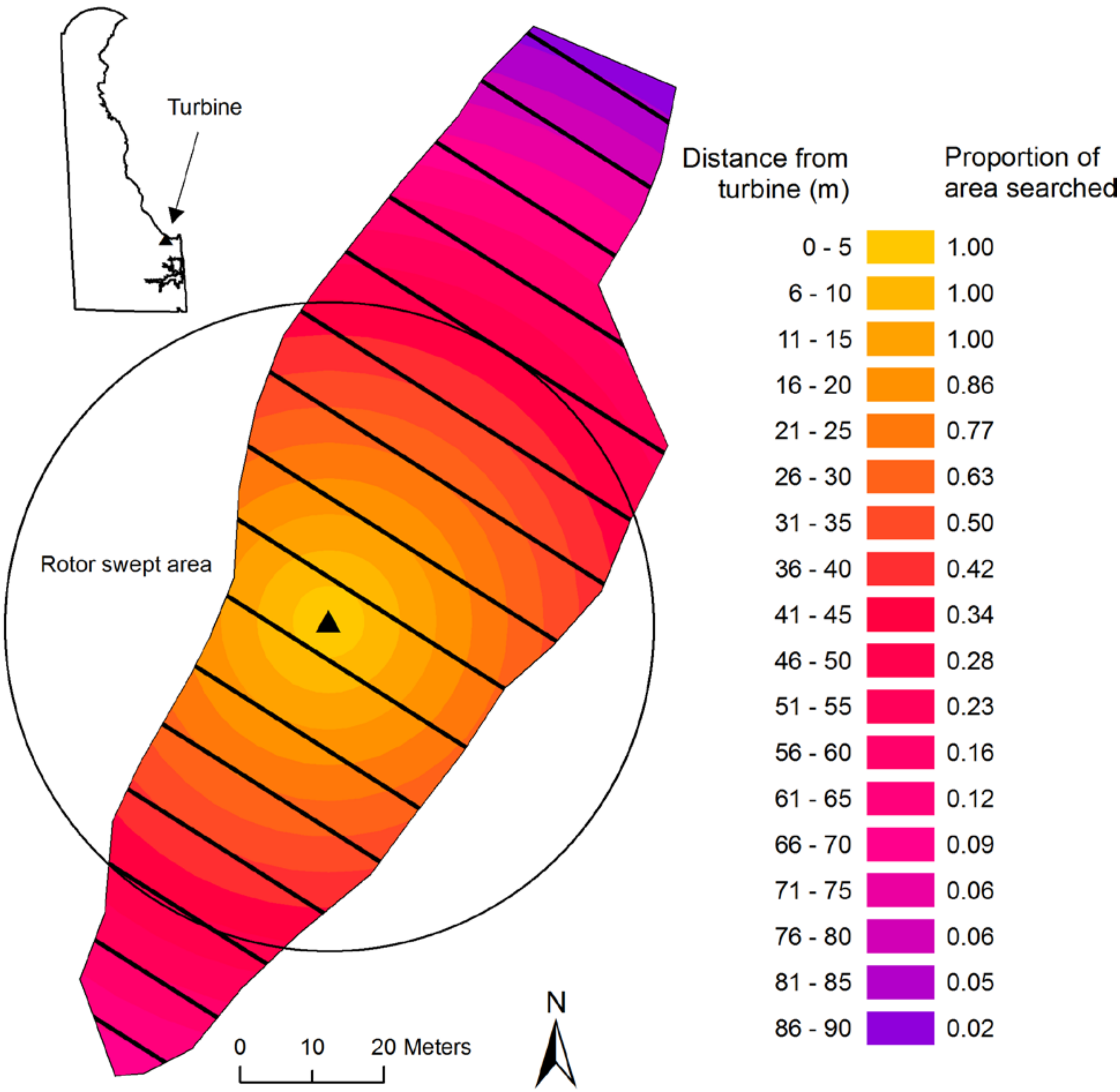
Our objectives to assess the post-construction wildlife impacts of the University of Delaware wind turbine in Lewes, DE include; 1) using various methods to monitor flight activity (primarily nocturnal) and the species composition of birds and bats present near the turbine, 2) documenting the number and identity of bird and bat species that fatally collide with the turbine, and 3) estimating collision fatality rate of flying birds and bats. We report here the results from the first year of sampling.

METHODS

Study Site

The University of Delaware wind turbine is located in Lewes, DE (38°46'58.53"N, - 75° 9'53.41"W) adjacent to Breakwater Harbor along the Delaware Bay. The site consists primarily of bare gravel surrounded by a mixture of scrubby vegetation and is bordered by salt marsh habitat to the west and south, and campus of The College of Earth, Ocean, and Environment (CEOE) to the east/northeast (Fig. 1).

Figure 1. Location of the University of Delaware wind turbine (triangle) in Lewes, DE. Transects (lines) within the carcass search area, colored according to distance from the turbine, are depicted. The proportion of distance band area searched is reported.



Carcass Searches

The carcass search area encompassed a total area of 0.57 ha (1.41 acres) centered on the base of the turbine and was restricted to areas with no vegetation (bare gravel) or with sparse vegetation under 1m in height. We split the search area into individually labeled, parallel transects that searchers walked in a serpentine pattern. Transect lines were 10 m apart and were of varying length due to the irregular shape of the search area. Each transect had a search width of 5 m on either side, so as not to overlap search effort but also to provide complete coverage.

We conducted carcass searches shortly after sunrise at daily intervals during spring (2 March – 30 May) and late summer - fall (16 July – 31 Oct), at three-day intervals during early summer (3 June – 13 July), and weekly during winter (1 Nov – 31 Dec). We did not conduct searches during inclement weather. Searchers walked at a rate of 15-25 m per minute along all transect lines. When a carcass was encountered, the searcher stopped, flagged the location of the carcass and recorded the distance along the transect at which the carcass was first observed before resuming the search. Upon completion of the entire search, the searcher would return to each carcass and record date, time found, observer name, species, identification number of carcass, habitat, perpendicular distance from the transect line to the carcass, distance from turbine, bearing from turbine, condition of carcass, probable scavenger of carcass, cause of death/visible injuries, and estimated time of death (e.g., < 1day, < 2 days). Searchers photographed each carcass before collecting it in a plastic bag while wearing rubber gloves. Dr. Kevina Vulinec at Delaware State University identified and took possession of bat carcasses. We instructed maintenance staff not move or disturb any carcass during any of their time at the turbine site and to only disclose the location of any specimen they found to the senior researcher, so as not to bias the searches. We recorded any carcasses found outside of formal searches as incidentals.

Searcher Efficiency

We estimated searcher efficiency rates by randomly placing frozen bird carcasses of varying sizes (warblers, thrushes and robins) within the search area for searchers to find. Each searcher was exposed to multiple trial carcasses during the spring and fall seasons. We randomly selected the date, location and number of trial carcasses placed (i.e., 1 or 2 carcasses at a time) within the search area for each trial. Searchers were unaware of when and where trial carcasses were being deployed. During the deployment of trial carcasses, the senior researcher would record the date, time of placement (generally in the afternoon or evening), species, condition and location of each carcass in relation to the turbine and nearest transect line. When a trial carcass was found, the searcher would record the same data as an actual carcass. However, trial carcasses were left out for use in the scavenging trials. Any trial carcass that was not found would be monitored by the senior researcher until it was removed or discovered during a formal search.

Scavenging and Carcass Removal

We monitored bird carcasses used for the searcher efficiency trials to estimate carcasses removal rates by scavengers. Prior to deployment, the data recorded included the species, date, habitat and location of each carcass in relation to the turbine and transect line. Once a carcass was deployed, it was monitored daily by the senior researcher until it was found by the searcher. The searcher then continued monitoring until the carcass was removed. Each additional day, the same variables were recorded, as well as the condition of the carcass.

Nocturnal flight activity

Weather surveillance radar: We obtained raw composite reflectivity ("unqc_cref") weather surveillance radar (WSR) data collected at the Dover, DE radar (KDOX) and processed through the National Severe Storms Laboratory's National Mosaic and Multi-Sensor QPE (NMQ) interface (Zhang et al. 2011). Radar reflectivity is a measure of radar echo strength in units of Z and serves as an index of bird density in the airspace (Gauthreaux and Belser 1998, Diehl et al. 2003). Because the raw data have not been "quality control edited", they retain non-precipitating radar echoes (e.g. flying animals). We obtained data from the individual National Mosaic 3D grid column located over the wind turbine (range 24.5 km, azimuth 101.5°) to quantify nocturnal animal flight activity in the vicinity of the turbine. WSR quantifies flying animals (i.e., bird, bat, and insect) distributed within the grid column and cannot resolve individual animals or identify taxa. At this location, the grid column has a two-dimensional area of ~1 km x 1 km, and the center of the lowest tilt (0.5° above the horizon) of the 6dB-wide radar beam is typically 294 m above ground level (AGL), extending from 1 to 587 m AGL. The temporal sampling rate of the WSR is 5 – 10 minutes. We excluded radar data from samples when precipitation was present in the grid column as determined from the NMQ precipitation flag product ("pcp_flag"). Additionally, we excluded sampling nights when precipitation was present for at least 25% of the night.

Audio detectors: We monitored bird and bat flight activity by recording flight calls using a Wildlife Acoustics, Inc. Song Meter 2 (SM2™) and Song Meter 2 ultrasonic (SM2BAT™) audio recorder, respectively. We detected bird flight calls using the Wildlife Acoustics, Inc. Night Flight Call microphone. The microphone capsule is mounted near the surface of a flat horizontal plate, which creates a pressure zone for sounds originating from above the plate and is designed for recording distant night flight calls above while attenuating sounds from at and below the horizon such as insects and amphibians. The microphone delivers flat frequency response up to 11kHz and 3-6dB signal gain with a beam angle of 125 degrees. We mounted the microphone ~10 m AGL and ~250 m NE of the turbine and recorded flight calls daily from sunset until sunrise.

We applied a single band limited energy detector algorithm to automatically detect potential bird flight calls using Raven Pro v1.4 (www.birds.cornell.edu/raven) software. The algorithm identified "high frequency" vocalizations within the frequency range of 6500 – 8000 Hz, the range of warbler (Parulidae) and sparrow (Emberizidae) flight calls, with a call duration of 16-597 ms, a minimum separation of 16 ms, a signal to noise ratio of 6.5 dB, and a minimum signal occupancy of 60% within the call duration. All detections were subsequently manually examined within Raven Pro v1.4 to confirm they were birds.

We detected bat flight calls using an omni-directional 192 kHz microphone mounted ~18 m AGL and ~15 m NE of the turbine and attached to a SM2BAT recording unit. We recorded flight calls daily from one hour before sunset until sunrise using a 16-bit full spectrum, which preserves the amplitude and harmonic details of the original bat signal and is more sensitive to detecting bat calls. Factors such as the intensity and frequency of flight calls and humidity affect the transmission of ultrasound through the air and the effective detection range of bat detectors, which has been roughly estimated to be about 30 m (Patriquin et al. 2003, Collins and Jones 2009). See the attached report by Vulinec for details about analysis of bat audio files.

Thermal video: We monitored nocturnal animal flight activity using a FLIR Guardsman HG-307 Pro thermal imaging camera with a 7° field of view. The camera was located approximately 40m south of the turbine and oriented vertically to record flying birds and bats passing over. Video was digitally recorded at a resolution of 320 x 240 pixels from approximately one hour before sunset until sunrise concurrent with ground transect surveys (i.e., daily during spring and fall and every three days during summer). Taxa of flying animals (e.g., bird, bat, or insect) could not be reliably discriminated so all animals were counted collectively. Video files were manually screened to quantify flight traffic rate (animal passes per decile of the night) and the flight direction of animals within eight direction categories (N, NE, E, SE, S, SW, W, NW).

Ground Surveys

To estimate avian use of the habitats in the vicinity of the turbine we established three strip transects (500-750 m x 25m) within each habitat type (*Phragmites*, marsh, and shrubland). We conducted surveys each morning after carcass searches (daily during spring and fall migration and every three days during non-migration periods). Observers walked the length of transects and recorded the species, number of individuals, and perpendicular distance from the transect to all birds detected. We estimated species density using the total number of individuals detected for each bird species within 25 m of either side of the observer (50 m total transect width) per length of transect surveyed (birds/km). We summarized these data by survey date for all birds detected, all birds detected within each habitat type, and all Partners in Flight (PIF) "Regional Concern" species within the New England / Mid-Atlantic Coasts Bird Conservation Region (http://www.rmbo.org/pif/pifdb.html).

Weather data

We have obtained weather data from multiple sources for use in modeling variability in nocturnal flight activity of birds and bats. We are using the NMQ precipitation flag WSR data product to provide continuous (every 5 minutes) measures of the type and prevalence of precipitation in the vicinity of the turbine. We have data from the meteorological tower located at the turbine, which provides hourly average measures of temperature, surface wind speed and direction, humidity, barometric pressure, and rainfall. We have data from the Lewes weather station operated by NOAA (USAF-WBAN ID 997281), to provide additional hourly data on cloud cover and ceiling. We have data on the nightly proportion of moon illumination from the United States Naval Observatory Portal (http://aa.usno.navy.mil/data/docs/MoonFraction.php). We also plan on obtaining daily winds aloft data from the KDOX radionsonde.

Data Analysis

We estimated mean number of fatalities per day (f_s) separately for each sampling season, s, according to the following equation:

$$f_s = A\frac{o_s}{r_i D}$$

where o_s is the observed fatality rate (number of carcasses found during formal searches / number of days during search season), r_i is the observed probability a carcass is not removed by a scavenger during the search interval i (daily, every three days, or weekly), D is the carcass detection rate, and A is the search area adjustment factor. We determined carcass detection rate D by multiplying the observed searcher efficiency rate by the modeled detection probability of carcasses within 5 m of the transect line. We calculated the searcher efficiency rate by dividing the total number of trial carcasses found by the total number of carcasses that were placed. We used program Distance (http://www.ruwpa.st-and.ac.uk/distance/) to model the probability of carcass detection within 5 m of the transect line as a function of distance from the transect line.

We determined the adjustment factor (A) for the distribution of carcasses relative to the turbine and the differential search effort at varying distances from the turbine using the following equation:

$$A = \sum_{j=1}^{18} \frac{c_j}{s_j}$$

where c_j is the proportion of observed carcasses found in the *j*th distance band from the turbine in 5 m increments, and s_j is the proportion of the *j*th distance band area that was searched. Ideally, this also would be adjusted for the prevailing wind and prevailing direction of flight, but the wind direction is relatively evenly distributed at this site, and a function of flight direction would be too complex.

We divided measures of traffic rates within nights into 10 time periods (deciles) rather than hourly time periods because of variability in the duration of nights throughout the year. We considered night duration as the span of time from evening civil twilight (sun angle 6° below horizon) until morning civil twilight. Twilight occurs approximately 35 min after and before sunset and sunrise, respectively. Evening civil twilight corresponds closely with the onset of nocturnal bird migration (Gauthreaux 1971, Hebrard 1971, Buler and Diehl 2009).

RESULTS AND DISCUSSION

From March 2011 through February 2012, we found 28 carcasses during formal searches and 7 carcasses incidentally (Table 1). Of the 35 total carcasses, 31 were bats and 4 were birds. Additionally, we opportunistically observed two large gulls collide with the turbine blades and fall within the dense stand of tall *Phragmites* grass to the east of the turbine, but the carcasses could not be found. Bat carcasses were comprised of 5 species: Eastern red bat (44.4%), hoary bat (16.7%), big brown bat (16.7%), tri-colored bat (2.8%), and silver-haired bat (2.8%). Out of the 6 bird fatalities, we observed a total of 4 species: Osprey (5.6%), gull sp. (5.6%), Yellow-billed Cuckoo (2.8%), and Common Grackle (2.8%). Necropsies of birds were not performed. Most bird specimens had visible external trauma and were located within the rotor swept area of the turbine, leading us to believe that they fatally collided with the turbine rather than other causes of death. Because the Common Grackle was found as a pile of feathers, we could not confirm whether it had initially collided with the turbine and then was scavenged by a predator, or if it was a victim of depredation in close proximity to the turbine. Because of this, we present alternative fatality results that exclude the Common Grackle carcass to account for this uncertainty.

Necropsies of bats were performed by researchers from Delaware State University (See accompanying report for details). They found that most (71%) bats had blood in the thoracic cavity and/or broken bones (53%) consistent with blunt trauma. Additionally, all aged bats were adults and there tended to be more males (62%) than females (38%). We note two bats that we found in June and gave to Delaware State University are missing from their dataset.

We placed 18 trial bird carcasses between 6m and 60m away from the turbine for estimating carcass removal rate and searcher efficiency. Scavengers removed 17% of trial carcasses within one day (r_1 = 0.83), 28% within 3 days (r_3 = 0.72), and 61% within a week (r_7 = 0.39; Fig. 2). All carcasses were removed by 21 days. The mean number of days a trial carcass persisted before being scavenged was 7.28 days. Searchers found 11 trial carcasses during formal searches. This yielded an overall searcher efficiency rate of 65%. Of the trial carcasses that were found, 45% of them were found within one day of deployment and 82% within two days of deployment. Additionally, detection of carcasses did not decline with distance from the search transect (Fig. 3). Therefore, we used a detection probability of carcasses within 5 m of the transect line of 1.0 and had a carcass detection rate (*D*) of 0.65.

Our searcher efficiency (65%) was greater than the regional average of 36% ± 8% reported by Arnett et al. (2008). This is likely because we restricted our search area to more open strata (i.e., bare ground and low grass) where detection of carcasses is better. We also had a shorter search interval (i.e., daily) throughout most of the study period (except during early summer) compared to other studies (i.e., weekly or greater search intervals).

The distribution of observed carcasses, expressed as the proportion of carcasses found within each distance band after adjusting for the amount of the distance band searched, generally increased with distance from the turbine and peaked at the 40-45 m distance band (Fig. 4). We found all carcasses within 50m of the turbine. The adjustment factor (*A*) accounting for carcass location and search area with respect to distance from the turbine was 1.56.

Table 1. Bird (bold) and bat carcasses found at the University of Delaware wind turbine in Lewes, DE based on searches conducted within a 0.56 ha area around the turbine. Spring searches were conducted daily from 2 March – 30 May (n=90). Early summer searches were conducted every three days from 3 June – 13 July (n=10). Late summer and fall searches were conducted daily from 16 July – 31 Oct (n=94). Winter searches were conducted weekly from 1 Nov – 29 Feb (n=16).

Season	Species		Date collected	Current location
Spring	**Osprey**	***Pandion haliaetus***	**4/10/2011**	**UD**
	Eastern Red Bat	*Lasiurus borealis*	4/27/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	5/3/2011	Del State
	Hoary Bat	*Lasiurus cinereus*	5/25/2011	Del State
Early Summer	Big Brown Bat	*Eptesicus fuscus*	6/19/2011	Unknown
	Common Grackle	***Quiscalus quiscula***	**6/19/2011**	**UD**
	Eastern Red Bat	*Lasiurus borealis*	6/23/2011	Unknown
Late Summer –Fall	Eastern Red Bat	*Lasiurus borealis*	7/17/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	7/20/2011	Del State
	Big Brown Bat	*Eptesicus fuscus*	7/21/2011	Del State
	Big Brown Bat	*Eptesicus fuscus*	7/21/2011	Del State
	Big Brown Bat	*Eptesicus fuscus*	7/21/2011	Del State
	Big Brown Bat	*Eptesicus fuscus*	7/27/2011	Del State
	Hoary Bat	*Lasiurus cinereus*	7/27/2011	Del State
	Hoary Bat	*Lasiurus cinereus*	7/27/2011	Del State
	Gull sp.[1]	***Larus sp.***	**7/29/2011**	**n/a**
	Gull sp.[1]	***Larus sp.***	**7/29/2011**	**n/a**
	Osprey	***Pandion haliaetus***	**7/30/2011**	**UD**
	Eastern Red Bat	*Lasiurus borealis*	7/30/2011	Del State
	Tricolored Bat	*Perimyotis subflavus*	7/31/2011	Del State
	Big Brown Bat	*Eptesicus fuscus*	7/31/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	8/10/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	8/10/2011	Del State
	Hoary Bat	*Lasiurus cinereus*	8/13/2011	Del State
	Hoary Bat	*Lasiurus cinereus*	8/21/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	8/23/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	8/25/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	9/13/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	9/13/2011	Del State
	Hoary Bat	*Lasiurus cinereus*	9/13/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	9/14/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	9/15/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	9/16/2011	Del State
	Silver-haired Bat	*Lasionycteris noctivagans*	9/17/2011	Del State
	Eastern Red Bat	*Lasiurus borealis*	9/25/2011	Del State
	Yellow-billed Cuckoo	*Coccyzus americanus*	**10/3/2011**	**UD**
	Eastern Red Bat	*Lasiurus borealis*	10/28/2011	UD

1 Two large gulls opportunistically observed colliding with turbine but carcasses were not recovered.

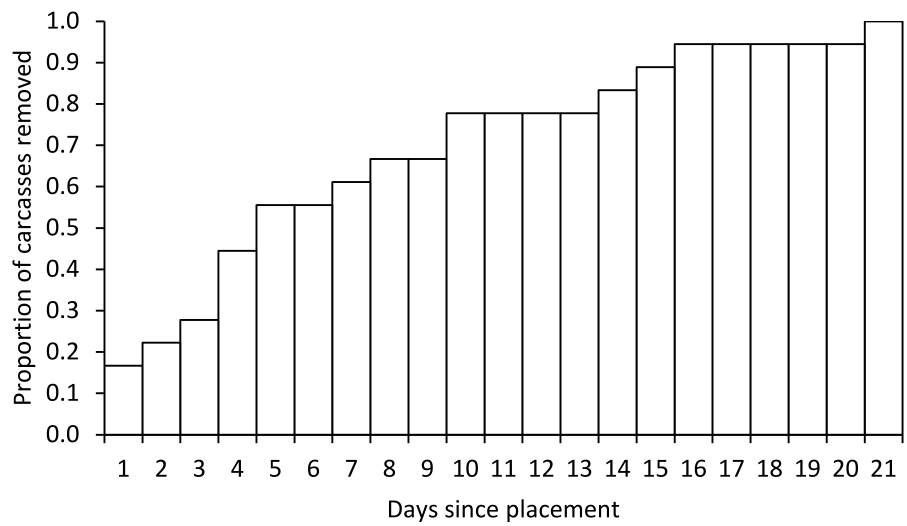


Figure 2. The proportion of trial carcasses removed by scavengers relative to the number of days since placement.

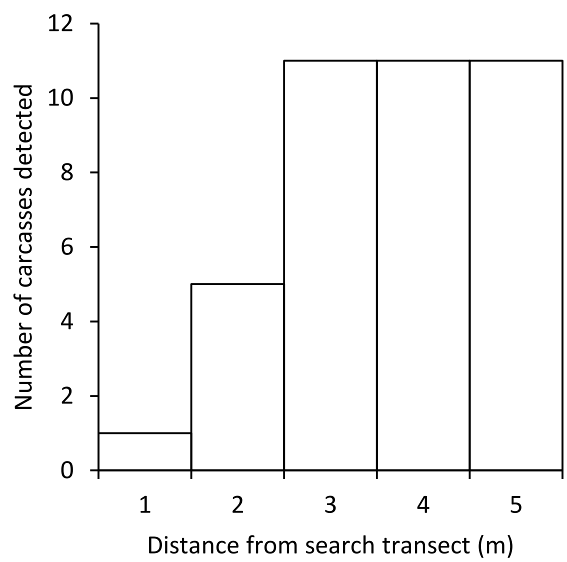


Figure 3. Distribution of observed and trial carcasses relative to distance from the search transect found during formal searches ($n = 31$).

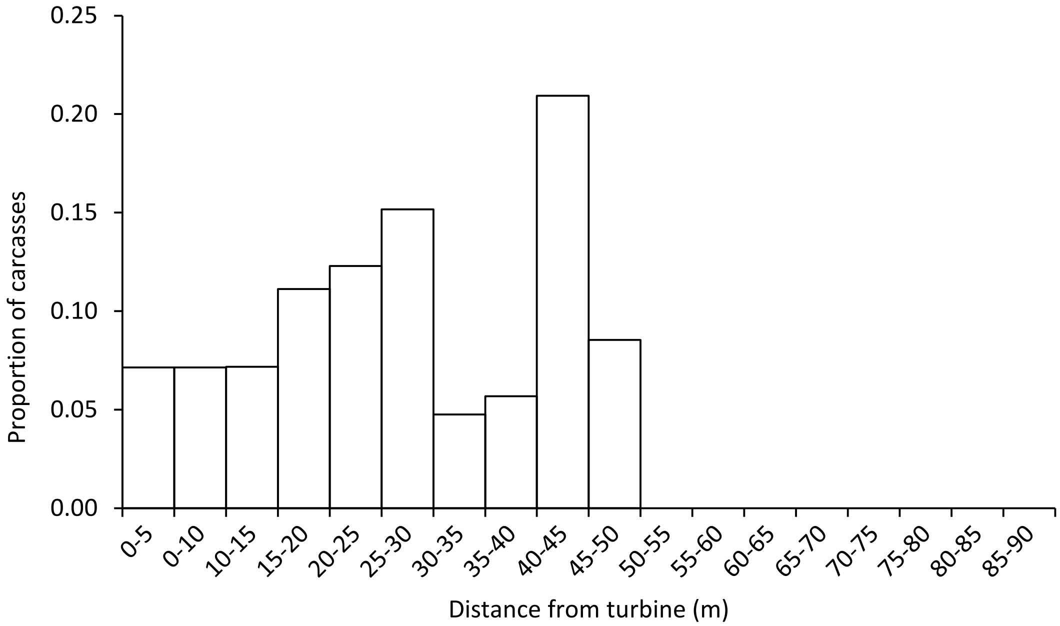


Figure 4. The distribution of observed carcasses relative to distance from the turbine. Proportions are adjusted for the amount of area searched at each distance band.

Fatality Estimates

We estimate that 82 fatal collisions by birds and bats occurred between March 2011 and February 2012 after adjusting observed fatality rates for search effort, search efficiency, and carcass removal by scavengers (Table 2). See Appendix A for a summary of all parameter values used for adjusting fatality rates. Most collisions of birds and bats occurred during the late summer and fall. Bats comprised 89% of estimated fatalities, and had an overall adjusted fatality rate of 0.200 bats/day; 8 times greater than that of birds (0.025 birds/day). Excluding the Common Grackle carcass found during the summer, which could not be confirmed as a turbine collision fatality, reduced the summer collision estimate to zero birds and the overall collision estimate to 6 birds (79 animals).

We assessed monthly variability in bat fatality rates and found bimodal peaks during July (0.746 bats per day) and September (0.771 bats per day; Fig. 5). Bats were found during 7 months from April through October. Among bat species, big brown and tri-colored bat fatalities peaked the earliest during July (Table 3). Hoary bat fatalities peaked in July and August. Eastern red bat and silver-haired bat fatalities peaked in September. Monthly bat mortality rate was positively correlated (Pearson $r = 0.78$, $n = 8$, $P = 0.02$) with the monthly mean number of nightly bat passes recorded by the audio detector based on the audio data we have processed to date.

Table 2. Estimated number of bird and bat collision fatalities at the University of Delaware wind turbine in Lewes, DE from 1 March 2011 through 29 February 2012. Alternative values in brackets exclude the Common Grackle carcass found during the summer, which could not be confirmed as a turbine collision fatality.

Taxon	Season				Total
	Spring (March – May)	Early summer (June – 15 July)	Late summer/Fall (16 July – October)	Winter (November – February)	
Birds	0	3.3 [0]	5.8	0	9.1[5.8]
Bats	8.7	6.7	57.8	0	73.1
All	8.7	10.0 [6.7]	63.6	0	82.2 [78.9]

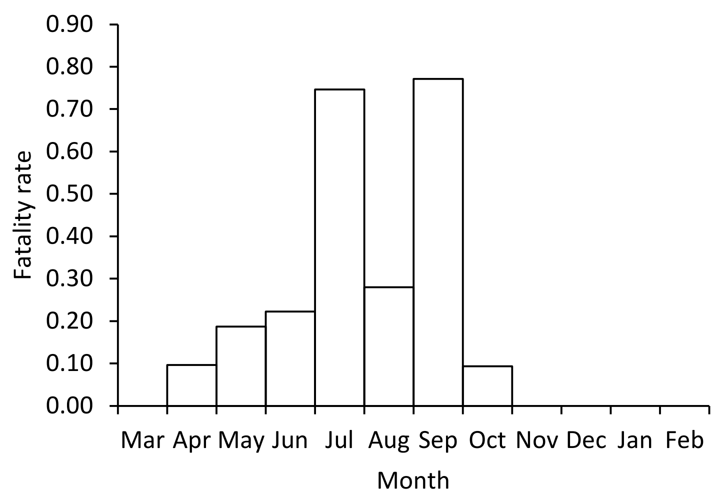


Figure 5. Estimated monthly bat fatality rate (number of bats per day) during 2011-2012 at the University of Delaware wind turbine in Lewes, DE.

Table 3. Bat carcasses found during the study period (formal and incidental) by species, season, and month. Monthly mean ± SE (number of sampled days processed) number of nightly bat passes based on audio detector also indicated.

Species	Spring			Summer		Fall			Winter			
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Eastern Red Bat	0	1	1	1	3	4	6	1	0	0	0	0
Big Brown Bat	0	0	0	1	5	0	0	0	0	0	0	0
Hoary Bat	0	0	1	0	2	2	1	0	0	0	0	0
Tri-colored Bat	0	0	0	0	1	0	0	0	0	0	0	0
Silver-haired Bat	0	0	0	0	0	0	1	0	0	0	0	0
Total	0	1	2	2	11	6	8	1	0	0	0	0
Mean number of nightly bat passes	7.4 ± 3.7 (5)	12.8 ± 3.7 (16)	8.2 ± 1.5 (26)	21.9 ± 3.7 (26)	45.7 ± 16.1 (6)	17.4 ± 5. (21)	10.9 ± 2.7 (26)	24.7 ± 7.4 (10)				

We estimate that few (6-9 birds) birds fatally collided with the University of Delaware wind turbine during the study period. Cast in terms of birds per megawatt of energy production capacity, the estimated fatality rate of birds at the UD turbine is 3-4.5 birds/MW/year. This range is greater than the national average rate of 2.1 birds/MW/year (Erickson et al. 2001), but much less than the estimated rate of 20 birds/MW/year at the nearby five-turbine Jersey-Atlantic Wind Farm (JAWF) along the coast of Atlantic City, NJ (New Jersey Audubon Society, unpub. data). However, our rate of bird collisions is very sensitive because of the general rarity of bird collisions and only one year of sampling has been conducted. Thus, it is difficult to draw strong inferences at this point about the bird mortality rate at the turbine until more monitoring produces a more precise rate.

We found that passerine birds (i.e., Common Grackle and Yellow-billed Cuckoo) comprised only 6% of the wildlife (33% of birds) that fatally collided with the turbine, despite a review that reports passerine birds are among the most frequently (78%) reported wildlife fatalities at wind-energy facilities in the eastern United States (Erickson et al. 2001). However, since Erickson et al. (2001) was published, monitoring of bat fatalities at wind turbine facilities has garnered more attention and evidence indicates that bats comprise the majority of wildlife colliding with wind turbines (Kunz et al. 2007b). For example, when bat carcasses are also monitored, passerine birds similarly comprise only 11% of the wildlife fatalities (33% of bird) based on three years of monitoring at the JAWF. Thus, the mortality of migratory passerine birds in particular is relatively low compared to other wildlife.

All of the birds observed colliding with the turbine or carcasses we found were of migratory species. However, there is considerable uncertainty as to whether most of these individual birds were actively migrating at the time of collision. We are uncertain as to whether the two Osprey collisions we detected were of migrating or breeding individuals because they occurred during April and July; times when both breeding and migrating individuals co-occur in the area (Poole et al. 2002). We are certain that the Yellow-billed Cuckoo was a migrating individual given that it was collected in October and Yellow-billed Cuckoos do not breed at the study site.

We identified 4 key findings that are similar to other bat fatality studies at wind-energy facilities reviewed by Arnett et al. (2008): 1) estimated fatality rates were similar to other facilities, 2) fatalities were heavily skewed toward migratory foliage-roosting lasiurine species, 3) the peak of collisions occurred in midsummer through fall, and 4) the distribution of fatalities declined as a function of distance from the turbine and was restricted to the rotor swept area. Our estimate of 36.6 bats/MW/year is similar to the average ± SD estimate of 30.1 ± 13.5 bats/MW/year among six other wind-energy facilities in the eastern U.S. (Arnett et al. 2008) and a rate of 30.7 bats/MW/year at the JAWF. Eastern red and hoary bats, which are migratory foliage-roosting species, were the dominant bat species; consistent with Arnett et al. (2008) and the only two bat species found at the JAWF. However, we found that the resident tree-roosting big brown bat comprised a larger proportion (19%) and the resident tri-colored bat a smaller proportion (3%) of bat fatalities compared to Arnett et al. (2008), who report average proportions of 3% and 16%, respectively. The majority of bat fatalities tend to occur during the mid-summer to mid- fall period corresponding with the southward post-breeding migratory movements of bats (Johnson 2005, Arnett et al. 2008). We estimate that 79% of bat fatalities occurred during this same time period. Similarly, 87% of bat fatalities occurred during August and September at the JAWF. Finally, the distribution of fatalities as a function of distance from turbines suggests that nearly all bat fatalities occur within the radius of the turbine blades (Arnett et al. 2008). Similarly, all bats that we found were within the radius of the rotor swept area.

Nocturnal Flight Activity

We assessed flight activity on 296 sampling nights with WSR data during the first sampling year (81% of all nights). Radar data provided the most comprehensive sample of the different monitoring methods. The presence of precipitation during at least 25% of the night excluded 52 sampling nights and missing data excluded the additional 17 sampling nights. Mean reflectivity (i.e., relative animal density) fluctuated dramatically from day to day and ranged from 0 to 244 Z among nights (Fig 6A). During spring, flight activity generally exhibited a unimodal distribution that spanned from late March through early June and peaked around the first week of May. The spring day with the greatest activity occurred on 21 May at 190 Z. The average ± SE of the mean nightly reflectivity during the spring sampling season (1 March – 13 May) was 15.7 ± 3.0 Z. Activity during the summer season (1 June – 15 July) was half as much as spring, averaging 7.6 ± 1.4 Z per night. Summer activity was greatest on 9 July at 35 Z. Fall flight activity was more protracted than in spring, exhibiting multiple pulses of activity that produced an overall unimodal pattern that spanned the beginning of August until early

November and peaking during the last week of September. The fall season also had the greatest average nightly activity of all seasons (37.6 ± 5.1 Z); nearly 2.5 times greater than during the spring. The two days that exhibited the greatest activity occurred on 9 Sep at 244 Z and 22 October at 214 Z. There was very little nocturnal flight activity during winter, which averaged 2.2 ± 0.4 Z.

We have presently analyzed 136 nights of bat audio files. See the attached report for the full results of the analysis of bat audio files. There are three main periods of nocturnal bat activity throughout the year (Fig 6B). Spring migration appears to occur from late March through early May, peaking in late April. The second period of activity occurs between June and early August. This is the main period of volancy of young of the year bats and exhibits the greatest activity. The night of greatest activity (among those analyzed) occurred on 11 July at 110 bat passes during the night. The third period of activity coincides with fall migration, occurring between the start of September through mid-October.

We have presently analyzed bird audio files for detection of high frequency flight calls (those made by warblers and sparrows) for 122 nights. An additional 8 nights were excluded from analysis due to the presence of rain and 110 days were excluded due to equipment problems (battery failure or poor quality recordings). Analysis of high frequency calls for another 125 nights and all low frequency flight calls (those made by thrushes, tanagers, and buntings) during the first sampling year are pending. Mean nightly high-frequency flight call rates ranged from 0 to 6.6 calls per decile during the spring season (Fig. 6C).

We monitored flight activity for at least one half hour after evening civil twilight on 113 of 210 potential sampling nights (54%) with the thermal camera during the first sampling year. Poor weather (precipitation), equipment problems (battery failure and camera overheating), and data loss prevented monitoring of all scheduled sampling nights. We are presently rescreening video due to low and variable observer detection rates. Mean nightly traffic rate varied widely among nights, ranging from 0 animals to 95 animals per decile of the night (Fig. 6D). The initial screening effort indicated spring nocturnal flight activity generally increased from late March through early May; peaking on 2 May before exhibiting a decline through the end of May. Fall flight activity had a roughly-bimodal distribution, with peaks occurring on 23 August and 6 October. Flight activity generally increased abruptly during the first decile of the night, peaked within the first third of the night, and then declined gradually throughout the rest of the night (Fig. 7B). The summer sampling effort resulted in no useable data due primarily to equipment problems.

Across all sampling nights, we found significant positive correlations between WSR reflectivity and bird flight calls, and between WSR reflectivity and thermal camera detection rate of animals (Table 4). No other pairwise comparisons among the four traffic rate sampling methods were significant. The low correlation between nocturnal bird calls and radar data is not unexpected, as there can be substantial differences between radar-observed migration traffic and calling rates of birds (Farnsworth et al. 2004). However, nocturnal call counts of migrating birds can be useful as indices of nocturnal bird density aloft (Larkin et al. 2002).

Table 4. Spearman rank correlations among measures of nightly mean traffic rate of flying animals. Number of nights sampled among pairwise comparisons in parentheses.

	Bat audio (# of bat passes)	Bird audio (# of high frequency bird calls)	Thermal video (# animal passes)	Weather radar (mean reflectivity)
Bat audio		-0.179 (71)	0.142 (40)	-0.005 (126)
Bird audio			0.257 (25)	**0.296* (116)**
Thermal video				**0.615* (73)**

* $P < 0.01$

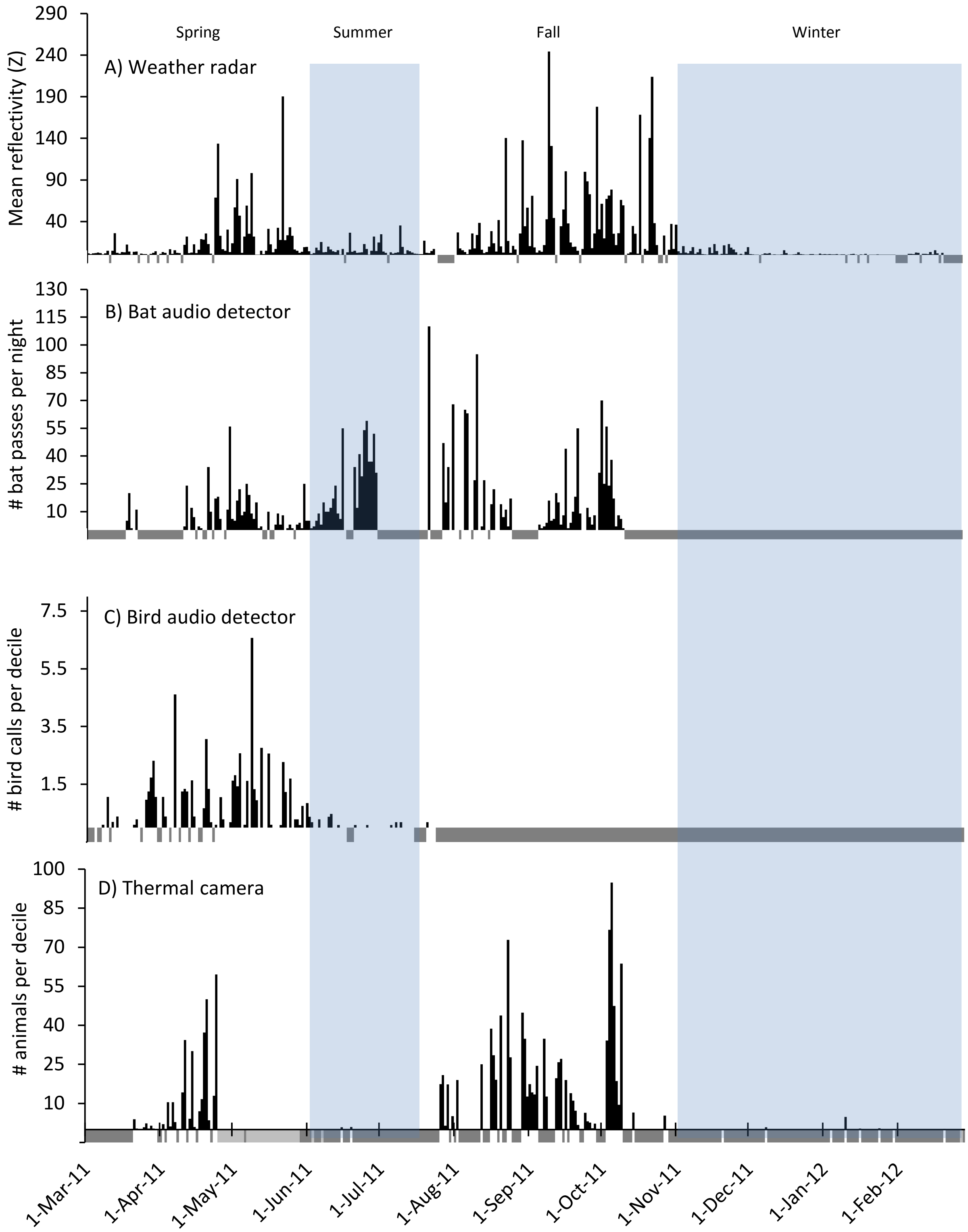


Figure 6. Mean nightly traffic rate of flying animals between evening and morning civil twilight based on A) weather radar [mean reflectivity in units of Z during the night], B) bat audio detections [number of bat passes per night] C) bird audio detections [number of flight calls per decile of the night], and D) thermal camera [number of animals per decile of the night]. Nights marked in dark gray were not sampled or analyzed yet. Nights marked in light gray of the thermal camera dataset have not been analyzed yet.

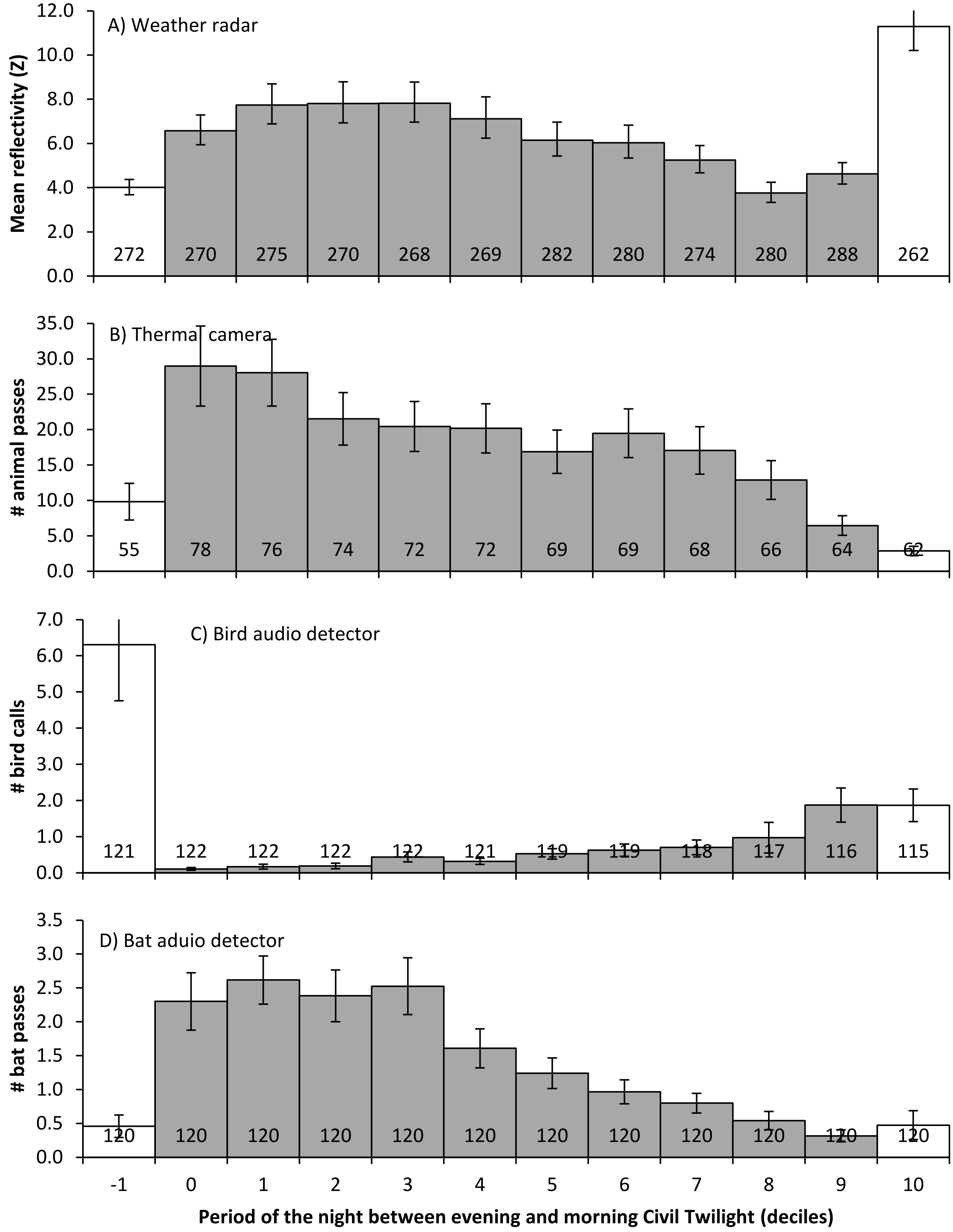


Figure 7. Mean (± SE) traffic rate of flying animals during the night (gray bars) between 1 March 2011 and 29 February 2012 based on A) weather radar, B) thermal camera, C) bird audio detector, and D) bat audio detector data. Number of sampling nights indicated at bar base.

The patterns of relative flight activity throughout the night we observed with the weather radar and thermal camera are consistent with the flight activity of nocturnally-migrating birds and nocturnally-active bats as reported by others. Peak activity occurs within 2 hour of sunset and gradually tapers off throughout the night (e.g., Zehnder et al. 2001, Horn et al. 2008). The pattern of increasing nocturnal flight call activity of birds throughout the night is consistent with flight call activity reported by others (Graber and Cochran 1960, Farnsworth and Russell 2007, Hüppop and Hilgerloh 2012). When comparing nightly activity across days, we found the months that exhibited peak nocturnal flight activity were May, August, and October. These peaks correspond with peak spring bird migration, peak summer bat migration, and peak fall bird migration, respectively. Additionally, preliminary analyses indicate that flight activity of birds and bats is correlated with several weather variables such as wind speed and temperature, but the analyses are not sufficiently far enough along to report at this point.

Ground Surveys

We detected 144 bird species from 3/3/2011 to 2/29/2012 at the University of Delaware wind turbine, Lewes, DE (Appendix B). Across all habitats, bird activity increased during the spring and fall migration periods (Fig. 8). On average, resident species were most abundant during fall, and exhibited peaks in abundance during spring and fall migration periods that we attribute to the passage of migratory populations of resident species through the area (Fig. 8A). Transient migratory species (occurring only during migration periods) were most abundant during spring (Fig. 8B). Migratory species that typically breed in DE (summer migrants) reached peak abundance during fall. Migratory species the typically overwinter in DE (winter migrants) reached peak abundance during winter. We detected 42 species in *Phragmites*, 80 species in salt marsh, and 101 species in scrub. Bird use in the three different habitats differed temporally with detections in *Phragmites* greatest in May and September (Fig. 9A), detections in salt marsh greatest in April and June (Fig. 9B), and detections in scrub greatest during the fall migration period (Fig. 9C). We detected 25 PIF species of regional concern (6 in *Phragmites*, 15 in marsh, and 19 in scrub) using the three habitats associated with the University of Delaware wind turbine. Detections of PIF regional concern species were greatest during the breeding season (Fig. 8C). This peak in PIF species detections was caused by a large number of seaside sparrows and marsh wrens detected in salt marsh habitat.

The three habitat types surrounding the UD wind turbine differed in the number of bird species detected with the greatest number detected in the scrub, second most in the salt marsh, and the fewest species in the *Phragmites*. Bird species richness also differed among seasons with the scrub supporting the greatest avian species richness during the fall migration. All the Partners in Flight species of regional concern we detected are migratory species and we detected more in the scrub and marsh habitats than in the *Phragmites.*

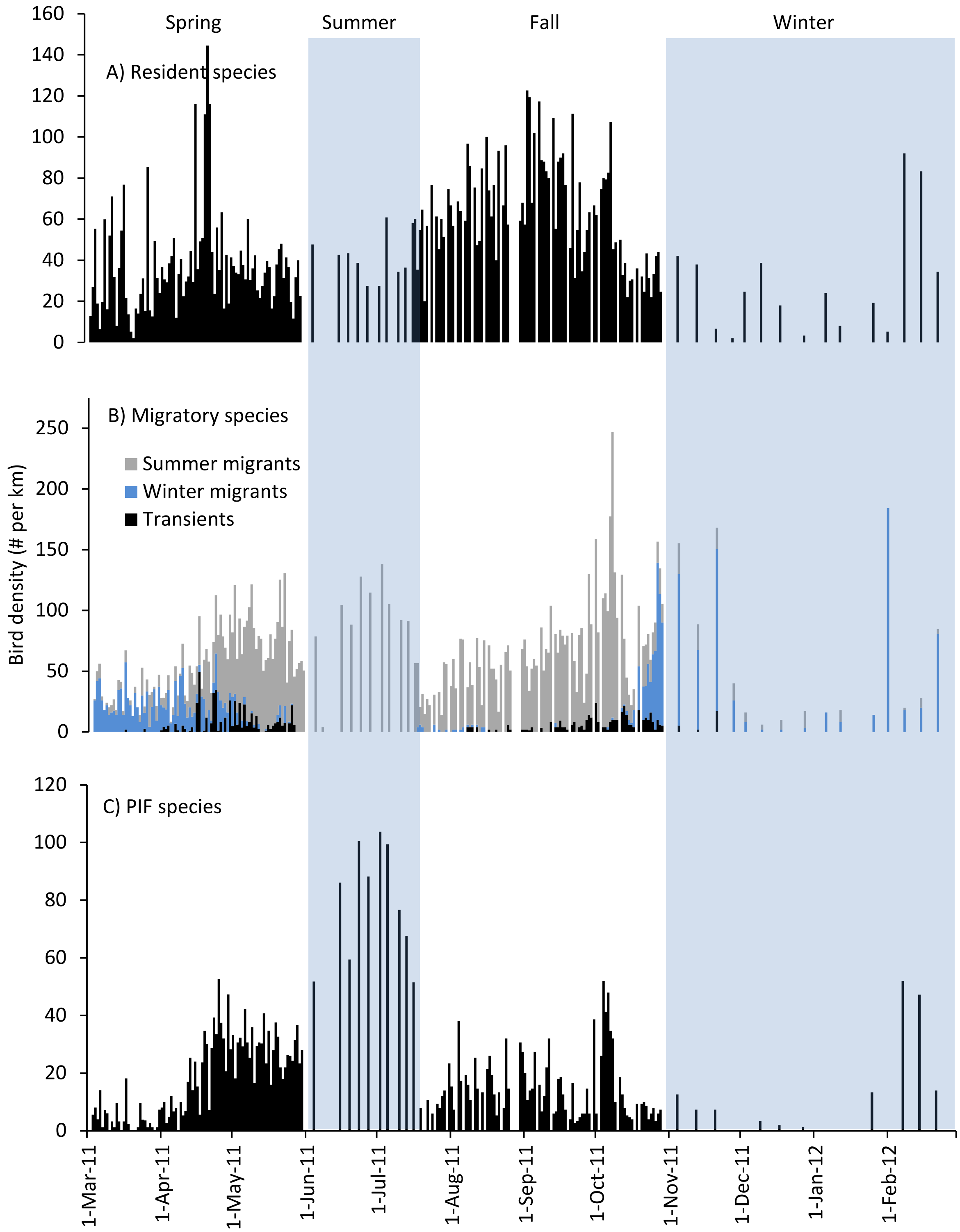


Figure 8. Total density of birds of A) resident, B) migratory, and C) Partners in Flight "Priority" species detected by date at the University of Delaware wind turbine, Lewes, DE, 3/3/2011 – 2/29/2012.

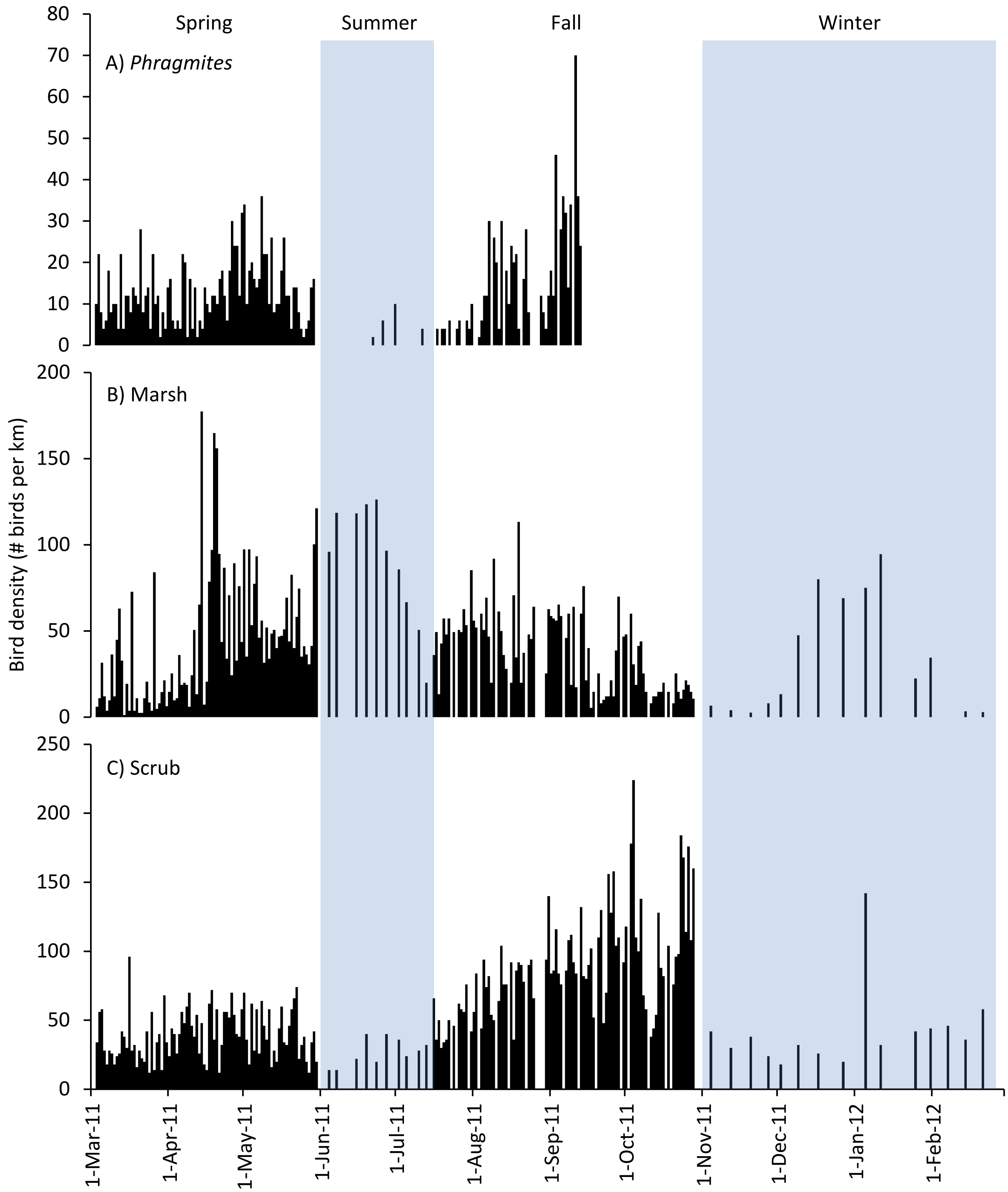


Figure 9. Total density of birds detected by date in A) *Phragmites australis*, B) marsh, and C) scrub habitat at the University of Delaware wind turbine, Lewes, DE, 3/3/2011 – 2/20/2012.

Future work

1) We plan to increase our sampling effort to a daily interval during the next summer because of the unexpectedly high bat activity during the summer months. This will also lend more continuity to the search effort across seasons. This effort can be accomplished without increasing salary costs through reallocating technician time. However, we will need additional housing funds to support the additional summer work and the higher housing cost in general based on the first year experience. We originally budgeted $6,500 for housing in 2012 (with no housing expenses for the summer season), but the actual cost will be $11,600 with the daily summer sampling. Thus, we are in need of an additional $5,100 to cover the housing costs in 2012 (Table 5).

2) Our carcass persistence rate (7.3 days) was similar to the regional average of 8.5 ± 6.6 days reported for bats by Arnett et al. (2008). However, we used frozen bird carcasses to assess scavenging rates. Because the majority of fatalities at the turbine were of bats, we plan to obtain bat carcasses to conduct scavenging trials in the future, but our efforts to procure bat specimens have been unsuccessful thus far. The difference between using bird versus bat carcasses may be important since there is some evidence that scavenging rates may be higher for bats than birds (Kerns et al. 2005).

Table 5. Request for additional funds to complete this effort.

Item	Justification	Amount
Housing costs	This was underestimated in the original budget	$5,100
Indirect costs @ 34.5%		$1,760
	TOTAL REQUEST	$6,860

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Appendix A. Parameter values used in estimation of fatality rates. Alternative values in brackets exclude the Common Grackle carcass found during the summer, which could not be confirmed as a turbine collision fatality.

Parameter	Value		
	Birds	Bats	Combined
Observed fatality rate (fatalities/day)			
$o_{overall}$	0.012 [0.008]	0.103	0.115 [0.111]
o_{spring}	0	0.033	0.033
o_{summer}	0.022 [0]	0.044	0.067 [0.044]
o_{fall}	0.019	0.185	0.204
o_{winter}	0	0	0
Carcass removal rate (proportion removed per search interval; 1= daily, 3 = every three days, 7 = weekly)			
r_1			0.83
r_3			0.72
r_7			0.39
Carcass detection rate (proportion of available carcasses found)			
D			0.65
Search area adjustment			
A			1.56

Appendix B. Bird species detected on line transect surveys at the University of Delaware wind turbine, Lewes, DE, 3/3/2011 – 3/20/2012. Bold species = Partners in Flight species of "Regional Concern".

Common Name	Scientific Name	Total number individuals detected
Acadian Flycatcher	*Empidonax virescens*	3
American Black Duck	*Anas rubripes*	78
American Crow	*Corvus brachyrhynchos*	209
American Goldfinch	*Carduelis tristis*	87
American Green-winged Teal	*Anas carolinensis*	3
American Kestrel	*Falco sparverius*	1
American Redstart	*Setophaga ruticilla*	36
American Robin	*Turdus migratorius*	273
American Woodcock	*Scolopax minor*	20
Bald Eagle	*Haliaeetus leucocephalus*	10
Barn Swallow	*Hirundo rustica*	149
Bay-breasted Warbler	*Dendroica castanea*	11
Belted Kingfisher	*Ceryle torquata*	2
Black Scoter	*Melanitta americana*	2
Black Vulture	*Coragyps atratus*	13
Black-and-white Warbler	*Mniotilta varia*	16
Blackburnian Warbler	*Dendroica fusca*	8
Black-crowned Night Heron	*Nycticorax nycticorax*	2
Blackpoll Warbler	*Dendroica striata*	30
Black-throated Blue Warbler	*Dendroica caerulescens*	5
Black-throated Green Warbler	*Dendroica virens*	8
Blue Grosbeak	*Guiraca caerulea*	58
Blue Jay	*Cyanocitta cristata*	56
Blue-gray Gnatcatcher	*Polioptila caerula*	25
Blue-winged Warbler	*Vermivora pinus*	10
Boat-tailed Grackle	*Quiscalus major*	24
Brown Creeper	*Certhia Americana*	3
Brown Thrasher	*Toxostoma rufum*	15
Brown-headed Cowbird	*Molothrus ater*	50
Canada Goose	*Branta canadensis*	89
Canada Warbler	*Wilsonia canadensis*	11
Cape May Warbler	*Dendroica tigrina*	1
Carolina Chickadee	*Poecile carolinensis*	269
Carolina Wren	*Thryothorus ludovicianus*	495
Cedar Waxwing	*Bombycilla cedrorum*	53
Chestnut-sided Warbler	*Dendroica pensylvanica*	1
Chipping Sparrow	*Spizella passerine*	38
Clapper Rail	*Rallus longirostris*	150
Common Grackle	*Quiscalus quiscula*	73
Common Tern	*Sterna hirundo*	5
Common Yellowthroat	*Geothlypis trichas*	332
Cooper's Hawk	*Accipiter cooperii*	4
Dark-eyed Junco	*Junco hyemalis*	3
Double-crested Cormorant	*Phalacrocorax auritus*	62
Downy Woodpecker	*Picoides pubescens*	56
Dunlin	*Calidris alpine*	1
Eastern Bluebird	*Sialia sialis*	3
Eastern Kingbird	*Tyrannus tyrannus*	34
Eastern Meadowlark	*Sturnella magna*	2
Eastern Phoebe	*Sayornis phoebe*	12

Common Name	Scientific Name	Total number individuals detected
Eastern Towhee	*Pipilo erythrophthalmus*	35
Eastern Wood-Pewee	*Contopus virens*	4
European Starling	*Sturnus vulgaris*	31
Field Sparrow	*Spizella pusilla*	22
Fish Crow	*Corvus ossifragus*	79
Forster's Tern	*Sterna forsteri*	12
Golden-crowned Kinglet	*Regulus satrapa*	5
Gray Catbird	*Dumetella carolinensis*	344
Great Black-backed Gull	*Larus marinus*	23
Great Blue Heron	*Ardea herodias*	185
Great Crested Flycatcher	*Myiarchus crinitus*	21
Great Egret	*Ardea alba*	46
Great Horned Owl	*Bubo virginianus*	2
Greater Yellowlegs	*Tringa melanoleuca*	92
Green Heron	*Butorides virescens*	24
Hairy Woodpecker	*Picoides villosus*	6
Herring Gull	*Larus argentatus*	77
Horned Grebe	*Podiceps auritus*	3
House Finch	*Carpodacus mexicanus*	38
House Sparrow	*Passer domesticus*	10
House Wren	*Troglodytes aedon*	11
Indigo Bunting	*Passerina cyanea*	153
Killdeer	*Charadrius vociferus*	5
Laughing Gull	*Leucophaeus atricilla*	203
Least Flycatcher	*Empidonax minimus*	5
Least Sandpiper	*Calidris minutilla*	54
Lesser Yellowlegs	*Tringa flavipes*	21
Little Blue Heron	*Egretta caerulea*	10
Magnolia Warbler	*Dendroica magnolia*	13
Mallard	*Anas platyrhynchos*	18
Marsh Wren	*Cistothorus palustris*	134
Merlin	*Falco columbarius*	2
Mourning Dove	*Zenaida macroura*	29
Mourning Warbler	*Oporornis philadelphia*	1
Nashville Warbler	*Vermivora ruficapilla*	11
Nelson's Sparrow	*Ammodramus nelsoni*	11
Northern (Baltimore) Oriole	*Icterus galbula*	13
Northern (Yellow-shafted) Flicker	*Colaptes auratus*	46
Northern Cardinal	*Cardinalis cardinalis*	635
Northern Harrier	*Circus cyaneus*	11
Northern Mockingbird	*Mimus polyglottos*	78
Northern Parula	*Parula americana*	2
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	1
Northern Waterthrush	*Seiurus noveboracensis*	6
Orchard Oriole	*Icterus spurius*	6
Osprey	*Pandion haliaetus*	255
Ovenbird	*Seiurus aurocapillus*	16
Peregrine Falcon	*Falco peregrinus*	1
Philadelphia Vireo	*Vireo philadelphicus*	3
Pine Warbler	*Dendroica pinus*	20
Prairie Warbler	*Dendroica discolor*	26
Purple Martin	*Progne subis*	1
Red-bellied Woodpecker	*Melanerpes carolinus*	16
Red-breasted Merganser	*Mergus serrator*	9

Common Name	Scientific Name	Total number individuals detected
Red-eyed Vireo	*Vireo olivaceus*	35
Red-shouldered Hawk	*Buteo lineatus*	2
Red-tailed Hawk	*Buteo jamaicensis*	2
Red-winged Blackbird	*Agelaius phoeniceus*	790
Ring-billed Gull	*Larus delawarensis*	44
Royal Tern	*Sterna maxima*	1
Ruby-crowned Kinglet	*Regulus calendula*	17
Ruby-throated Hummingbird	*Archilochus colibris*	13
Ruddy Turnstone	*Arenaria interpres*	1
Saltmarsh Sparrow	*Ammodramus caudacutus*	47
Sanderling	*Calidris alba*	27
Savannah Sparrow	*Passerculus sandwichensis*	7
Scarlet Tanager	*Piranga olivacea*	10
Seaside Sparrow	*Ammodramus maritimus*	657
Sharp-shinned Hawk	*Accipiter striatus*	5
Short-billed Dowitcher	*Limnodromus griseus*	11
Snow Goose	*Chen caerulescens*	6
Snowy Egret	*Egretta thula*	50
Solitary Sandpiper	*Tringa solitaria*	3
Song Sparrow	*Melospiza melodia*	104
Spotted Sandpiper	*Actitis macularia*	1
Summer Tanager	*Piranga rubra*	1
Swamp Sparrow	*Melospiza georgiana*	17
Tree Swallow	*Tachycineta bicolor*	30
Tricolored Heron	*Egretta tricolor*	1
Tufted Titmouse	*Baeolophus bicolor*	30
Turkey Vulture	*Cathartes aura*	57
unidentified Crow	*Corvus sp.*	13
Veery	*Catharus fuscescens*	4
White-crowned Sparrow	*Zonotrichia leucophrys*	1
White-eyed Vireo	*Vireo griseus*	66
White-throated Sparrow	*Zonotrichia albicollis*	233
Wild Turkey	*Meleagris gallopavo*	1
Willet	*Tringa semipalmata*	235
Wood Thrush	*Hylocichla mustelina*	8
Yellow Warbler	*Dendroica petechia*	78
Yellow-billed Cuckoo	*Coccyzus americanus*	6
Yellow-breasted Chat	*Icteria virens*	10
Yellow-crowned Night-Heron	*Nyctanassa violaceus*	1
Yellow-rumped (Myrtle) Warbler	*Dendroica coronate*	294
Yellow-throated Warbler	*Dendroica dominica*	9