# Applications of Acoustic Bird Monitoring for the Wind Power Industry

by

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## *Introduction*

Participants at the National Avian-Wind Power Planning Workshop III recognized that there is inadequate knowledge concerning the effect of wind turbines on night-migrating birds. The emerging technique of acoustic monitoring of avian night flight calls, as the only means for acquiring species-specific information about birds in active night migration, is a method uniquely suited to help fill this void. Sensitive microphones aimed at the night sky are used in recording the vocalizations of night-migrating birds. About 200 species of North American birds are known to give calls during night migration, with roughly 150 of these being distinctive enough to identify with certainty. Others are currently lumped into a number of similar-call complexes. The calls by individual species within these groups are not reliably distinguishable from one another at present (Evans and Rosenberg 1999). On a good migration night east of the Rocky Mountains, thousands of calls may be recorded from a single monitoring station. In the west, calling rates are believed to be lower, though little acoustic work has been conducted there. Nocturnal flight call monitoring has evolved slowly during the 20th century, limited by the difficulty in identifying many of the cryptic night flight calls from passerines, and by the challenge of processing the large quantities of data generated. Recent progress on both of these fronts has been aided by advances in electronics and computers.

Three applications of acoustic monitoring for assessing and minimizing the impact of wind turbines on night-migrating birds are discussed in this paper. Two of these applications were carried out in a study for Nebraska Public Power District (NPPD) at a proposed wind turbine site during the fall 1996 and spring 1997 migration periods. A third application was tested experimentally in fall 1994 at an existing wind turbine site in northern New York State operated by Niagara Mohawk Power Corporation (NIMO).

## *Methods*

At the core of acoustic monitoring is the recording station. Various equipment designs have been used depending on the specific monitoring goals and the recording location's environment (Graber and Cochran 1959; Dierschke 1989; Evans 1994; Evans and Mellinger 1999). Other variables in acoustic monitoring are the methods of analyzing recordings and interpreting call data.

***Nebraska***.—In the Nebraska study, a pressure zone microphone (PZM) designed by Evans was located underneath a 317 ft, guyed communications tower near Ainsworth (Fig. 1). The microphone was mounted inside a housing built from concrete blocks that served to shield the microphone from wind. The microphone element stood about 60 centimeters above ground level and about 50 centimeters below the tops of the concrete block housing. The resulting microphone structure had roughly a 75 degree, unimpeded, conical pickup pattern. The actual pickup pattern of the microphone varied with the intensity

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of birdcalls, their audio frequency, the birds' positions in the sky, and weather variables. Previous tests on this microphone showed it was capable of detecting a variety of the weakest night flight calls—the short high-pitched chip notes of warblers and sparrows—to a height of at least 300 m in conditions with low ambient noise (Evans et al. in press).

The audio signal was carried by a cable run through PVC piping to a shack at the base of the communications tower where the signal was recorded on the soundtracks of hi-fi video cassette recorders (VCRs). Recordings were made each evening; employees from KBR Rural Power District and NPPD changed the tapes in the VCRs twice a week. The fall 1996 monitoring period extended from 26 July to 15 November. The spring 1997 monitoring period extended from 5 March to 15 June.

The recordings were analyzed each season for species composition and call detection rate. Tapes were analyzed by ear and with the help of sound analysis software developed by the Cornell Laboratory of Ornithology's Bioacoustics Research Program. Calls were tallied by time of occurrence and call data were interpreted to estimate the minimum number of individuals passing (MIP technique; see Evans and Mellinger 1999). For example, if an American Bittern (*Botaurus lentiginosus*) passed over the recording station and "squoked" five times, one bird rather than five calls would be tallied. In the case of the Dickcissel (*Spiza americana*) data illustrated in this paper, each time their low "bzrrt" call was heard on the tapes, the time of occurrence was noted. Dickcissel calls separated by more than 1.5 minutes were assumed to be from different individuals based on the birds estimated flight speeds, previously determined studies on the pickup pattern of the microphone, and the fact that weather and artificial lighting conditions were not such that circling flight patterns were suspected.

With tight flocking species like waterfowl, discerning how many individuals are in a flock from calling data is not possible. Therefore, tallied incidences of waterfowl calling may refer to the passage of an individual or of a flock of unknown size.

On the evening of 6-7 October 1996, in addition to the recording station near Ainsworth, an array of five recording stations was operated across eastern Nebraska (Fig. 1). Portable microphone stations were placed in plowed fields and 12-volt, deep-cycle batteries powered the equipment.

***New York***.—In the study in New York State, eight skyward-facing PZM microphones were positioned accurately (using a theodolite) in a field approximately 300 m from two wind turbines operated by NIMO at Tug Hill (Evans et al. in prep). Four microphones were placed at the corners of a 75 m x 75 m square area, and four at the corners of a 30 m x 30 m square area centered in the interior of the larger square. This layout potentially allowed the calls of birds flying over the array to be picked up by all eight microphones. In these cases, the approximate point of origin of the birdcall could be determined by analyzing its varying arrival times at the different microphones. Software developed by the Cornell Bioacoustics Lab was used to facilitate these analyses. Birdcalls were classified by ear as one of a number of species of night-migrating thrushes (and species with similar call-types), or as a species of warbler or sparrow. The thrush-class calls are in the 2-5 kHz range and typically less than 300 ms in duration. In this study they were primarily species of *Catharus* thrushes and the Rose-breasted Grosbeak (*Pheucticus ludovicianus*). The sparrow- and warbler-class calls are in the 5-10 kHz range and typically less than 150 ms in duration. Over 40 different species give such calls in migration over the Tug Hill region of New York State.

## *Results*

***Nebraska***.—The recording station at the proposed wind turbine site in Nebraska detected migratory bird calls on 26 of 98 nights of recordings during fall 1996 and 26 of 87 nights during spring 1997. Surprisingly, in fall 1996 over 75% of the acoustically determined migratory passage occurred on just seven nights and in spring 1997 over 80% occurred on just seven nights.

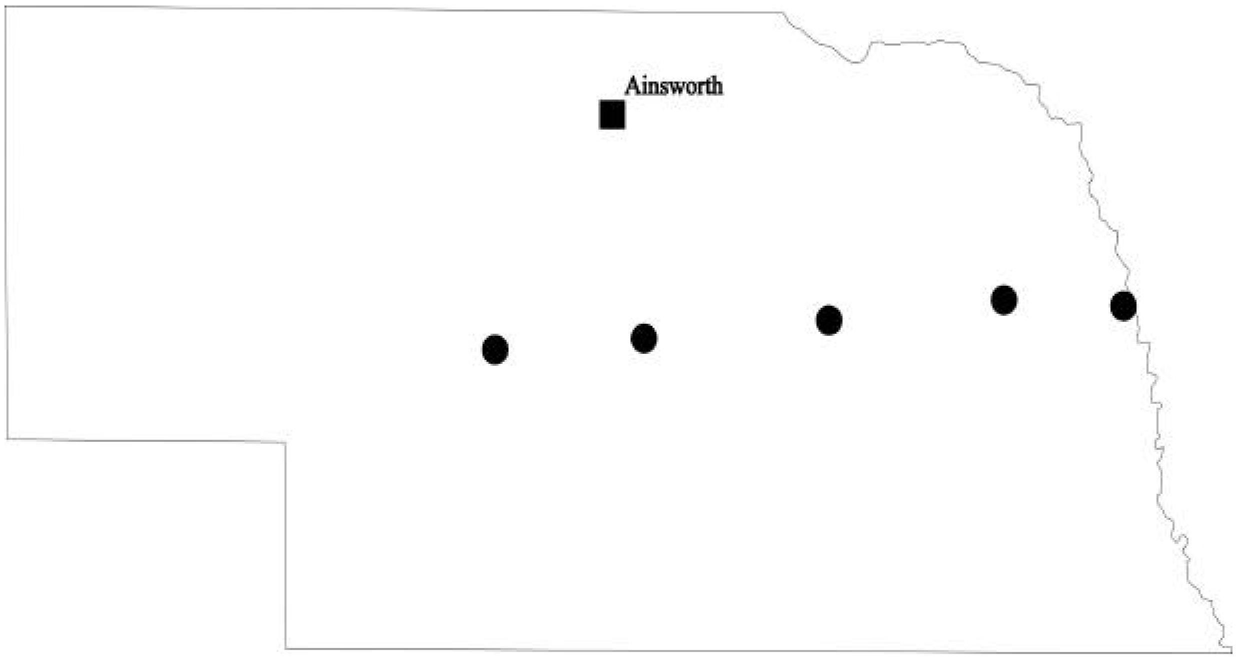



FIGURE 1. Locations of acoustic recording stations in the Nebraska study. The black square indicates the site of the Ainsworth recording station, which operated during the fall 1996 and spring 1997 migration seasons. The black circles indicate sites of five recording stations that operated on 6-7 October 1996 (stations 1-5, from west to east).

An additional surprise on the recordings was the sound of apparent bird collisions with the 317 ft communications tower. Three collisions were evident in the fall 1996 recordings. These events were recorded on quiet windless nights; two occurred during light rain. The wing sounds of individual birds were heard approaching the communications tower before the loud sound of the collision. In one case a "thud", presumably of a carcass hitting the ground, is audible shortly after the collision; around this time NPPD personnel found a dead Blue-winged Teal (*Anas discors*) under the tower.

Besides documenting bird strikes with the guyed communications tower, the recordings indicate that many birds gave alarm calls near the tower. Over 50 incidences of waterfowl giving alarm calls were documented during three nights in spring 1997 that had low cloud ceiling and light rain showers. In many cases their wing sounds suggested veering motion during the alarm call sequence. A variety of shorebird and rail species were also recorded giving alarm calls. Passerine alarm calls were more difficult to distinguish from their normal night flight calls; however, the acoustic station did indicate several instances when small birds apparently were disoriented and circling the tower. Figure 2 illustrates one such event involving an increased rate of call detections and an increased average received level for the passerine calls.

Figure 1 shows the locations of the acoustic recording stations and Table 1 shows the rates of call detection at these stations for sparrow- and warbler-class calls. Figure 3 illustrates the broadfront gradient as interpolated density of calling per time. This graph suggests that the density of migration was larger on this evening in the eastern half of Nebraska (see discussion). Table 2 illustrates the acoustically-determined minimum number of Dickcissels passing over the stations per hour. During five hours on the night of 6-7 Oct 1996, a minimum of 67 Dickcissels were interpreted to have passed over the stations. This was based on analyses of the timing of 76 recorded calls.

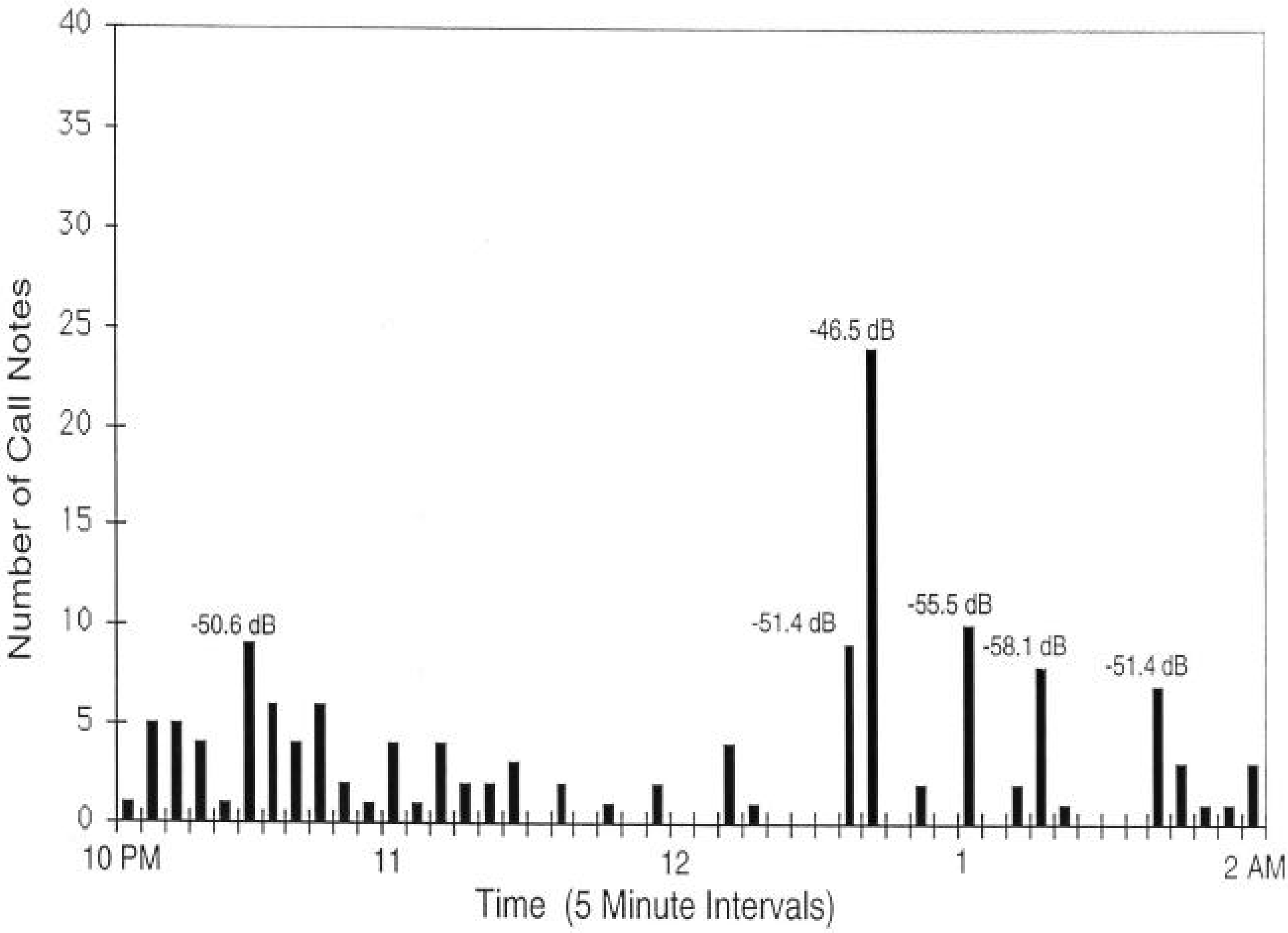



FIGURE 2. Number of sparrow calls detected per five minute period at the Ainsworth, NE, recording site on the evening of 6-7 October 1996. The average amplitude of calls is indicated for some of the 5-min periods with high call rates. The period 12:35-12:40 AM had the highest number of calls of any five minute period during the evening. The average received level of these calls (on a relative scale) was -45 dB, which was at least 4 dB higher than for any other 5-min period during the evening. The recording sounds as though the same sparrows were circling the tower during this period. This evening had a low cloud ceiling with light rain beginning at 01:30 AM. A birdstrike with the tower was recorded at 01:20 AM.

TABLE 1. Number of sparrow and warbler class calls per hour detected by ear from recordings at five similar acoustic monitoring stations across eastern Nebraska on the evening of 6-7 Oct 1996 (see Fig. 1 & 3).

| | Station # | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 20:30-21:30 | 31 | 100 | 162 | 242 | 52 |
| 21:30-22:30 | 77 | 192 | 286 | 384 | 131 |
| 22:30-23:30 | 80 | 214 | 302 | 562 | 192 |
| 23:30-00:30 | 52 | 112 | 262 | 393 | 284 |
| 00:30-01:30 | 24 | 66 | 74 | 210 | 311 |
| Five hour total | 264 | 684 | 1086 | 1791 | 970 |

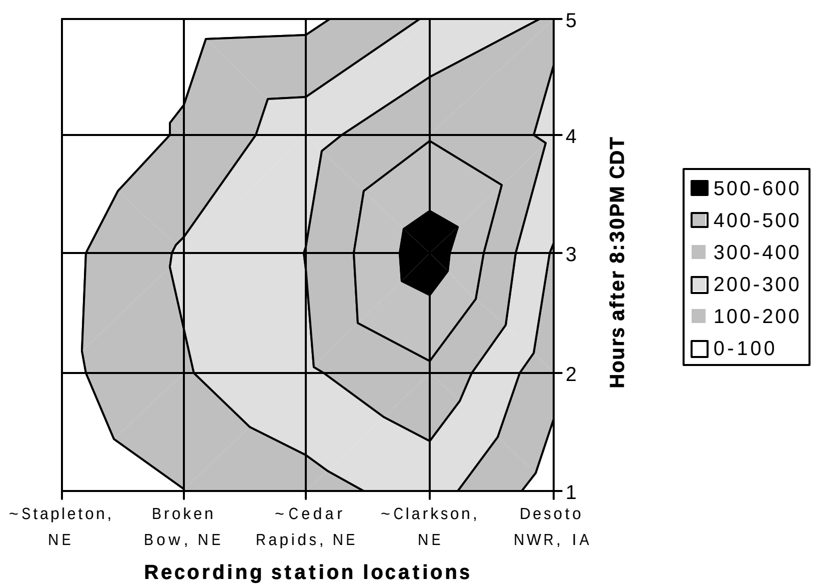



FIGURE 3. Density gradient of warbler and sparrow nocturnal flight calling detected across the Nebraska transect on 6-7 October 1996. Hourly call totals at each station are interpolated across time and space.

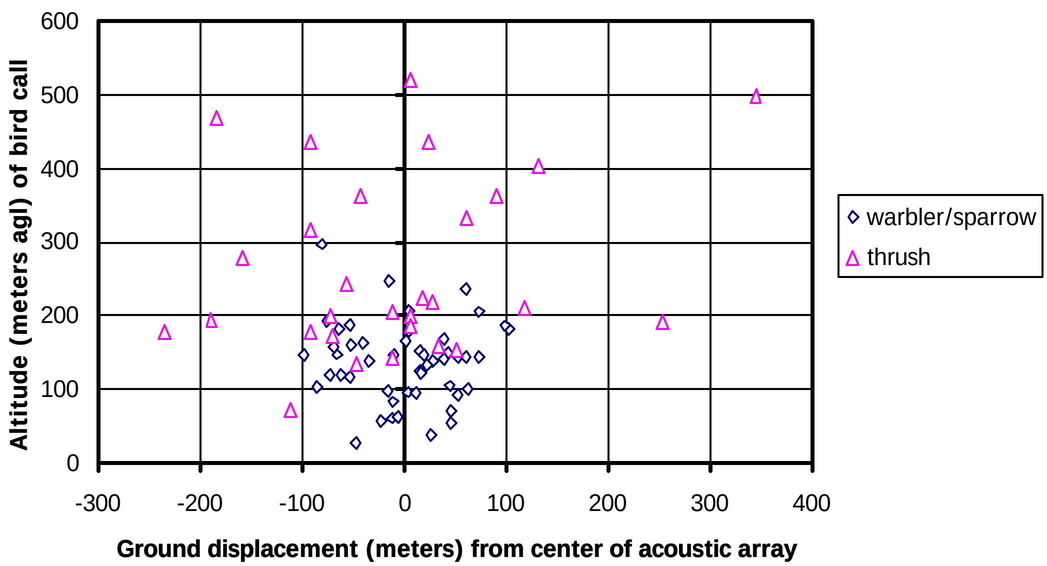
TABLE 2. Minimum estimated number of Dickcissels passing over the transect stations evaluated using the MIP counting technique. (Dickcissel calls separated by more than 1.5 minutes were assumed to be different individuals.)

| | Station # | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 20:30-21:30 | 0 | 2 | 7 | 10 | 5 |
| 21:30-22:30 | 0 | 5 | 3 | 10 | 4 |
| 22:30-23:30 | 2 | 4 | 5 | 3 | 3 |
| 23:30-00:30 | 0 | 2 | 0 | 1 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 00:30-01:30 | 0 | 0 | 0 | 1 | 0 |
| | 2 | 13 | 15 | 25 | 12 |

~~During five hours on the night of 6-7 Oct 1996, a minimum of 67 Dickcissels were interpreted to have passed over the stations. This was based on analyses of the timing of 76 recorded calls.~~

***New York***.—Figure 4 shows sample acoustic location data from the eight channel acoustic array used to study nocturnal bird migration near the NIMO wind turbines at Tug Hill in New York State. Acoustically-determined points of origin of birdcalls recorded over a two-hour period on two different nights are illustrated. Each point has an associated positional uncertainty due to weather variables and the accuracy of the array and analysis. However, there was a strong correlation between the altitudes of acoustically-located birds and altitudes of birds near the turbines as measured simultaneously with vertical beam radar. The radar was operated by Brian Cooper of Alaska Biological Research Inc. This strong correlation suggests that altitudes of calling birds were estimated sufficiently accurately to



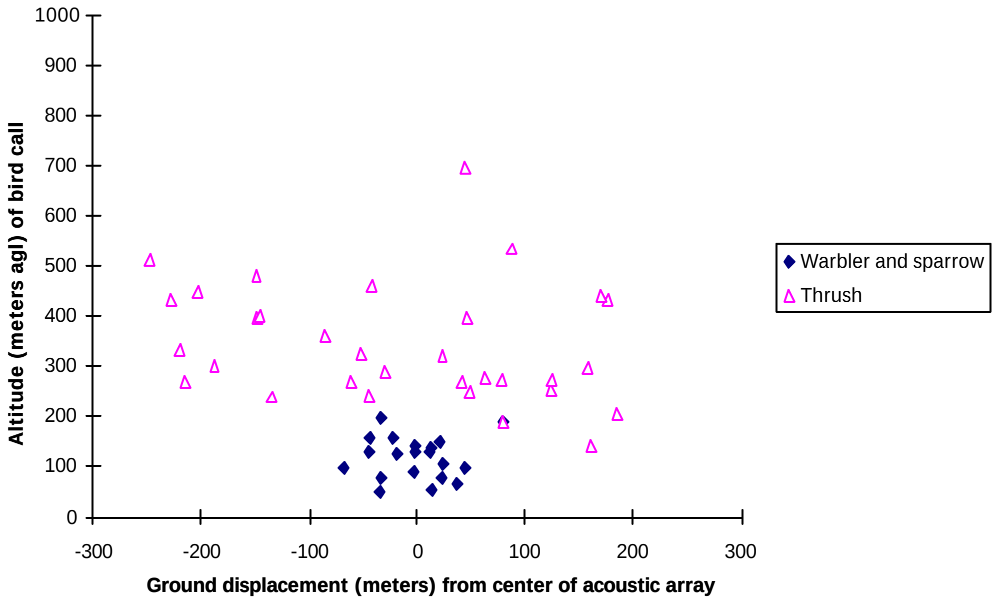



FIGURE 4. Acoustically determined points of origin of two classes of avian night flight calls above a microphone array at Tug Hill, New York, on ***(A)*** 9 September 1994 and ***(B)*** 21 September 1994. Triangles indicate thrush-class call types and diamonds indicate warbler or sparrow notes.

document the altitude differences between thrush-class species and smaller passerines (warblers and sparrows). It also provides an indication of the flight altitudes of migrants with respect to the turbines. Detailed species analyses on these data are in progress.

## *Discussion*

Three applications of acoustic monitoring of night flight calls have been carried out. These have profiled the species composition of night migrants over a region, provided an index to their abundance, and demonstrated a capability to estimate flight altitudes for particular species.

***Night Migration Near Existing Tall Structures***.—The large number of alarm calls recorded in the Nebraska study suggests that calling by night-migrating birds may be elicited when they become aware of their unexpected close proximity to a tall structure. Certain weather conditions may obscure a structure such that migrating birds are startled and give distress calls when they do become aware of it. The hazard from an existing wind turbine structure for many species of night-migrating birds might therefore be evaluated acoustically by logging the frequency and species composition of alarm calls. Collisions with the turbine structure could be documented acoustically as well. Such a study could be performed on nights with light winds when turbines were not operating. Whether such acoustic monitoring could be performed during turbine operation would depend on the frequency band of the turbine noise and the audio frequency and intensity of the calls or collision sounds. For pre-construction assessment of proposed wind turbine sites, existing communications towers in the region could be monitored acoustically at night to evaluate collisions and near misses based on species alarm calls. Such towers are rapidly proliferating across the continent and are likely to occur near most proposed wind turbine sites. For example, Figure 5 illustrates the locations of communications towers in the 60-120 m height range across Nebraska. Companies constructing such communications towers may be interested in pooling birdkill research efforts with the wind power industry.

Lighting on wind turbines may, at times, help reduce collisions caused from lack of visibility. However, the primary threat for small passerines, which has been amply documented around the continent (Avery et al. 1980), occurs when inclement weather conditions (low ceiling, fog, and precipitation) lead night-migrating birds to congregate around lighted structures. These birds have lost access to some of their normal orientation cues for nocturnal migration (e.g., stars; view of horizon) due to weather conditions. In these conditions, they tend to approach lights, become disoriented, and fly about in the lighted area. Mortality occurs when they run into the structure or even other migrating birds as more and more birds fly around in the relatively small, lighted space. Therefore an important consid-eration in minimizing the collision risk at wind turbines for night-migrating passerines is the lighting of these structures. Wind turbines should not be strongly illuminated.

Recent advances in computers and signal processing techniques have allowed automated birdcall detection systems to be developed. Such systems might be applied to wind turbine farms to enable automated monitoring of calls and collisions at every turbine in the facility. This assumes that noise from the turbines proves not to cause serious interference with acoustic monitoring of bird calls. Researchers could access such data remotely and be alerted to nights when wind turbines are hazardous to migrating birds. In this way, the timing of ground searches for carcasses could be optimized. If necessary, real-time acoustic monitoring might be used to shut down turbines under especially high-risk conditions.

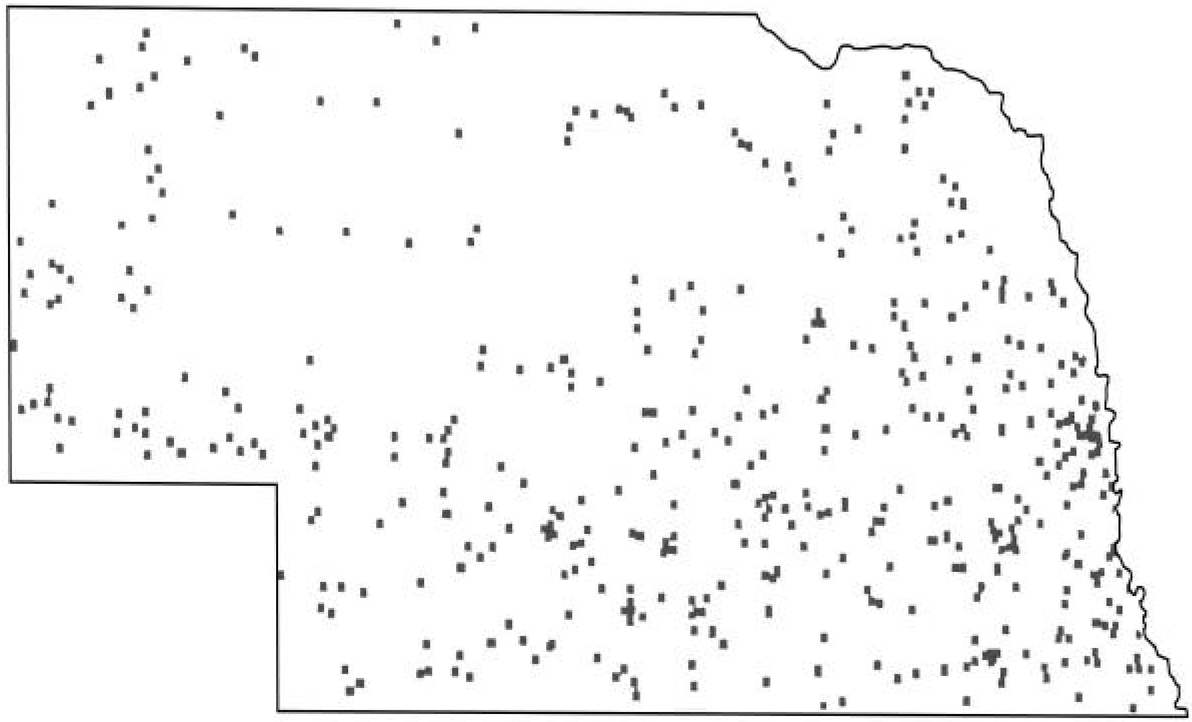


FIGURE 5. Locations of Nebraska communications towers in the 60-120 meter height class as of April 1998 (source: FAA digital obstacle file).

***Document Broad Front Density Gradients by Species at Night.***—In the Nebraska acoustic study, a single recording station near Ainsworth was operated through the fall 1996 and spring 1997 migration seasons. However, on the night of 6-7 October 1996, a five-station recording transect was operated across the eastern half of Nebraska to illustrate the utility of such data for siting wind turbine

operations (Fig. 1). The data from this night revealed that a large wave of predominantly grassland sparrows passed over east-central Nebraska (Table 1). The sparrow calls have not yet been classified to species because they were from a group with similar call-types that have not yet been fully discriminated from one another: Nelson's Sharp-tailed Sparrow (*Ammodramus nelsoni*), LeConte's Sparrow (*Ammodramus leconteii*) and Savannah Sparrow (*Passerculus sandwichensis*). Figure 3 illustrates the higher density of sparrow calling (and presumed numbers of birds) over east-central Nebraska, with numbers diminishing toward the west end of the array. Note that Figure 3 illustrates the number of detected calls of birds, not the number of birds. Use of the MIP method to estimate the minimum number of individuals passing has not yet been carried out on these data because of the species identification problem. MIP is more accurate for assessing migration density because it accounts (at least in part) for variable calling rates of individual birds caused by weather, varying migration density, artificial lighting, etc.

MIP analysis was possible on the distinctive calls of the Dickcissel (Table 2). These data suggest that Dickcissel migration density was also larger in the east-central portion of the transect, but peak numbers appear to have occurred earlier in the evening than the large wave of grassland sparrows.

Though the transect data are just from one evening, and therefore no turbine siting conclusions can be drawn, this type of information about broad front migration suggests that season-long monitoring efforts with a transect of recording stations could elucidate migration density patterns for a region. Indeed, multiple years of transect recording across New York State strongly indicate that certain consistent calling patterns are due to migration patterns of different species, not simply to locally variable weather (Evans and Mellinger 1999; Evans and Rosenberg 1999). Such broad front information obviously could be valuable for siting wind turbines (especially a larger wind turbine operation) if the siting intention is to minimize risk to certain species of nocturnal migrants.

Besides the Nebraska study, acoustic assessment of the species composition of night migrants using recording station transects has been carried out in New York, Florida, and most recently in south Texas (Evans and Mellinger 1999; Evans and Rosenberg 1999; www.oldbird.org). One of the purposes of the south Texas study is to provide the United States Fish and Wildlife Service (USFWS) with information for making decisions on siting wind turbine operations and communication towers in southern Texas.

One suggestion often made when people see data from acoustic transects is that these density data should be correlated with radar data. There are a number of challenges in making such correlations. Due to horizon effects and the angle of surveillance radar beams (including NEXRAD), their minimum altitude of coverage rises as distance from the radar increases. This, along with problems from ground clutter, make correlation with broad-front acoustic data difficult. Using a transect of vertical beam radars could provide broad-front altitude data, but the cost of such monitoring would be roughly 20 times that of the acoustic method. Furthermore, vertical beam radars typically have problems in detecting targets at heights lower than 50 meters. One of the strong points of acoustic monitoring is that there is no lower height limit of bird detection. Acoustic monitoring does have upper altitude limits but these are well above the altitudes of interest regarding wind power impacts.

Radar and acoustic techniques are two different means for monitoring nocturnal bird migration, each with its own strengths and weaknesses. Radar is the only way to monitor every target flying but gives little species information. Acoustic methods give species information but do not provide information on birds that don't call. The best coverage for wind turbine studies would use both techniques. In cases where budgets limit coverage to one technique, the technique chosen would need to be determined depending on the monitoring priorities of the study. For example, in the NPPD study, the USFWS was specifically interested in the impact of the proposed wind turbines on Baird's Sparrow (*Ammodramus bairdii*), a threatened grassland bird. Clearly, radar would have been ineffective for this purpose.

***Localization of Calling Night Migrants***.—Characterizing the typical migratory altitude of different species in a region has obvious utility for assessing the impact of wind turbines, especially regarding their height. The study conducted in upstate New York was the first experiment with acoustic localization of night flight calls. Although the data have been analyzed only to species classes, they do reveal the exciting potential of this technique. The apparent difference in flight altitudes for warblers and sparrows as compared with species giving thrush-class calls is reliable only for the lower altitudes. Warbler and sparrow calls could have occurred at higher altitudes but their relatively faint calls may not have been picked up by the microphone system. However, because the altitude data from the vertical beam radar were closely correlated with the acoustically determined altitude data, it is probable that few warblers and sparrows were migrating above the reach of the acoustic system. Furthermore, the relatively strong calls of the thrush-class species certainly would have been detected if some of these birds had flown at lower altitudes. Thus, the results indicate that thrush-class species were flying predominantly at higher altitudes than warblers and sparrows.

One caveat is necessary in assessing mortality hazard by evaluating mean flight heights of birds over a proposed or existing tall structure: For many species, collisions with tall structures occur mainly when birds are forced to fly lower than normal due to lowering cloud ceilings, when they are flying in conditions of poor visibility (e.g., fog), or when they remain near a tall structure because of disorientation caused by the structure's lighting. Relying on seasonal mean flight height data to evaluate collision hazard may therefore yield misleading information. In eastern North America, the mean height of migration over a region may be less important for assessing tall structure bird collision hazard than quantifying the number of nights of fog or low cloud ceiling at the site during the migration periods.

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## *General Discussion*

The post-presentation discussion focussed on details of the application of this technology, and its future. The initial question concerned noise interference at the turbines. Given that the turbine site will be windy, and the turbines themselves are noisy, do these noise sources interfere with the recording of bird vocalizations? Bill Evans admitted that this is a problem if the recordings are made right at the wind turbines. At the Tug Hill, New York site, for example, the array of microphones was placed about 250 m away from the turbines to reduce the noise interference. It may be possible for direct collisions to be picked up by a microphone at the turbine site, but probably not on a windy night. One attendee commented that noise cancelling software is capable of reducing environmental background noise somewhat, but is not yet perfected.

The suggestion was made that an array of microphones, set "downwind" from the turbines possibly could function as a "distant early warning" system. If a certain threshold level of calling was being recorded, the turbines could be shut down. Bill Evans agreed that this is a potential application of this technology.

How big an area can be monitored with this technology? The area varies with the species being monitored and the environmental conditions, but generally within about a mile of the microphones, Evans estimated.

One participant commented that there is weak correlation between the numbers of birds aloft as measured by call rates versus by radar. While the acoustic approach is admittedly good for identification of species, it may not provide a good index of numbers of birds aloft. Bill Evans thought that there may be ways around this shortcoming.

Are there species that do not call during nocturnal migration, and thus that would not be detected acoustically? Evans mentioned that vireos call infrequently.

Where do we go from here with this acoustic technology? How far off is species call-recognition software? Evans feels that automated call recognition is possible, given sufficient development funding, and would dramatically reduce the time and cost of data analysis. In the Nebraska study, computer call-recognition algorithms were used to detect probable calls and to copy them to a computer hard drive. Thus allowed remote access to call data without the intervening "quiet" periods. Acoustic technology could be applied to document migration paths. For example, a broad front array of recording stations could be established to determine nocturnal migration corridors by species.

It was pointed out by an attendee that acoustic (or other remote sensing) technology may not be necessary as an "early warning system". Weather forecasts could be used to predict those relatively few nights during which the majority of nocturnal migration occurs, especially those when nocturnal migrants may be flying low (at turbine height). On these nights, the wind turbines could be shut down in advance.