NIGHT MIGRANT FATALITIES AND OBSTRUCTION LIGHTING AT WIND TURBINES IN NORTH AMERICA: A REVIEW

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Abstract. Avian collision fatality data from studies conducted at 30 wind farms across North America were examined to determine how many night migrants collide with turbines and how aviation obstruction lighting relates to collision fatalities. Fatality rates, adjusted for scavenging and searcher efficiency, of night migrants at turbines 54 to 125 m in height ranged from <1 bird/turbine/year to ~7 birds/turbine/year, with higher rates recorded in eastern North America and lowest rates in the west. Multi-bird fatality events (defined as >3 birds killed in one night at one turbine) were rare, recorded at <0.02% (n = 4) of ~25,000 scheduled turbine searches. Lighting and weather conditions may have been causative factors in the four documented multi-bird fatality events, but in no case were flashing red lights (L-864, recommended by the Federal Aviation Administration [FAA]) involved, which is the most common obstruction lighting used at wind farms. Non-parametric analysis of unadjusted fatality rates revealed no significant differences between fatality rates at turbines with FAA lights as opposed to turbines without lighting at the same wind farm. .

Songbirds often collide with communication towers, lighthouses, skyscrapers, and other structures during nocturnal migration, with fatalities sometimes numbering in the hundreds or even thousands of birds in a single night (Banks 1979, Avery et al. 1980, Trapp 1998, Kerlinger 2000). Research suggests that lighting plays a primary role in attracting or disorienting night-migrating songbirds at those structures, especially during overcast, foggy, or rainy conditions (Cochran and Graber 1858, Caldwell and Wallace 1966, Avery et al. 1976). Many of the studies that have attempted to assess how lights influence bird behavior have focused on communication towers. Larkin and Frase (1988) used tracking radar to show that during fog and low cloud ceiling night migrants circled a >305 m tall communication tower with Federal Aviation Administration (FAA)-approved obstruction lighting, but departed the tower when the lights were extinguished. Gauthreaux and Belser (2006) used marine surveillance radar and infrared scopes to compare night migrant activity at two tall (>305 m), lighted communication towers with guy wires and at a control plot. One of the towers had flashing and steady-burning red lights, the other had only flashing white strobe lights. They found that birds flew in straight flight paths over the control plot, but at the lit towers, flight paths were curvilinear and birds concentrated near the towers. More birds concentrated at the tower with flashing and steady-burning red lights than at the tower with flashing white strobe lights. This led Gauthreaux and Belser (2006) to suggest that research was needed to improve understanding of the attractive power of different obstruction lighting systems on night-migrating songbirds.

Recently, a study in Michigan by Gehring et al. (2009) of 24 communication towers with different heights, support systems, and lighting determined that towers lit at night with only flashing red or white lights had significantly fewer avian fatalities than towers lit with a combination of steady-burning and flashing lights. These results suggest that avian fatalities can be reduced, perhaps by 50-71%, at communication towers supported by guy wires by replacing steady-burning lights with flashing lights.

Avian collision fatalities are well documented at wind turbines, but the estimated total number of birds killed annually is small relative to communication towers and other structures (Erickson et al. 2005, National Research Council 2007). Wind turbines >60 m in height are often deployed with FAA-approved obstruction lighting, but not all turbines need to be lit, as long as gaps between lighted structures do not exceed 0.8 km (FAA 2000). This means that ~25-33% of turbines at most wind farms have obstruction lighting (Table 1), which is located on the nacelle adjacent to where the rotors are attached. The FAA (2000) recommends flashing red lights be placed on the turbine nacelle (where the blades are attached to the rotor hub; Figure 1), but flashing white and steady-burning red lights have also been used on a limited number of turbines. The flashing red lights are model L-864, a red strobe, LED, or pulsating incandescent light that flash 20-40/min and have an intensity of 2,000 candela. Steady-burning red lights are classified as model L-810, an incandescent red lighting that has a minimum intensity of 32.5 candela. L-810 lights are red and occasionally are modified to flash. Flashing white lights are classified as model L-865 and are a white strobe typically set at 40-60 flashes/min with an intensity of up to 2,000 candela. These same types of obstruction lights are used on communication towers (FAA 2000, Gehring et al. 2009).

Concerns about avian mortality have prompted fatality studies at wind farms across the United States and Canada. Most of these studies are available as reports to meet permit requirements and are often reviewed by state and federal wildlife agencies. This paper reviews existing information on night migrant mortality at wind farms derived from 31 studies of 30 wind farms. Objectives were to: (1) examine the incidence of multi-bird fatality events at individual wind turbines and their relationship with lighting, and (2) examine whether disproportionately greater numbers of fatalities occur at turbines equipped with FAA-approved lights as opposed to turbines without such lights.

STUDY AREA AND METHODS

Data were extracted from post-construction, avian fatality studies conducted at 30 wind farms across the United States and Canada (Table 1). Studies prior to 1995 were not used because turbines lacked obstruction lighting and were <50 m in height (to maximum blade tip height). Excluded studies in this category were conducted at Altamont Pass Wind Resource Area, San Gorgonio Pass, and Tehachapi Mountains, all in California. The results of studies at several small wind farms conducted after 1995 were also not included because lighting or search methodologies could not be verified. Other wind farms in the United States and Canada were not included because they have not been studied or, if they have been studied, reports were not available.

Data extracted included geographic region; turbine nameplate output in megawatts (MW); turbine height (to the maximum blade tip height); total number of turbines in the wind farm and the subset of turbines studied; lighting type, including the total number of turbines with lighting and the number of lit turbines studied; study duration and search interval during migration seasons; unadjusted number of nocturnal migrant carcasses found; and estimated fatality rate (in birds/turbine/year). Carcasses were assigned as night-migrating songbirds or similar species (i.e., cuckoos, etc.) based on migration tendency (nocturnal vs. diurnal) and date recorded.

Methodologies for studying collision mortality at wind farms varied, but they basically followed accepted practices (e.g., Anderson et al. 1999). With respect to search interval, carcass searches were usually conducted every week to 1 month in the western United States, whereas they were usually conducted every 1-2 days to 1 month in the eastern United States and Canada. Some studies used different search intervals at different subsets of turbines. Searchers were often on site for 2-5 days per week because it required several days for turbines at a site to be searched. On-site technicians and maintenance staff at most wind farms were instructed to report avian fatalities, increasing the likelihood of recording large scale collision events at towers that were not part of the study.

We report both the raw numbers of night-migrant carcasses found during each study and estimates of fatalities per turbine per year. Most studies calculated estimates of fatalities per turbine per year from raw numbers of carcasses found, searcher efficiency tests or estimates, carcass removal (scavenging) tests or estimates, and area adjustments if the entire area beneath a turbine could not be searched. We used rates from studies in similar habitats to estimate fatalities likely per turbine per year for studies where searcher efficiency and carcass removal rates were not measured empirically. We did not estimate fatality rates at three sites where large portions of migration seasons were not covered or where searcher efficiency and carcass removal rates could not be estimated. Our rationale for including raw, unadjusted fatality numbers was to provide a comparison of actual carcass finds to fatality estimates, and to permit comparison with communication tower studies, where corrections for carcass removal and searcher efficiency have rarely been used.

From 12 of 30 wind farms (Table 2) we compared the unadjusted number of night migrant fatalities/turbine/year at lit (flashing red) and unlit turbines using a non-parametric Wilcoxon signed-rank test (Wilcoxon 1945). We wished to determine whether a significantly greater number of wind farm studies reported more carcasses at lit turbines versus unlit turbines.

RESULTS

Eight wind farms were examined in the western United States, seven in the central region, 12 in the eastern region, and three in Canada (Table 1). For Buffalo Mountain, Tennessee, two studies were reported because the type of lighting changed when the wind farm was expanded and larger turbines were installed. The number of turbines at these sites ranged between 1 and 454 and the number of turbines studied ranged from 1 to 153. Turbine nameplate output ranged from 0.4 to 2.0 MW, and turbine height ranged from 54 to ~125 m. Obstruction lighting was present at 28 of 30 wind farms studied. The percentage of turbines equipped with lighting ranged from ~25-33% (n = 22 studies) to 100% (n = 7 studies). Lighting on most illuminated turbines was flashing red lights (mainly L-864), but a few sites had steady-burning red (L-810), and two sites had flashing white lights (L-865). More than one type of lighting was used at four sites. Study durations ranged from 5 months to five years. As noted above, there was variation in search interval among studies. We estimate the total number of individual turbine searches for all studies combined to be ~25,000 during spring and fall migration seasons.

INCIDENCE OF MULTI-BIRD FATALITY EVENTS

The number of carcasses found in the studies ranged from 0 to 36 per year, but when the number of turbines studied was considered, the average at turbines ranged from 0 to ~5/turbine/year. Only three studies reported multi-bird fatality events (defined as >3 birds killed in one night at one structure), but they were at turbines with lighting other than flashing red or at turbines with ancillary, non-FAA-type lighting. At Buffalo Ridge in southwestern Minnesota (Johnson et al. 2000), 14 freshly killed birds (11 warblers, 2 flycatchers, and 1 vireo) were recovered on 19 May 1999 at two adjacent turbines in a section of the wind farm where every other turbine was lit with steady-burning red lights. This event may have been related to a severe thunderstorm that occurred the night before the carcasses were discovered. This was the only multi-bird fatality event reported at the Minnesota site during four years of study.

At Buffalo Mountain I in Tennessee (Nicholson et al. 2005), where each of three turbines had a pair of flashing white lights, two multi-bird fatality events were recorded: (1) three fatalities at turbine # 2 on 10 October 2000, (2) seven fatalities at turbine # 3 on 31 October 2002. The 10 October 2000 mortality event occurred during clear, cold, windy conditions following passage of a strong cold front, and the 31 October 2002 mortality event occurred during mild, rainy weather.

At Mountaineer in West Virginia (Kerns and Kerlinger 2004), ~27 night-migrating passerines were found dead on the morning of 23 May 2003 in the vicinity of three turbines and an electrical substation that was brightly lit at night by at least four sodium-vapor lamps (steady-burning white flood lights). Heavy fog occurred the night before this fatality event was discovered by maintenance workers, who alerted searchers. Seventeen of the fatalities were discovered at turbine # 23, which was ~50 m from the substation, five at the substation (collisions with fencing), and three and two respectively at the flanking turbines, # 22 and 24. No further multi-bird fatality events occurred at the substation and adjacent turbines, including foggy nights, after the sodium-vapor lamps were extinguished. Throughout the study, few fatalities were found at searched turbines, including those that had flashing red lights.

COMPARISON OF LIT AND UNLIT TURBINES AT SAME SITE

Because the FAA does not recommend that all turbines at a wind farm be lit, we were able to test whether disproportionate numbers of fatalities occurred at turbines with obstruction lighting. There were two sites at which none of the turbines were lit and seven at which all of the turbines were lit (Table 1). The two completely unlit sites had 0.55-0.60 MW turbines in the 59-61 m height range, and estimated fatality rates of <1 night migrant/turbine/year. Sites where all turbines were lit had 0.66-1.65 MW turbines in the 79-117 m height range, and estimated fatality rates of <1 to ~7 night migrants/turbine/year. Sites in eastern North America reported slightly greater estimated fatality rates (Table 1). Wind farms ($n = 22$) with both lit and unlit turbines had 0.36-2.00 MW turbines in the 54-125 m height range. Estimated fatalities ranged from <1 to ~4 birds/turbine/year, with the greater rates being in eastern North America. Absolute numbers of fatalities were large enough at 13 of 22 sites to make quantitative comparisons of fatality rates at lit and unlit turbines (Table 2). The rates were roughly the same at sites with flashing red lights, but may have been slightly greater at turbines lit with steady-burning red lights. We did not find that a significantly greater proportion of wind farm studies (Table 2) reported greater numbers of fatalities at lit turbines versus unlit turbines than expected by chance (Wilcoxon sign-rank test, $n = 20$, $Z = 0.18$, $p = 0.43$, ns). This lack of evidence of a consistent trend with respect to fatality rates at lit vs. unlit turbines across North America indicates that it is highly unlikely flashing red lights are associated with greater fatalities. Further, of the studies reviewed here that tested for differences in fatality rates at lit and unlit turbines all but one reported no significant differences. The one exception was at Maple Ridge in New York, where a marginally significant difference was reported ($0.10 > p > 0.05$) in one out of two statistical tests..

No significant differences in collision mortality were reported at wind farms with lit and unlit turbines where some or all lit turbines had other than flashing red lights. These included Crescent Ridge, Illinois (Kerlinger et al. 2007), Buffalo Ridge, Minnesota (Johnson et al. 2002, 2000), and Buffalo Mountain, Tennessee (Fiedler et al. 2007). At Erie Shores, Ontario (James 2008), where all lit turbines had steady-burning red lights, unadjusted mortality was four times greater at lit than at unlit turbines (0.4/turbine versus 0.1/turbine). But, when turbines along the shore of Lake Ontario were removed from the calculations, the unadjusted rates were similar (0.35/turbine at lit versus 0.28/turbine at unlit).

DISCUSSION

Collision fatality data from 30 wind farms studied in North America demonstrate that the fatalities rates of night migrating birds at these structures are relatively low, ranging between ~1 and 7 per turbine per year. A comparison of estimated fatalities by geographic region showed a gradient with fatalities increasing from western to eastern North America. This result mirrors continent-wide studies of bird migration patterns (Gauthreaux et al. 2003, Lowrey and Newman 1966) that show that the density of migration in central and eastern states is greater than that recorded for western states.

What is striking about the data from wind farms is the relative absence of large-scale fatality events, such as those recorded at tall communication towers supported by guy wires, where collisions of hundreds of birds sometimes occur in a single night (Avery et al. 1980, Kerlinger 2000). With respect to multi-bird fatality events at wind turbines (*n* = >3 carcasses at a single turbine on a single night), only four incidents (<0.02% of searches) were reported during ~25,000 turbine searches in all studies combined. That so many studies and so many searches have been conducted at wind turbines without recording large-scale fatality events strongly suggests that the probability of large-scale fatality events occurring is extremely low. That far more systematic research has been conducted at wind turbines than at communication towers or other structures supports our contention that large-scale fatality events rarely, if ever, occur at wind turbines.

We believe there are three reasons why large-scale fatality events do not occur at wind turbines and why fatality rates at wind turbines are so much lower than has been reported for communication towers. First, the communication towers for which large-scale fatality events and large numbers of fatalities have been reported are taller than wind turbines. Whereas wind turbines have rarely exceeded 125 m (this study), the communication towers for which large-scale fatalities have been found largely exceed 150 m and often exceed 305 m (Avery et al. 1980, Shire et al. 2000). Thus, communication towers extend into altitudes where more night migrants fly (Kerlinger and Moore 1989), than do wind turbines. Second, all communication towers for which large numbers of night migrant fatalities and large-scale events have been noted have guy wires (papers and reports cited in Shire et al. 2000), whereas wind turbines do not.

The third reason for higher fatality rates and large-scale fatality events at communication towers as opposed to wind turbines is related to the types of lights that are deployed on communication towers and wind turbines. A majority of communication towers that are equipped with aviation obstruction lights have both steady-burning red (L-810) lights and flashing red (L-864) lights (FAA 2000). Wind turbines are most often equipped with only flashing red (L-864) lights (FAA 2000). The three multi-bird fatalities at single (or adjacent) turbines during a single night occurred at turbines with flashing white lights, steady-burning red lights, or ancillary facility lighting (sodium vapor lamps). In no case were flashing red lights implicated in these multi-bird fatality events at turbines.

That steady-burning red lights attract night migrants, but flashing red lights do not has recently been demonstrated for communication towers (Gehring et al. 2009). When looking at communication towers supported by guy wires and with heights ranging from 116 to 146 m, Gehring et al. (2009) demonstrated that towers equipped with only flashing red lights experienced 50-70% fewer fatalities than towers with both flashing and steady burning red lights. With both flashing and steady-burning red lights, the average fatality rate was 17.5 carcasses found per communication tower per 40 days of peak migration (20 days in spring and 20 days in fall). The estimated fatality rate at these towers when adjustments for searcher efficiency and carcass removal by scavengers is included (equal to about a twofold increase; Gehring et al. 2009) is likely to be as high as 70 night migrants per tower per year when adjustments are made to include the entire spring and fall migration seasons. At guyed towers >305 m in height, Gehring et al. (2009) reported 74 carcasses found per 40 days of searching per year (spring and fall seasons), without carcass removal or searcher efficiency adjustments. With such adjustments, as well as adjustments that include the entire spring and fall migration seasons these towers likely killed ~300 birds per tower per year. Thus, communication towers equipped with guy wires and a combination of flashing and steady-burning red lights have fatality rates that are one to two orders of magnitude greater than wind turbines.

We found that fatalities of night migrating birds are minimal at wind turbines, especially when compared to tall, guyed communication towers. In addition, we did not find evidence that large-scale fatality events occur at wind turbines or that the flashing red lights normally used on wind turbines cause large numbers of fatalities of night migrants. Our results, combined with those reported by Gehring et al. (2009), strongly suggest that wind turbines be equipped only with flashing red lights (strobe or LED) and that steady burning red lights never be used on turbines. Finally, it is prudent that post-construction fatality studies continue to be conducted at wind turbines, especially those that are taller than those reported herein and at turbines erected in geographic areas where such studies have not been conducted and greater numbers of birds may migrate.

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Figure 1. Wind turbine showing location of Federal Aviation Administration obstruction lights.

WIND TURBINE GENERATOR

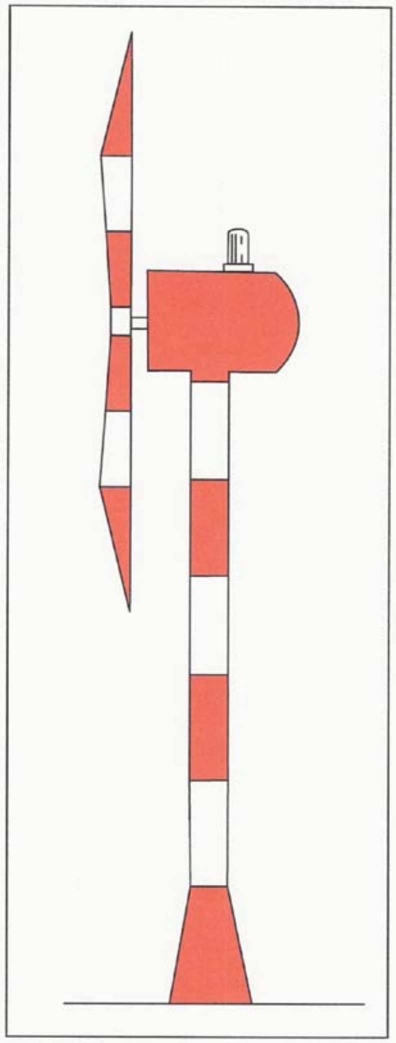

FIG 12