New York State Energy Research and Development Authority

An Evaluation of the Potential for Using Acoustic Monitoring to Remotely Assess Aerial Vertebrate Collision at Industrial Wind Energy Facilities

Final Report

December 2012

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An Evaluation of the Potential for Using Acoustic Monitoring to Remotely Assess Aerial Vertebrate Collisions at Industrial Wind Energy Facilities

Final Report

Prepared for the

New York State Energy Research and Development Authority

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NOTICE

Table of Contents

List of Figures

SUMMARY

Results from this study suggest that acoustic monitoring could be applied as a means for monitoring avian collisions with rotating blades of commercial-scale wind turbine generators (WTGs). While bat collisions may also be detected acoustically, we found no pattern of distinctive collision sounds associated with 19 fresh bat fatalities. This may be explained by recent evidence that many bat fatalities at WTGs are caused by barotrauma (and not collision impact with spinning WTG blades).

INTRODUCTION

The following report presents results from Task #4 of New York State Energy Research and Development Authority (NYSERDA) study #10164. This study, conducted by New Jersey Audubon Society, North East Ecological Services and Old Bird Incorporated, involved radar, acoustic and night vision assessments of nocturnal bird and bat flight activity at the Maple Ridge Wind Power (MRWP) facility in the Tug Hill Plateau region, Lewis County, NY. The primary objective of Task #4 was to evaluate the potential of acoustic monitoring for detecting bird and bat collision sounds with modern WTGs. A secondary objective of Task #4 was to document whether night migrating birds give alarm calls while flying in close proximity to WTGs.

Currently, human surveyors perform most fatality monitoring at wind plants (dogs have been used in some cases). However, such methods are not feasible for offshore wind energy projects. Expansion of wind energy offshore in Europe has led to the development of alternative means for assessing aerial vertebrate (i.e., bird and bat) collisions. Similar offshore proposals exist in North America and Minerals Management Service, the agency overseeing offshore projects in the U.S in 2007, identified fatality assessment as a major knowledge gap (Michel et al. 2007). In Europe, research in this area has proceeded along two lines. The first uses acoustic and accelerometer devices to detect possible aerial vertebrate collision sounds or collision vibrations at WTGs. Detection of such events then triggers video documentation to provide aerial vertebrate collision verification and species information (Verhoef et al. 2004; Wiggelinkhuizen et al. 2007). The second approach from Europe employs a thermal target detection system (Desholm et al. 2006) to document aerial vertebrates flying near or colliding with WTGs. However, the equipment for both these methods is expensive and "there remains a need for a cheap equipment solution that provides time-specific records of avian collision on an extensive scale…" (Desholm et al. 2006).

Knowing which species are involved in WTG collisions is important for assessing wind energy project impacts, thus it is understandable why European investigators have included species identification in their methods. However, if collisions of aerial vertebrates with WTG blades produce distinct sounds that can be automatically logged, then acoustic (or accelerometer) strike detection alone could provide a way to assess whether a collision has occurred and a means to gauge the quantity of aerial vertebrate collisions at a wind power plant.

Acoustic monitoring has documented avian collision sounds at communication towers (Evans 2000) and experimentation with the acoustic monitoring method to document bird vocalizations within a wind plant has documented sounds that were suspected to be aerial vertebrate collisions (Howe et al. 2002; Evans, unpub. data). These latter studies suggest that direct-hit collisions of aerial vertebrates with rotating WTG blades produce very loud and distinctive transient sounds amidst the normal operational sounds produced by WTGs.

Acoustic monitoring has the potential to provide an automated collision strike system that would be less expensive than other systems (Pandey et al. 2006). While this method would not provide species information, its substantially lower cost could potentially enable every turbine in a wind project to be monitored for collisions. For onshore wind projects, such systems might trigger when a surveyor searches under a turbine for a collision victim (e.g., for relatively rare raptor collisions). For offshore projects, such a system might be installed simply to catalog the quantity and temporal pattern of collisions. This information could then be used to evaluate whether and when more detailed studies (e.g., using thermal or video) might be implemented to elucidate the species of aerial vertebrates involved.

The main objective of this study was to investigate the potential for the acoustic method, as a low cost and relatively simple means, to document aerial vertebrate collisions with WTG blades. The first step in this endeavor was to document such collisions and evaluate the characteristics of the collision sounds. The following report discusses such analysis.

The second objective of Task #4 was to evaluate bird vocalizations received by the acoustic sensors mounted on the WTGs. This component of the study was designed to investigate whether alarm calls are given by night migrating birds when they fly in close proximity to WTG structures. Our thesis was that in some cases bird vocalizations might directly precede collision strike sounds. The ability to identify the species killed with strike sounds provides valuable information. Such data could be compared with species found during the on-ground fatalities search. Documentation of alarm calling behavior (or lack of) is also important information for indicating whether birds are aware of obstruction danger. For example, alarm calls of waterfowl have been detected in the immediate vicinity of communications towers at night, strongly suggesting they had become aware of the presence of the tower as an obstacle (Evans 2000).

METHODS

APPROACH

In order to document the acoustic characteristics of a bird or bat collision with a WTG blade, a method is needed to document that such a collision occurs while simultaneously recording the collision sound. The strongest evidence for a collision is video documentation. However, most collisions at the MRWP study have involved species that primarily migrate at night (Jain et al. 2007, 2008) so standard videography of daytime WTG operation would not likely be productive. Nocturnal video documentation can be achieved using a thermal imaging video camera. However, these devices are expensive to purchase (i.e., approximately $40,000 USD). Given the limited budget for this task of the study, we opted to rent a camera (FLIR Systems, $1,600/wk) for short periods. The FLIR camera has a narrow field of view (25-degree lens) that functionally covers approximately a quarter of the rotor-swept zone. This limitation, combined with the relatively low rates of collision fatalities per turbine documented at MRWP in 2006 (<2 birds/turbine/month and <3.5 bats/turbine/month, Jain et al. 2007) meant that the probability of documenting a collision using the thermal imaging camera would be very low.

To improve the chances of documenting collision sounds, an experimental, indirect, collision detection method was initiated prior to the thermal imaging study. A number of WTGs (mounted with acoustic sensors) would be surveyed daily for fresh bird or bat mortality. The concept was finding a fresh nocturnal migrant fatality (bird or bat) under a WTG would strongly suggest that a strike had occurred the previous evening. If the strike sounds were distinctive, then there should be correlation of the occurrence of fresh fatality records with the incidences of such distinctive collision sounds in the previous evenings' audio recordings.

No definitive references documenting the sounds of aerial vertebrates colliding with a WTG were available for reference at the beginning of this investigation. Consequently, we proceeded with the assumption that these sounds might be similar to sounds produced by birds colliding with the guy wires of communications towers, for which several collision sound examples were available (Evans 2000).

ACOUSTIC RECORDING, STRIKE SOUND DETECTION, ALARM CALL DETECTION

Old Bird developed a custom-designed audio recording system for this study. The acoustic receiving devices used a Knowles EK3029 electret condenser microphone element mounted inside a small plastic pyramid as a pressure zone microphone (see www.oldbird.org/mike_home.htm for circuit schematic). The pyramid housing created a pressure zone microphone that amplified sound above 3 kHz in frequency. This microphone design had roughly a 60-degree cone of high sensitivity, which was aimed at the WTG's rotor-swept zone. During the portion of this study that sought to correlate bird and bat collision fatalities with potential collision sounds, two of these "pyramid" microphones were temporarily mounted on opposite sides of the tubular tower structure of a WTG, approximately 6 m above ground level (Figure 1). The received audio signals were transmitted to a PC computer for automated nightly recording. In spring 2007, several of these audio recording systems were tested for 8 hours/night on 20 nights to work out any technical issues with the recording equipment and microphone design. The audio recordings also provided test data from which to develop software for automatic detection of potential strike sounds. This software automatically extracted short transient signals (possible strike sounds) that were in the targeted frequencies and more than twice the amplitude of the average background sound. The extracted signals were then manually studied using the Raven sound analysis software from the Cornell Laboratory of Ornithology's Bioacoustics Research Program (www.birds.cornell.edu/raven/Raven.html).

During the 2007 study period the goal of the acoustic monitoring system was simply to record potential collision sounds. One of the challenges that became obvious was distinguishing a potential collision sound from mechanical sounds made by the WTG. In the 2008 study period, the acoustic monitoring design was altered so that transient collision sounds could be better localized in the airspace around the WTG. The goal was to use differences in a potential collision sound's arrival time at microphones to determine whether the sound arose from the rotor blades or the mechanical apparatus inside the tower or nacelle. To accomplish this, one microphone was located near the base of the WTG. Two others were located on the ground; 40 meters from the tower base at the outer edge of the rotor-swept area in the same plane of the rotor sweep (Figure 2). This setup was dependent on the winds not shifting during the active monitoring period. If the wind direction changed significantly, then the exterior microphones would need realignment to maintain alignment with the new rotor-swept plane. Therefore, this was a temporary setup solely used for the purpose of testing the concept of whether the time-delay approach would be effective for discriminating mechanical sounds emanating from within the WTG from aerial vertebrate collision sounds with the rotor blades.[1] Arrival time differences were measured using the Cornell Raven software (e.g., Figures 3-5).

Figure 1. Illustrates the position of one of the microphones (in red circle) on a wind turbine support tower. Stakes in the grass behind the turbine mark midpoints in the transect lines for the Curry & Kerlinger fatality study.

[1] This particular acoustic array would not be able to make such discrimination when a collision occurred with a blade that was oriented vertically to the earth (e.g., top blade in distant WTG in Figure 1).

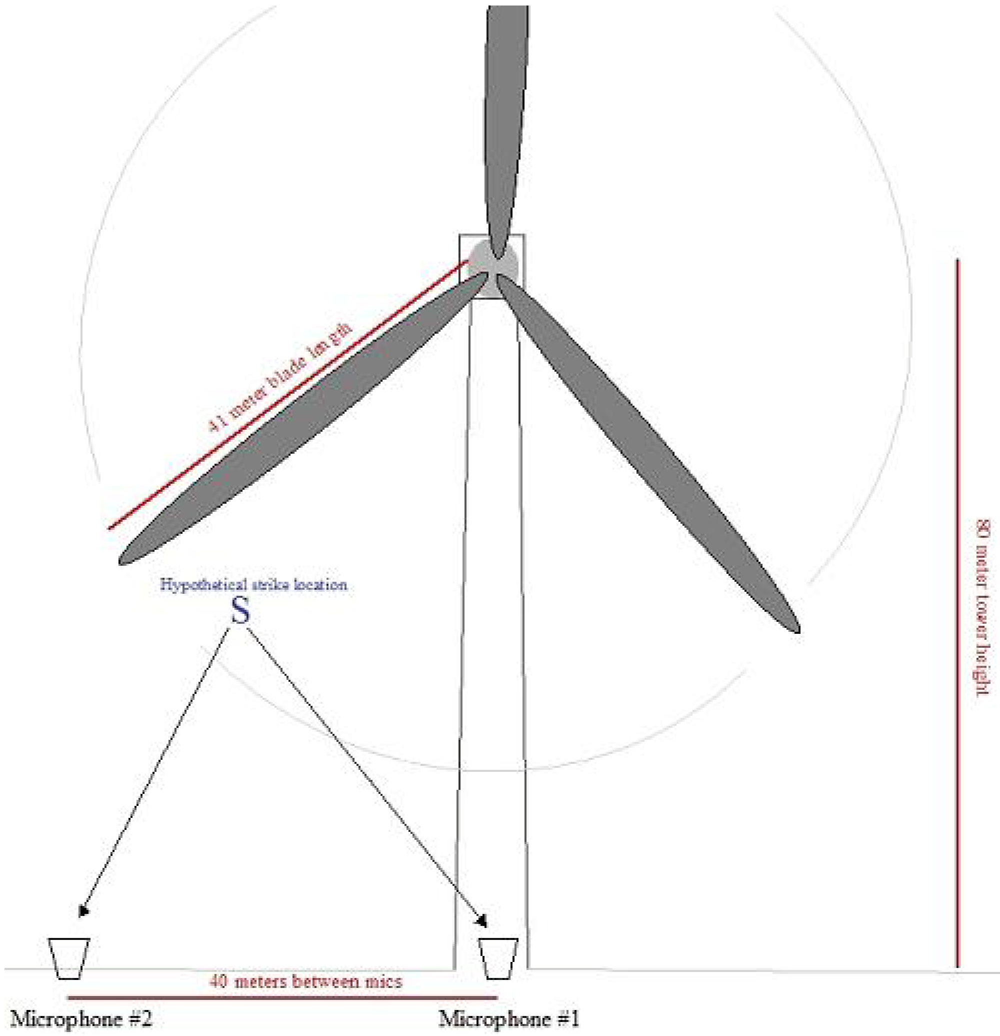

Figure 2. Layout of microphones in plane of rotor sweep. A third microphone was located 40 meters to the right of microphone #1.

A second objective of Task #4 was to assess whether alarm vocalizations are given by night migrating birds flying in close proximity to WTGs. To evaluate this, Tseep and Thrush software from Old Bird were used to extract bird vocalizations from all-night recordings made at WTGs. Extracted bird vocalizations were then manually inspected using Old Bird's GlassOFire software. The extracted sounds were then listened to by W. Evans to evaluate whether they sounded different than typical avian nocturnal flight calls.

COLLISION DETECTION VIA FATALITY STUDY

Eight WTGs were monitored for fresh bird and bat fatalities for 28 days in the 2007 fall migration season. The study days were divided into two, two-week periods, one centered in mid-August and the other in the last week of September through the first week of October. These periods roughly correlated to the times when most bats (first two-weeks) and most birds (second two-weeks) had been found in the prior year's bird and bat fatality study carried out by Curry & Kerlinger (Jain et al. 2007).

The WTGs selected for inclusion in this study were among those being monitored for fatalities in fall 2007 by the ongoing Curry & Kerlinger fatality study at MRWP. These turbines already had a 5 m survey grid laid out for observers to survey for fatalities and a weekly mowing regimen for optimizing carcass detectability. Staff from Curry & Kerlinger recommended specific WTGs that had higher fatality rates in 2006. We coordinated the strike detection fatality surveys so they would occur earlier in the day than those conducted by Curry & Kerlinger staff.

Daily mortality searches were conducted under eight WTGs on most days by observers working on the strike detection study, except if specific turbines were not operating the prior night. There were a few nights when specific turbines were not operating because of maintenance, but on most nights all eight turbines were functioning. Searches typically began between 7 and 8 a.m. and were completed by 2 p.m. Rain on several days caused delays in search start and completion time. A different turbine order was searched each day and daily searches were coordinated with those conducted Curry & Kerlinger staff so that "strike detection" study observers could survey the turbines first. This was done so that no fresh carcasses were removed by the larger concurrent fatality study. The 5-m transect lines laid out for the Curry & Kerlinger study were surveyed at a normal walking pace with search attention focused on roughly 1-5 m in front of the observer.

Carcasses we found were not handled or removed so that results of the larger Curry & Kerlinger fatality study were not affected. We documented the location and position relative to the WTG and took photos of each carcass so that old carcasses could be identified on subsequent searches and not mistaken for fresh kills.

COLLISION DETECTION VIA THERMAL IMAGING

We rented a FLIR P640 thermal imaging camera for one week during our second two-week study period in 2007 and for a week in mid-September 2008. FLIR Systems, Inc. also loaned this same model camera to us for an additional four-day study period in late September 2008. In each of these study periods, we focused the camera on a portion of the rotor-swept zone at one turbine in conjunction with acoustic monitoring equipment. The video information was captured on VCR tape and the aerial vertebrate activity was later logged manually by a person watching the video. We concentrated our analysis on nights with low cloud ceiling and wind directions favorable for bird migration.

RESULTS

FALL 2007 FATALITY AND STRIKE SOUND CORRELATION STUDY

Twenty-five bats and two birds were found during the first two-week study period at the eight WTGs involved in the study. The birds, a Red-tailed Hawk (*Buteo jamaicensis)* and European Starling (*Sturnus vulgaris)*, were presumed killed during the day because that is when these species are typically active. Six bats were found during the first day's baseline mortality survey. Nineteen, apparently freshly killed bats were found during subsequent surveys after nights when the acoustic equipment was in operation. Analysis of the acoustic data from these nights did not reveal distinctive sounds that might be related to collisions with rotor blades. While several possible strike sounds were evident, the sample was insufficient to make a statistical correlation with the record of fatality events. It appeared most bat "collision" fatalities were not distinctly evident on the acoustic record. The fatality surveyors in the strike detection study did not inspect bats extensively for evidence of collision (e.g., blood, contusions, broken bones) in order to avoid interfering with the Curry & Kerlinger fatality survey. However, two of the 19 apparently fresh-killed bats did show evidence of wounds that suggested a collision with a WTG blade.

The second two-week study period (September 23 through October 6, 2007) corresponded to a time in 2006 when a notable number of bird collision fatalities were recorded at MRWP (Jain et al. 2007). This was also a time of low cloud ceiling and generally poor weather conditions (Jain et al. 2007). In contrast, the last week in September and first week in October in 2007 had unusually warm temperatures, generally clear skies, and there were few nights with northerly winds conducive for bird migration (Northeast Regional Climate Center, pers. comm.). Nights that were favorable for bird migration had clear conditions favoring high altitude migration. Searchers did not find any birds or bats during the two-week fatality study. Consequently, we decided not to analyze the acoustic data for collision sounds so that additional resources could be directed toward thermal imaging work in 2008.

FALL 2007 AND FALL 2008 THERMAL IMAGING & STRIKE SOUND STUDY

The thermal imaging camera did not document any collisions during two nights of study in fall 2007. One night had optimal weather conditions for low altitude bird migration in having a low cloud ceiling, but no migration activity was apparent. The second night had heavy bird migration under clear skies, and only a few migrants were observed within the rotor-swept zone.

In fall 2008, a thermal imaging camera was used on eight nights in conjunction with our acoustic strike detector at WTG #134. One of the study nights, September 28–29, had optimum conditions for dense low-altitude bird movements with the WTG occasionally shrouded in fog/cloud. On this night the thermal imaging video indicated many migrants passing through the rotor-swept zone and the acoustic system documented evidence that strongly suggests aerial vertebrate collisions occurred with the WTG blades. In three of these cases, W. Evans heard a very loud "pop" sound while he was standing near the base of the WTG. The "pop" noises sounded as if they came from the region toward the end of the rotor blades and not from the WTG tower or nacelle. In two of these cases, analyses of the acoustic data and the arrival time differences of these loud "pop" sounds at the acoustic monitoring stations indicated that the sound could not have originated from the nacelle or tower structure. The acoustic time delay analysis was consistent with W. Evans' observation that the sounds originated toward the end of a rotor blade.

Figure 3 illustrates the acoustic energy and audio spectrograph of one of the presumed strike sounds recorded by a microphone at the base of the WTG and one microphone 40 m away from the base in the plane of the active rotor sweep. Figure 4 shows a close up of this collision sound's audio spectrograph, while Figure 5 shows an even closer portrayal of the audio spectrograph with an indication of the arrival time difference of the collision sound at the two microphones.

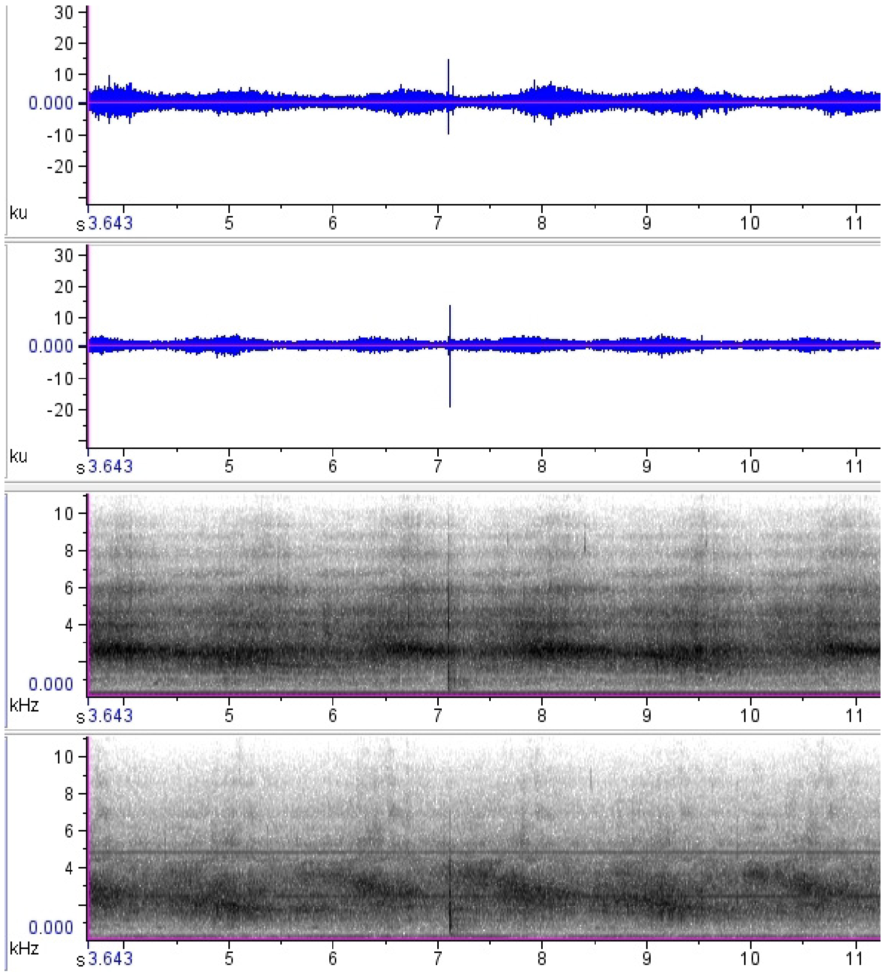

Figure 3. Shows amplitude (upper two tracks) and frequency (lower two tracks) of sound energy recorded by two ground-based microphones positioned under a wind turbine. The sharp spikes near the center of each audio track are due to a presumed avian collision with a rotor blade.

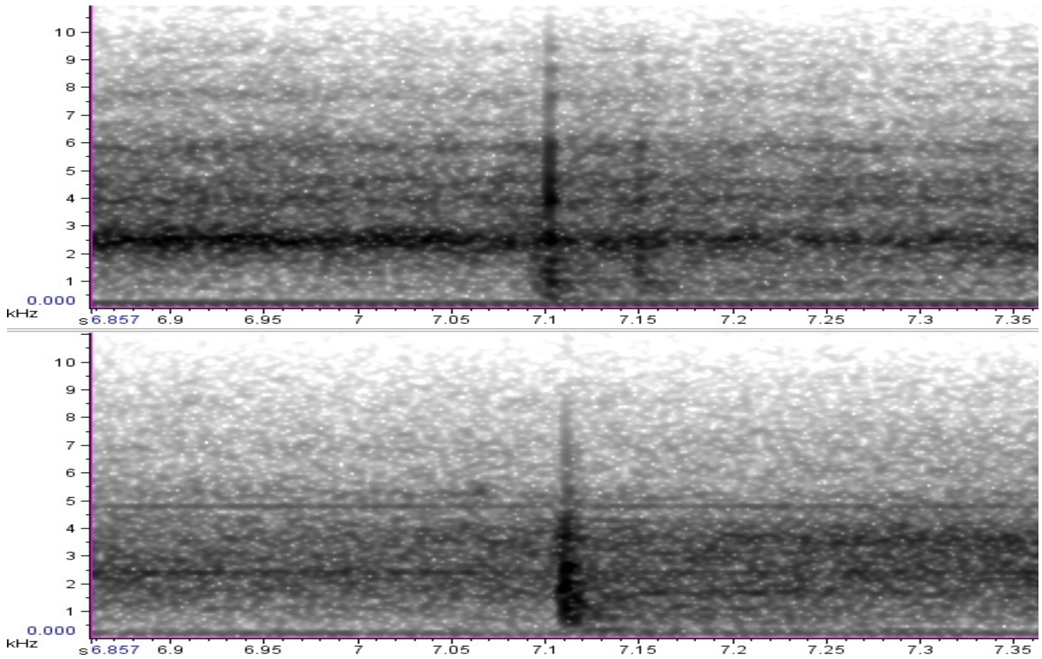

Figure 4. Closer view of the time-frequency spectrograph of the presumed collision sound in Figure 3. The dark spikes near the center of each audio track are the presumed avian collision with a rotor blade. The upper track is from the microphone that was 40 meters from the base of the wind turbine (in the rotor-swept plane). The lower track is from the microphone that was near the tower base. The fainter second spike in the top audio track may have been the collision sound's reflection off nearby forest edge.

The first dark spike in the upper track of the spectrogram in Figure 5 is the strike sound arriving at the distant microphone (40 m away from tower base). The first dark spike in the lower track is the strike sound arriving at the microphone near the tower base. The arrival time difference of the collision sound at these two microphones is approximately 9 ms (i.e., arrival at the distant microphone first). This sound and another similar sound with a 5 ms arrival time delay, also arriving at distant microphone first, were the cases when the sounds were heard by W. Evans as he stood at the base of the WTG. These sounds seemed to come from the direction of the left half of the turbine sweep (i.e., from a perspective looking at the WTG from upwind and perpendicular to the plane of the rotor sweep; see Figure 6).

Unfortunately, we did not document collisions with the thermal imaging camera when the presumed collision sounds occurred because the thermal camera was then aimed at the upper right quadrant of the rotor sweep. However, the thermal record for this night showed frequent activity of migrant birds within the rotor-swept zone and several apparent near collisions. Additionally, the audio record indicated abundant flight calling of night migrating passerines. A sample of the thermal imaging data from this night can be viewed at http://www.oldbird.org/NYSERDA/Thermal.htm. This four-minute video shows passage of approximately 30 aerial vertebrate targets and the audio portion contains more than 60 flight calls of night-migrating passerines.

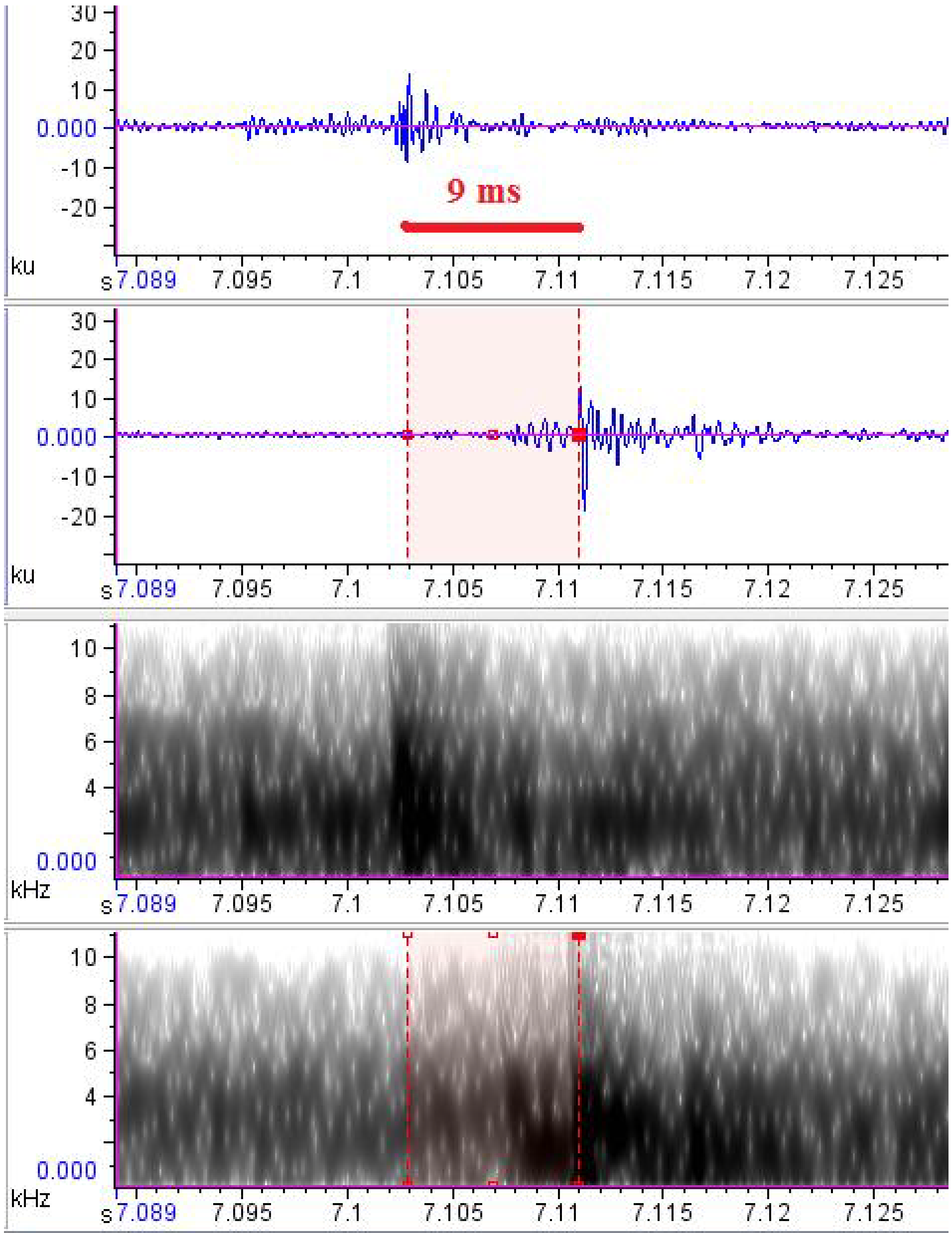

Figure 5. Closer temporal view of the presumed strike sound in Figures. 3 and 4 with the measurement of an approximately 9 ms arrival time difference of the collision sound at the respective microphones (as measured from highest amplitude and frequency component of the strike sound).

Link to presumed collision sound shown in Figs. 3-5 (~9 ms time delay).
www.oldbird.org/NYSERDA/Collision-1.wav (1.25 MB)

Link to presumed collision sound (with ~5 ms time delay)
www.oldbird.org/NYSERDA/Collision-2.wav (0.8 MB)

W. Evans heard a third presumed strike sound on this study night that emanated from the outer reaches of the rotor sweep (upper right). A collision was not evident in the thermal imaging at that time, which was then focused on the lower right quadrant of the rotor sweep. The microphone on the right side of the rotor-swept zone had malfunctioned due to rain earlier in the evening and the sound could not be localized away from the wind turbine structure by time delay analysis. In this case there is an accordingly larger time delay (~44 ms) arrival time delay between the microphone at the turbine base and the distant microphone (microphone #2 in Figure 2), with the sound arriving at the microphone at the tower base first.

> Link to third presumed collision sound (note Gray-checked Thrush flight call just before strike sound) www.oldbird.org/NYSERDA/Collision-3.wav (0.7 MB)

The ample acoustic record of passerine flight calling and the thermal image record of many small targets flying in close proximity to the WTG are inconclusive as direct evidence for the presumed strike sounds discussed above. However, it is notable that the Curry & Kerlinger fatality survey team found two bird fatalities on the ground near WTG #134 in their survey in the week after the presumed strike sounds were documented (Slobodnik, pers. comm.).

Figure 6 shows the possible loci of points in the plane of the turbine sweep where 9 ms and 5 ms time delays could have arisen from based on analysis of their arrival time delays (arrival at outer microphone before base microphone).

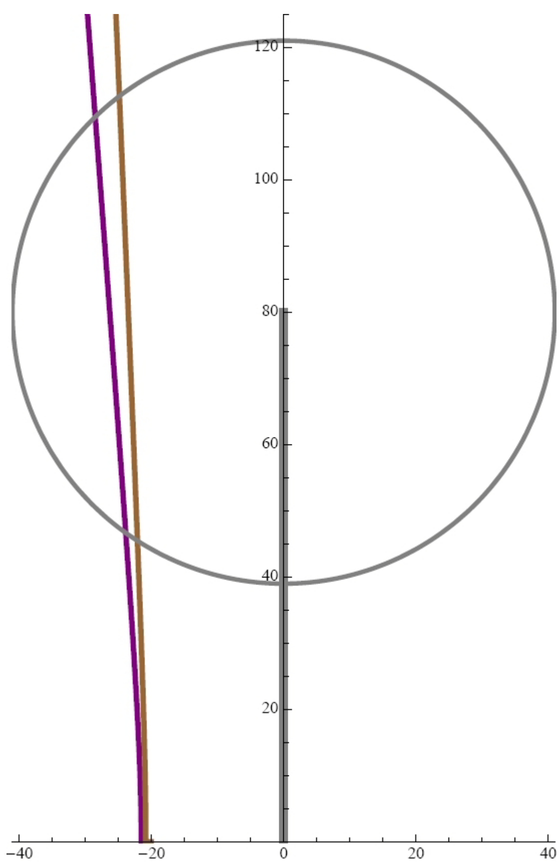

Figure 6. Illustration of the loci of points in the plane of the rotor sweep where 9 ms (purple) and 5 ms (brown) arrival time delays might have originated from. Gray circle represents the area of the rotor sweep. Thick gray vertical line represents the WTG tower. All units are in meters.

ALARM CALL STUDY

More than two thousand flight calls of night-migrating passerines were detected by the acoustic monitoring equipment mounted on (or near) WTGs in this study. Over 90 percent of these calls were recorded on several nights when there was steady bird migration and only light winds. On these nights the WTGs were not often in operation and there was very little WTG noise to impede flight call detection. Therefore, many relatively weak amplitude calls were recorded that would have not been detected if the WTGs were operating. Most of these were thought to originate from altitudes above the WTGs. During analysis, we determined that these vocalizations were similar to those given by passerines in typical nocturnal migration and were not alarm calls.

On the night of 28-29 September 2008, low cloud ceiling apparently forced many migrant passerines to fly at low altitudes. Thermal imaging showed that many were passing within the rotor-swept zone–including numerous, apparent near collisions with the rotating rotor blades. Of the more than 300 passerine flight calls recorded in four hours on this night, no alarm vocalizations were noted. The flight notes documented were similar to those given during typical nocturnal migration events. However, the rate at which individual birds called was greater than on typical migration nights. That is, individual birds often gave multiple calls in closer temporal proximity than on typical migration nights. This phenomenon was not documented in detail, but was clearly evident in listening to the audio recordings (e.g., an ovenbird calling six times in rapid succession over approximately 20 seconds).

Very few non-passerine flight calls were recorded by the acoustic devices mounted on or near the WTGs, although several flocks of Canada Geese were recorded on the night of 28-29 September 2008. W. Evans heard these flocks continuously calling apparently from within the cloud layer well above WTG #134.

DISCUSSION

This study began with the premise that if aerial vertebrate collisions with revolving WTG blades are distinctly audible, then the quantity of such distinctive strike sounds might correlate with the daily record of fatalities found during ground surveys over the same period. With respect to bats, this approach failed because we did not find distinctive collision sound patterns associated with a substantial record of bat fatalities during the first two-week study period in August 2007. While some of the 19 apparently fresh-killed fatalities may have been the result of collision impact, barotrauma (i.e., collapsed lungs resulting from the steep pressure gradient imparted by rapidly rotating WTG blades) likely was a major source of fatalities (T. Erdman, pers. comm. 2007; Baerwald et al. 2008). Such mortality would not be detectable using acoustic monitoring for collision sounds.

Although of questionable utility for bats in this study, the method of using daily fatality study data to evaluate a previous evening's strike sound record (and vice versa) can still have application for bird strikes. Longer study periods that result in greater numbers of bird strikes coupled with daily fatality surveys would be necessary to validate a bird collision detection system solely based on acoustics.

The use of thermal imaging was effective for documenting significant activity of aerial vertebrates, presumed to be mostly birds, including numerous images of apparent near misses with rotating WTG blades. However, no definitive video of a collision was recorded to conclusively verify a strike sound. One of the limitations of the thermal imaging system that was available to us was its limited field of view. This system could generally cover about 25% of the rotor-swept zone, but even to achieve that limited coverage, the camera had to be positioned about 100 meters from the base of the WTG. During periods of dense clouds that might have exacerbated collision risk, small water droplets between the thermal camera and the turbine attenuated the camera's sensitivity for resolving aerial targets near the WTG.

Although we do not have definitive evidence that specific sounds documented in this study were aerial vertebrate strike sounds, we believe the following lines of circumstantial evidence support this contention:

1. Human auditory registration of collision-like sounds originating from the outer reaches of the rotor-swept zone away from the WTG tower structure
2. Acoustic arrival time-delay information from two of these sounds collected by a microphone array is consistent with the human auditory experience in localizing where the sounds originated.
3. No mechanism exists for such sounds to be created from the outer reaches of the rotor-swept area other than by a collision of something with one of the rotor blades. Such distinctive hollow-sounding "pop" sounds were rare events in over 1,000 hours of additional acoustic monitoring of WTGs carried out in this study. This includes over 100 hours of study at the MRWP WTG #134, where the presumed aerial vertebrate collisions were documented.
4. Concurrent low-altitude bird migration of substantial density recorded using a thermal imaging system and flight call monitoring during the time of the presumed collision sounds. The thermal imaging data includes numerous apparent near misses where the track of a flying target abruptly changes course when in close proximity to a revolving rotor blade. The acoustic data indicates a dense migration of warblers, sparrows, and *Catharus* thrushes.
5. Two dead passerines documented in the weekly survey at this WTG shortly after the night the presumed collision sounds were recorded.

The "pop" sound of presumed bird collisions with rotor blades documented in this study is quite distinctive. It has a hollow tone, which suggests contributing sound energy from the hollow (foam filled) fiberglass rotor blades. While somewhat similar, though less loud, sounds often emanate from the mechanical apparatus inside the WTG's nacelle or from inside the tower structure, we stress that there is no mechanism for such a sound being produced toward the end of a rotor blade except through collision with an object.

When less impact occurs between the rotor blade and a bird, for example a collision with only the wing of a small passerine, the amount of energy transferred to the blade may not be enough to cause it to resonate in a way that creates the hollow "pop" sound. In such cases, the characteristics of the emitted collision sound may have more to do with the resonant frequencies of the body part of the aerial vertebrate that is struck. These typically would be higher frequency sounds, which suggest that a complex array of possible sounds could be produced by aerial vertebrate collisions.

The approach taken in The Netherlands with their “Wind Turbine-Bird strike detection system” has apparently been to use computer software to discriminate distinctive acoustic patterns of collision sounds from other loud mechanical noises produced by the WTG. When a potential strike sound is identified, the thermal camera video-capture is triggered. Evidence from our study suggests, however, that a time delay method (instead of a pattern recognition method) could be used to discriminate a collision sound. This would likely be a simpler and more accurate method of strike detection because only relatively simple time delay algorithms would be involved.

The acoustic monitoring layout we used was a simple way to demonstrate the feasibility of this time-delay discrimination concept. For practical application of the time-delay method on a WTG, an effective strategy might be to mount four acoustic sensors on the nacelle. Mounting acoustic sensors on the corners of a nacelle (Figure 7) would maintain a consistent position for the sensors relative to the rotor-swept plane. This arrangement would allow discrimination of rotor blade collision sounds from mechanical sounds originating from the tower or the gear system in the nacelle simply based on arrival time delays. Sounds emanating from within the tower or nacelle would have relatively small arrival time delays. Sounds emanating from the rotor-swept zone would have relatively large time delays. The nacelles of most modern WTGs are large enough to accommodate the sensors (e.g., 6 m high by 6 m wide for some newer models).

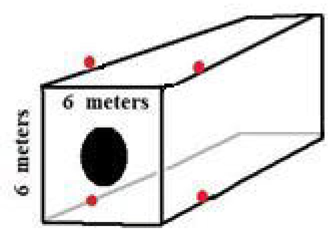

Figure 7. Crude illustration of wind turbine nacelle with theoretical location of acoustic sensors (red dots) for application in discriminating rotor blade collision sounds by acoustic arrival time delay. Black circle represents the nacelle’s interface with the rotor.

We do not believe a nacelle location of acoustic sensors would impact functionality of WTGs and would be relatively easy to install and maintain. Signals could be transmitted from the acoustic sensors via a wire entering the nacelle to a PC where an algorithm would process the time delay data and indicate likely strike sounds. Initial estimates indicate that equipment costs for such a system would be less than $5,000 USD per unit compared to more than ten times that cost for the European collision detection systems.

The collision sound illustrated in Figure 3 shows that the energy level of a collision sound is of distinctly high amplitude and is distributed differently than the background noise produced by the WTG. Presuming this specific case was a direct collision, then we might expect that indirect collisions (e.g., with a bird wing) would produce less sound amplitude and be more difficult to discriminate energetically. This means that collision systems using acoustic sensors will likely miss some collision events. We do not believe this is an impediment to the advancement of acoustic collision detection monitoring. Ground searches do not account for all fatalities incurred by a WTG because surveyors are not 100% efficient at detecting collision events. Some carcasses are missed by surveyors and others are scavenged. Some impacts, such as wing strikes, will not be evident because the affected individual may travel beyond the range of the fatality survey area. The important criterion for any fatality survey method is that it samples uniformly so that a comparative index to fatality rates is produced.

To effectively classify sounds as probable aerial vertebrate strikes, it is essential to rule out sounds arising from the mechanical apparatus in the nacelle or tower. In most terrestrial WTG locations there are no other sources of such transient sound (i.e., collision-like) in close proximity to WTGs. However, loud transient sounds emanating from the local environment need to be considered (e.g. farming or other human activity). In the offshore environment it is difficult to imagine a source for such collision-like sounds outside of the WTG tower and nacelle. However, sounds produced by fishing boats or WTG maintenance activity would need to be explored. Additionally, hail or lighting strikes could be rare sources of transient sounds distal to the nacelle or tower structure.

The next step toward validation of this experimental aerial vertebrate collision detection system is to test the equipment installation process and functionality of the nacelle-mounted (four-microphone) acoustic strike detection system. Once time-delay calibration, weatherproofing, and microphone installation and attachment issues on the nacelle are optimized, this methodology would be ready for a field test at multiple turbines within a wind plant in conjunction with a concurrent on-ground fatality study. WTG strike information could be transmitted in near real time to a fatality survey crew and the acoustically determined strike detection record compared to the surveyor-documented fatality record.

A secondary purpose of this study was to evaluate whether birds give alarm calls while flying in the close proximity of wind turbines. Such a dynamic could provide species information and frequency of interaction information for birds encountering WTG obstacles. Various species of waterfowl have been documented to give alarm calls when encountering a 90 m communication tower in north-central Nebraska in spring migration (Evans 2000). In the present study, very few waterfowl vocalizations were recorded. More than 99 percent of the vocalizations documented in the vicinity of WTGs were from night-migrating passerines, but we did not detect alarm calls from this species group during our study. While increased calling rate per individual was noted on one occasion, passerines frequently exhibit this behavior in situations of navigational confusion (e.g., birds swarming around artificial light) or when migrants are concentrated. Therefore, no direct link can be attributed to wind turbines in causing this increased passerine calling rate.

CONCLUSION

The results of this study strongly suggest that aerial vertebrate collisions with modern WTG blades may be detected automatically through processing arrival time differences of collision sounds recorded at an array of microphones. The usefulness of this methodology for assessing aerial vertebrate fatalities at wind energy projects will not be known until further evaluation is completed, including field trials in conjunction with fatality studies carried out by human surveyors.

Night migrating passerines were not found to give alarm vocalizations while in the near vicinity of WTGs, but their typical nocturnal flight calls were recorded. This latter information provides utility in indicating species that are at risk of collision with WTGs.

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