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

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ABSTRACT.—Avian collision fatality data from studies conducted at 30 wind farms across North America were examined to estimate how many night migrants collide with turbines and towers, 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 1 night at 1 turbine) were rare, recorded at <0.02% (n = 4) of ~25,000 turbine searches. Lighting and weather conditions may have been causative factors in the four documented multi-bird fatality events, but flashing red lights (L-864, recommended by the Federal Aviation Administration [FAA]) were not involved, which is the most common obstruction lighting used at wind farms. A Wilcoxon signed-rank 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. *Received 30 May 2006. Accepted 29 June 2010.*

Songbirds often collide with communication towers, lighthouses, skyscrapers, and other structures during nocturnal migration with fatalities, at times, 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 lighting has a primary role in attracting or disorienting night-migrating songbirds at those structures, especially during overcast, foggy, or rainy conditions (Cochran and Graber 1958, Caldwell and Wallace 1966, Avery et al. 1976). Many studies, attempting 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 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 separate 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 attraction of different obstruction lighting systems to night-migrating songbirds.

A recent study in Michigan by Gehring et al. (2009) of 24 communication towers with different heights, support systems, and lighting found 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 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 (turbine rotor or tower), 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 equipped 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). Thus ~25–33% of turbines at most wind farms should have obstruction lighting on the nacelle (where the

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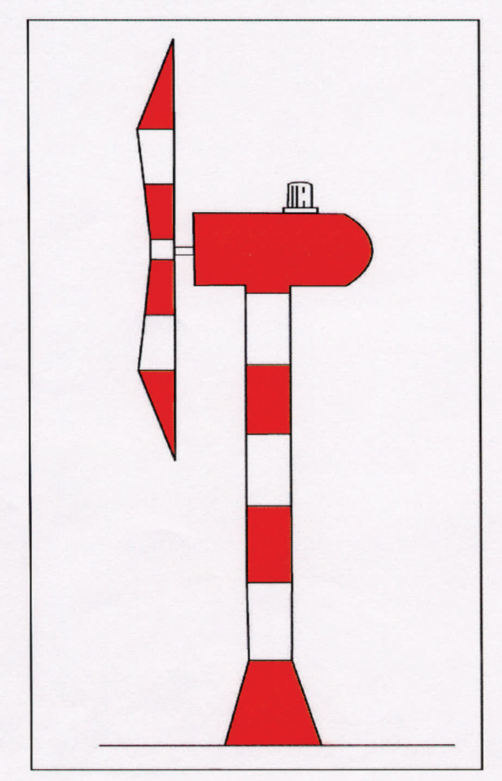

FIG. 1. Wind turbine showing location of Federal Aviation Administration obstruction lights on the nacelle.

blades are attached to the rotor hub; Fig. 1) adjacent to where the rotors are attached. The FAA (2000) recommends flashing red lights be placed on the turbine nacelle 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 (light-emitting diode), or pulsating incandescent light that flashes 20–40 times/min with 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 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 at 30 wind farms. Our 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 approved lights.

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 included 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 production 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 (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 basically followed accepted practices (e.g., Anderson et al. 1999). 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

TABLE 1. Estimated avian migrant mortality per year (spring and fall) from 31 studies at 30 wind farms (Buffalo Mountain studies were done at each of the 2 types of turbines on site).

Location	Turbine type (total/study)	Turbine height (m)	Lighting type (total/study)	Study duration	Search interval during migration	Observed nocturnal migrant fatalities/yr	Estimated fatalities/turbine/yr	Reference
Western U.S.								
High Winds, CA	1.8 MW (90/90)	100	Flashing red (26/26)	2 years	14 days	15	<1/turbine/yr	Kerlinger et al. 2006
Ponnequin, CO	0.66–0.75 MW (44/44)	79	Flashing red (21/21)	5 years	7 days–1 month	5	<1/turbine/yr	Kerlinger and Curry 2000, unpubl. data
Judith Gap, MT	1.5 MW (90/20)	119	Flashing red (30/7)	7 months	1 month	6	~2–3/turbine/yr	TRC Env. Corp. 2008
Klondike, OR	1.5 MW (16/16)	100	Flashing red (9/9)	1 year	1 month	4	<1/turbine/yr	Johnson et al. 2003
Vansycle, OR	0.66 MW (38/38)	74	Flashing red (11/11)	1 year	14–28 days	5	<1/turbine/yr	Erickson et al. 2000
Stateline, OR/WA	0.66 MW (454/124–153)	72	Flashing red (~140/~45)	2.5 years	0.5 months	20	<1/turbine/yr	Erickson et al. 2004
Nine Canyon, WA	1.3 MW (37/37)	91	Flashing red (15/15)	1 year	2 weeks	7	<1/turbine/yr	Erickson et al. 2003
Foote Creek Rim, WY	0.60 MW (69/69)	61	None	3.5 years	14–28 days	12	<1/turbine/yr	Young et al. 2003
Central U.S.								
Top of Iowa, IA	0.90 MW (89/26)	98	Steady red, flashing red, and flashing white (89/26)	2 years	2 days	2.5	<1/turbine/yr	Jain 2005, Koford et al. 2005
Crescent Ridge, IL	1.5 MW (33/33)	120	Steady red and flashing red (10/10)	7 months	5 days	5	<1/turbine/yr	Kerlinger et al. 2007
Buffalo Ridge, MN	0.36–0.75 MW (354/111)	54–76	Steady red and flashing red (75/~25)	4 years	2 weeks	10	~3/turbine/yr	Johnson et al. 2000, 2002
Ainsworth, NE	1.5 MW (36/36)	110	Flashing red (24/24)	7 months	2 weeks	18	~2.5/turbine/yr	Derby et al. 2007
Blue Canyon II, OK	1.8 MW (84/50)	~125	Flashing red (38/23)	7.5 months	1 week	2	<1/turbine/yr	Schnell et al. 2007
Buffalo Gap I, TX	2.0 MW (67/21)	~120	Probably flashing red (21/~6?)	10 months	~1 month	6	<1/turbine/yr	Tierney 2007
Kewaunee, WI	0.66 MW (31/31)	89	Flashing red (22/22)	2 years	0.5 weeks	5	<1/turbine/yr	Howe et al. 2002
Eastern U.S.								
Mars Hill, ME	1.5 MW (28/28)	119	Flashing Red (10/10)	2 years	1–7 days	18	~2–3/turbine/yr	Stantec 2008, 2009
Atlantic County, NJ	1.5 MW (5/5)	116	Flashing red (5/5)	7 months	~2 days	9	Not estimated	NJ Audubon 2008
Bliss, NY	1.5 MW (67/23)	119	Flashing red (21/7)	8 months	1, 3, and 7 days	12	<1–~3/turbine/yr	Jain et al. 2009d
Clinton, NY	1.5 MW (67/23)	119	Flashing red (31/15)	6 months	1, 3, and 7 days	9	Not estimated	Jain et al. 2009c
Ellenburg, NY	1.5 MW (54/18)	119	Flashing red (17/5)	6.5 months	1, 3, and 7 days	7	Not estimated	Jain et al. 2009b

TABLE 1. Continued.

Location	Turbine type (total/study)	Turbine height (m)	Lighting type (total/study)	Study duration	Search interval during migration	Observed nocturnal migrant fatalities/yr	Estimated fatalities/turbine/yr	Reference
Madison, NY	1.65 MW (7/7)	100	Flashing red (7/7)	1 year	7–10 days	5	~1–2/turbine/yr	Kerlinger 2002b
Maple Ridge, NY	1.65 MW (195/50–64)	122	Flashing red (~60/17–18)	2 years	7 days	32	~2–4/turbine/yr	Jain et al. 2009a, b
Garrett, PA	1.3 MW (8/8)	90	Flashing red (8/8)	1 year	7–10 days	0	<1/turbine/yr	Kerlinger 2001
Buffalo Mountain I, TN	0.66 MW (3/3)	88	Flashing white (3/3)	3 years	0.5 weeks	15.7	~7/turbine/yr	Nicholson et al. 2005
Buffalo Mountain II, TN	0.66–1.8 MW (18/18)	88–120	Flashing white and flashing red (9/9)	1 year	7 days	5	~2/turbine/yr	Fiedler et al. 2007
Searsburg, VT	0.55 MW (11/11)	59	None	5 months	3–7 days	0	<1/turbine/yr	Kerlinger 2002a
Mountaineer, WV	1.5 MW (44/44)	105	Flashing red (12/12)	8 months	1 week	30[a]	~3/turbine/yr[a]	Kerns and Kerlinger 2004
Mt. Storm, WV	2.0 MW (82/27)	118	Flashing red (27/12)	6 month	1–7 days	36	~2–4/turbine/yr	Young et al. 2009
Eastern Canada								
Erie Shores, ON	1.5 MW (66/66)	119	Steady red (41/41)	2 years	3–24 days	~20	~1–2/turbine/yr	James 2008
Exhibition Place, ON	0.75 MW (1/1)	94	Flashing red (1/1)	11 weeks	0.5 weeks	2	~3–4/turbine/yr	James and Coady 2003
Pickering, ON	1.8 MW (1/1)	117	Flashing red (1/1)	1 year	3–7 days	2	~3–4/turbine/yr	James 2004

[a] A multi-bird fatality event caused by sodium-vapor lamps at a substation was excluded from this analysis.

TABLE 2. Night migrant mortality comparison at lit and unlit turbines; wind farms with flashing red lights only. Lit-unlit column represents the difference between numbers of actual carcasses found at lit vs. unlit turbines, on a per turbine basis.

	Lit turbines			Unlit turbines			Lit-unlit		
Location	# lit turbines	# carcasses found at lit turbines	Observed fatalities per turbine	# unlit turbines	# carcasses found at unlit turbines	Observed fatalities per turbine	Difference in fatalities per turbine	Reference	Statistical test, significance
Western U.S.									
High Winds, CA	26	10	0.385	64	21	0.328	0.06	Kerlinger et al. 2006	Chi-square test, ns
Klondike, OR	9	0	0.000	7	4	0.571	−0.57	Johnson et al. 2003	Statistical test not reported
Stateline, OR/WA, 2002	39	9	0.231	85	23	0.271	−0.04	Erickson et al. 2004	Statistical test reported, $P > 0.10$, ns
Stateline, OR/WA, 2003	46	4	0.087	107	34	0.318	−0.23	Erickson et al. 2004	Statistical test reported, $P > 0.10$, ns
Nine Canyon, WA	15	3	0.200	22	3	0.136	0.06	Erickson et al. 2003	Overlapping 95% CI, ns
Judith Gap, MT	7	1	0.143	13	3	0.231	−0.09	TRC Env. Corp. 2008	Statistical test not reported
Central U.S.									
Ainsworth, NE	24	4	0.167	12	4	0.333	−0.17	Derby et al. 2007	Statistical test not reported
Kewaunee, WI	20	4	0.200	11	3	0.273	−0.07	Howe et al. 2002	Statistical test not reported
Eastern U.S.									
Mars Hill, ME, 2007	10	10	1.000	18	12	0.667	0.33	Stantec 2009	Statistical test not reported
Mars Hill, ME, 2008	10	7	0.700	18	8	0.444	0.26	Stantec 2009	Statistical test not reported
Clinton, NY, 2008, three-day searches	5	3	0.600	3	1	0.333	0.27	Jain et al. 2009c	Chi-square test, ns
Clinton, NY, 2008, weekly searches	5	1	0.200	2	2	1.000	−0.80	Jain et al. 2009c	Chi-square test, ns
Bliss, NY, 2008, daily searches	2	3	1.500	6	7	1.167	0.33	Jain et al. 2009d	Chi-square test, ns
Maple Ridge, NY, 2006, daily searches	3	24	8.000	7	34	4.857	3.14	Jain et al. 2007	Chi-square test, $0.10 > P > 0.05$, marginal significance
Maple Ridge, NY, 2006, weekly searches	7	2	0.286	23	18	0.783	−0.50	Jain et al. 2007	Chi-square test, ns
Maple Ridge, NY, 2007	18	7	0.389	46	18	0.391	0.00	Jain et al. 2009a	Chi-square test, ns
Maple Ridge, NY, 2008	17	14	0.824	47	25	0.532	0.29	Jain et al. 2009b	Chi-square test, ns
Mountaineer, WV	12	9	0.750	31	22	0.710	0.04	Kerns and Kerlinger 2004	Statistical test not reported
Mt. Storm, WV, daily searches	4	6	1.500	5	11	2.200	−0.70	Young et al. 2009	Overlapping 90% CI, ns
Mt. Storm, WV, weekly searches	8	7	0.875	10	5	0.500	0.38	Young et al. 2009	Overlapping 90% CI, ns

were often on site for 2–5 days/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/turbine/year. Most studies calculated estimates of fatalities/turbine/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/turbine/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.

We compared the unadjusted number of night migrant fatalities/turbine/year at lit (flashing red) and unlit turbines from 12 of 30 wind farms (Table 2) using a non-parametric Wilcoxon signed-rank test (Wilcoxon 1945). We wished to ascertain 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). Two studies were reported for Buffalo Mountain, Tennessee 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 one and 454 and the number of turbines studied ranged from one to 153. Turbine nameplate production 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 >3 months to 5 years. 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 zero to 36/year, but when the number of turbines studied was considered, the average at turbines ranged from zero to ~5/turbine/year. Only four 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. Fourteen 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 at Buffalo Ridge in southwestern Minnesota (Johnson et al. 2000) 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 4 years of study.

Two multi-bird fatality events (3 fatalities at turbine # 2 on 10 Oct 2000, 7 fatalities at turbine # 3 on 31 Oct 2002) were recorded at Buffalo Mountain I in Tennessee (Nicholson et al. 2005) where each of three turbines had a pair of flashing white lights. 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.

About 27 night-migrating passerines were found dead on the morning of 23 May 2003 at Mountaineer in West Virginia (Kerns and Kerlinger 2004) 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, which were ~250 and 125 m, respectively from the substation. No further multi-bird fatality events occurred at the substation and adjacent turbines, including foggy nights, after the sodium-vapor lamps were extinguished. Few fatalities were found at searched turbines throughout the study, including those that had flashing red lights.

Comparison of Lit and Unlit Turbines at Same Site.—The FAA does not recommend that all turbines at a wind farm be lit, but 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 was lit and seven at which all of 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). This appeared to be the case for turbines of roughly equal height. 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 greater rates in eastern North America. Absolute numbers of fatalities were sufficiently large 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, $n = 20$, $Z = 0.18$, $P = 0.43$). This lack of evidence of a consistent trend with respect to fatality rates at lit versus unlit turbines across North America indicates it is highly unlikely flashing red lights are associated with greater fatalities. All but one of the studies reviewed that tested for differences in fatality rates at lit and unlit turbines 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 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. 2000, 2002), and Buffalo Mountain, Tennessee (Fiedler et al. 2007). Unadjusted mortality at Erie Shores, Ontario (James 2008), where all lit turbines had steady-burning red lights, was four times greater at lit than at unlit turbines (0.4/turbine vs. 0.1/turbine). The unadjusted rates, when turbines along the shore of Lake Ontario were removed from the calculations, were similar (0.35/turbine at lit vs. 0.28/turbine at unlit).

DISCUSSION

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

What is striking about the data from wind farms is the relative absence of large-scale fatality events, similar to those recorded at tall communication towers supported by guy wires, where collisions of hundreds of birds at times occur in a single night (Avery et al. 1980, Kerlinger 2000). Only four incidents (<0.02% of searches) were reported of multi-bird fatality events at wind turbines (n = >3 carcasses at a single turbine on a single night) 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 the probability of large-scale fatality events occurring is extremely low. Far more systematic research has been conducted at wind turbines than at communication towers or other structures, which supports the finding that large-scale fatality events rarely occur at wind turbines.

We believe there are three reasons why large-scale fatality events apparently do not occur at wind turbines and why fatality rates at wind turbines are much lower than has been reported for communication towers. First, communication towers at which large-scale fatality events and large numbers of fatalities have been reported are taller than wind turbines. Wind turbines have rarely exceeded 125 m in height (this study), while 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 (Shire et al. 2000), whereas wind turbines do not.

The third reason for higher fatality rates and large-scale fatality events at communication towers opposed to wind turbines may be related to the types of lights that are placed on communication towers and wind turbines. A majority of communication towers 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 four 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). Flashing red lights were not implicated in these multi-bird fatality events at turbines.

Gehring et al. (2009) recently demonstrated for communication towers that steady-burning red lights attract night migrants, but flashing red lights do not. Gehring et al. (2009) also demonstrated towers at heights ranging from 116 to 146 m, supported by guy wires and equipped with only flashing red lights, experienced 50–70% fewer fatalities than towers with both flashing and steady burning red lights. The average fatality rate was 17.5 carcasses found per 40 days of peak migration (20 days in spring and 20 days in fall) per communication tower with both flashing and steady-burning red lights. The estimated fatality rate at these towers, when adjustments for searcher efficiency and carcass removal by scavengers is included (equal to about a 2-fold increase; Gehring et al. 2009), is likely to be as high as 70 night migrants/tower/year when adjustments were made to include the entire spring and fall migration seasons. Gehring et al. (2009) reported 74 carcasses/40 days of searching/year (spring and fall seasons) without carcass removal or searcher efficiency adjustments at towers >305 m in height with guy wires. Adjustments for carcass removal and searcher efficiency, as well as adjustments that include the entire spring and fall migration seasons, increased these estimates to ~300 birds/tower/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 strongly suggest that reported fatalities of night-migrating birds are minimal at wind turbines based on results reported for communication towers (Gehring et al. 2009), especially when compared to tall, communication towers with guy wires. Note that Smallwood et al. (2010) estimated mortality at wind turbines was greater when novel scavenger removal methods were used. 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 not be used on turbines. It is prudent that post-construction fatality studies continue at wind turbines, especially those taller than those we report, and at turbines erected in geographic areas where studies have not been conducted and greater numbers of birds may migrate.

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LITERATURE CITED

Anderson, R. L., M. Morrison, K. Sinclair, and M. D. Strickland. 1999. Studying wind energy/bird interactions: a guidance document. Metrics and methods for determining or monitoring potential impacts on birds at existing and proposed wind energy sites. National Wind Coordinating Committee, Washington, D.C., USA.

Avery, M., P. Springer, and J. Cassel. 1976. The effects of a tall tower on nocturnal bird migration—a portable ceilometer study. Auk 93:281–291.

Avery, M. L., P. F. Springer, and N. S. Dailey. 1980. Avian mortality at man-made structures: an annotated bibliography. USDI, Fish and Wildlife Service, FWS/OBS-80/54. Washington, D.C., USA.

Banks, R. C. 1979. Human related mortality of birds in the United States. USDI, Fish and Wildlife Service, Scientific Report Wildlife 215. Washington, D.C., USA.

CALDWELL, L. AND G. WALLACE. 1966. Collections of migrating birds at Michigan television towers. Jack-Pine Warbler 44:117–123.

COCHRAN, W. AND R. GRABER. 1958. Attraction of nocturnal migrants by lights on a television tower. Wilson Bulletin 70:378–380.

DERBY, C., A. DAHL, W. ERICKSON, K. BAY, AND J. HOBAN. 2007. Post-construction monitoring report for avian and bat mortality at the NPPD Ainsworth Wind Farm. Report to the Nebraska Public Power District, Columbus, Nebraska, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.

ERICKSON, W., K. KRONNER, AND B. GRITSKI. 2003. Nine Canyon Wind Power Project avian and bat monitoring report: September 2002–August 2003. Report to the Nine Canyon Technical Advisory Committee and Energy Northwest, Benton County, Washington, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.

ERICKSON, W. P., G. D. JOHNSON, AND D. P. YOUNG. 2005. A summary and comparison of bird mortality from anthropogenic causes with an emphasis on collisions. Pages 1029–1042 *in* USDA, Forest Service, General Technical Report PSW-GTR-191. Albany, California, USA.

ERICKSON, W. P., G. D. JOHNSON, M. D. STRICKLAND, AND K. KRONNER. 2000. Avian and bat mortality associated with the Vansycle Wind Project, Umatilla County, Oregon: 1999 study year. Report to Umatilla County Department of Resource Services and Development, Pendleton, Oregon, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.

ERICKSON, W. P., J. JEFFREY, K. KRONNER, AND K. BAY. 2004. Stateline Wind Project Wildlife Monitoring Final Report: July 2001–December 2003. Technical report peer-reviewed by and submitted to FPL Energy, the Oregon Energy Facility Siting Council, and the Stateline Technical Advisory Committee, Umatilla County, Oregon and Walla Walla County, Washington, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.

FEDERAL AVIATION ADMINISTRATION (FAA). 2000. Obstruction marking and lighting. AC 70/7460-1K. U.S. Department of Transportation, Washington, D.C., USA.

FIEDLER, J. K., T. H. HENRY, R. D. TANKERSLEY, AND C. P. NICHOLSON. 2007. Results of bat and bird mortality monitoring at the expanded Buffalo Mountain Windfarm, 2005. Tennessee Valley Authority, Knoxville, USA.

GAUTHREAUX JR., S. AND C. BELSER. 2006. Effects of artificial night lighting on migrating birds. Pages 67–93 *in* Ecological consequences of artificial night lighting (C. Rich and T. Longcore, Editors). Island Press, Washington, D.C., USA.

GAUTHREAUX JR., S. A., C. G. BELSER, AND D. A. VAN BLARICOM. 2003. Using a network of WSR-88D weather surveillance radars to define patterns of bird migration at large spatial scales. Pages 335–346 *in* Avian migration (P. Berthold, E. Gwinner, and E. Sonnenschein, Editors). Springer-Verlag, Berlin, Germany.

GEHRING, J. L., P. KERLINGER, AND A. M. MANVILLE II. 2009. Communication towers, lights, and birds: successful methods of reducing the frequency of avian collisions. Ecological Applications 19: 505–514.

HOWE, R. W., W. EVANS, AND A. T. WOLF. 2002. Effects of wind turbines on birds and bats in northeastern Wisconsin. Report to Wisconsin Public Service Corporation and Madison Gas and Electric Company, Madison, Wisconsin, USA. University of Wisconsin-Green Bay, USA.

JAIN, A. A. 2005. Bird and bat behavior and mortality at a northern Iowa windfarm. Thesis. Iowa State University, Ames, USA.

JAIN, A., P. KERLINGER, R. CURRY, AND L. SLOBODNIK. 2007. Annual report for the Maple Ridge Wind Power Project: post-construction bird and bat fatality study-2006. Report to PPM Energy and Horizon Energy and Technical Advisory Committee for the Maple Ridge Project Study, McLean, Virginia, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

JAIN, A., P. KERLINGER, R. CURRY, AND L. SLOBODNIK. 2009a. Annual report for the Maple Ridge Wind Power Project: post-construction bird and bat fatality study – 2007. Report to PPM Energy and Horizon Energy and Technical Advisory Committee for the Maple Ridge Project Study, Houston, Texas, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

JAIN, A., P. KERLINGER, R. CURRY, AND L. SLOBODNIK. 2009b. Annual report for the Maple Ridge Wind Power Project: post-construction bird and bat fatality study-2008. Report to PPM Energy and Horizon Energy and Technical Advisory Committee for the Maple Ridge Project Study, Houston, Texas, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

JAIN, A., P. KERLINGER, R. CURRY, L. SLOBODNIK, J. HISTED, AND J. MEACHAM. 2009c. Annual report for the Noble Clinton Windpark LLC: postconstruction bird and bat fatality study–2008. Report to Noble Environmental Power LLC, Bliss, New York, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

JAIN, A., P. KERLINGER, R. CURRY, L. SLOBODNIK, J. QUANT, AND D. PURSELL. 2009d. Annual report for the Noble Bliss Windpark LLC: postconstruction bird and bat fatality study–2008. Report to Noble Environmental Power LLC, Bliss, New York, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

JAIN, A., P. KERLINGER, R. CURRY, L. SLOBODNIK, A. FUERST, AND C. HANSEN. 2009e. Annual report for the Noble Ellenburg Windpark LLC: postconstruction bird and bat fatality study–2008. Report to Noble Environmental Power LLC, Bliss, New York, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

JAMES, R. D. 2004. Bird observations at the Pickering wind turbine. Ontario Birds 21:84–97.

JAMES, R. D. 2008. Erie Shores Wind Farm, Port Burwell, Ontario: fieldwork report for 2006 and 2007, during the first two years of operation. Report to Environment Canada, Ontario Ministry of Natural Resources, Erie Shores Wind Farm LP–McQuarrie North American, and AIM PowerGen Corporation, Ontario, Canada.

JAMES, R. D. AND G. COADY. 2003. Bird monitoring at Toronto's Exhibition Place wind turbine. Ontario Birds 22:79–88.

JOHNSON, G., W. ERICKSON, J. WHITE, AND R. MCKINNEY. 2003. Avian and bat mortality during the first year of operation at the Klondike Phase I Wind Project, Sherman County, Oregon. Draft report to Northwestern Wind Power, Goldendale, Washington, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.

JOHNSON, G. D., W. P. ERICKSON, M. D. STRICKLAND, M. F. SHEPHERD, AND D. A. SHEPHERD. 2000. Avian monitoring studies at the Buffalo Ridge, Minnesota Wind Resource Area: results of a 4-year study. Report to Northern States Power Company, Minneapolis, Minnesota, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.

JOHNSON, G. D., W. P. ERICKSON, M. D. STRICKLAND, M. F. SHEPHERD, D. A. SHEPHERD, AND S. A. SARAPPO. 2002. Collision mortality of local and migrant birds at the large-scale wind power development on Buffalo Ridge, Minnesota. Wildlife Society Bulletin 30:879–887.

KERLINGER, P. 2000. Avian mortality at communications towers: a review of recent literature, research, and methodology. Report to the USDI, Fish and Wildlife Service, Washington, D.C., USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

KERLINGER, P. 2001. Avian mortality study at the Green Mountain Windpower Project, Garrett, Somerset County, Pennsylvania: 2000-2001. Report to National Wind Power, Oakland, California, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

KERLINGER, P. 2002a. An assessment of the impacts of Green Mountain Power Corporation's wind power facility on breeding and migrating birds in Searsburg, Vermont. Report NREL/SR-500-28591 to National Renewable Energy Laboratory, U.S. Department of Energy, Golden, Colorado, USA. Cape May, New Jersey, USA.

KERLINGER, P. 2002b. Avian fatality study at the Madison Wind Power Project, Madison, New York. Report to PG&E Generating, Athens, New York, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

KERLINGER, P. AND R. CURRY. 2000. Impacts of a small wind power facility in Weld County, Colorado, on breeding, migrating, and wintering birds: preliminary results and conclusions. Pages 64–69 *in* Proceedings of the National Avian-Wind Power Planning Meeting III. National Wind Coordinating Committee/RESOLVE, Washington, D.C., USA.

KERLINGER, P. AND F. R. MOORE. 1989. Atmospheric structure and avian migration. Current Ornithology 6:109–142.

KERLINGER, P., R. CURRY, A. HASCH, AND J. GUARNACCIA. 2007. Migratory bird and bat monitoring study at the Crescent Ridge Wind Power Project, Bureau County, Illinois: September 2005–August 2006. Report to Orrick, Herrington, and Sutcliffe LLP, Washington, D.C, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

KERLINGER, P., R. CURRY, L. CULP, A. JAIN, C. WILKERSON, B. FISCHER, AND A. HASCH. 2006. Post-construction avian and bat fatality monitoring study for the High Winds wind power project, Solano County, California: two year report. Report to High Winds LLC and FPL Energy, Livermore, California, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

KERNS, J. AND P. KERLINGER. 2004. A study of bird and bat collision fatalities at the Mountaineer Wind Energy Center, Tucker County, West Virginia: annual report for 2003. Report to FPL Energy and the MWEC Technical Review Committee, Vero Beach, Florida, USA. Curry & Kerlinger LLC, McLean, Virginia, USA.

KOFORD, R., A. JAIN, G. ZENNER, AND A. HANCOCK. 2005. Avian mortality associated with the Top of Iowa Wind Farm. Report to the Iowa Department of Natural Resources, Ames, USA. Iowa State University, Ames, USA.

LARKIN, R. AND B. FRASE. 1988. Circular paths of birds flying near a broadcasting tower in cloud. Journal of Comparative Psychology 102:90–93.

LOWREY JR, G. H. AND R. J. NEWMAN. 1966. A continent-wide view of bird migration on four nights in October. Auk 83:547–586.

NATIONAL RESEARCH COUNCIL. 2007. Environmental impacts of wind-energy projects. NRC, Committee on Environmental Impacts of Wind Energy Projects. The National Academies Press, Washington, D.C., USA.

NEW JERSEY AUDUBON SOCIETY. 2008. Post-construction wildlife monitoring at the Atlantic County Utilities Authority-Jersey Atlantic Wind Power Facility: periodic report covering work conducted between 1 January and 30 September 2008. Report to the New Jersey Board of Public Utilities and New Jersey Clean Energy Program, Newark, New Jersey, USA. New Jersey Audubon Society, Cape May Court House, New Jersey, USA.

NICHOLSON, C. P., R. G. TANKERSLEY JR., J. K. FIEDLER, AND N. S. NICHOLAS. 2005. Assessment and prediction of bird and bat mortality at wind energy facilities in the southeastern United States: final report, 2005. Tennessee Valley Authority, Knoxville, USA.

SCHNELL, G. D., E. A. MOSTELLER, AND J. GRZYBOWSKI. 2007. Post-construction avian/bat risk assessment and fatality study for the Blue Canyon II Wind Power Project, Oklahoma: summary of first-year findings. Report to Horizon Wind Energy, Houston, Texas, USA. Sam Noble Oklahoma Museum of Natural History, University of Oklahoma, Norman, USA

SHIRE, G. G., K. BROWN, AND G. WINEGRAD. 2000. Communication towers: a deadly hazard to birds. American Bird Conservancy, Washington, D.C., USA.

SMALLWOOD, K. S., D. A. BELL, S. A. SNYDER, AND J. E. DIDONATO. 2010. Novel scavenger removal trials increase wind turbine-caused avian fatality estimates. Journal of Wildlife Management 74:1089–1097.

STANTEC CONSULTING. 2008. 2007 spring, summer, and fall post-construction bird and bat mortality study at the

Mars Hill wind farm, Maine. Report to UPC Wind Management LLC, Cumberland, Maine, USA. Stantec Consulting, Topsham, Maine, USA.

STANTEC CONSULTING. 2009. Post-construction monitoring at the Mars Hill wind farm, Maine–year 2, 2008. Report to First Wind Management LLC, Portland, Maine, USA. Stantec Consulting, Topsham, Maine, USA.

TIERNEY, R. 2007. Buffalo Gap I Wind Farm avian mortality study, February 2006–January 2007, final survey report. Report to AES West Inc., Albuquerque, New Mexico, USA. TRC, Albuquerque, New Mexico, USA.

TRAPP, J. L. 1998. Bird kills at towers and other man-made structures: an annotated partial bibliography (1960–1998). USDI, Fish and Wildlife Service, Washington, D.C., USA.

TRC ENVIRONMENTAL CORPORATION. 2008. Post-construction avian and bat fatality monitoring and grassland bird displacement surveys at the Judith Gap Wind Energy Project, Wheatland County, Montana. Report to Judith Gap Energy LLC, Chicago, Illinois, USA. TRC Environmental Corporation, Laramie, Wyoming, USA.

WILCOXON, F. 1945. Individual comparisons by ranking methods. Biometrics 1:80–83.

YOUNG JR., D. P., W. P. ERICKSON, R. E. GOOD, M. D. STRICKLAND, AND G. D. JOHNSON. 2003. Avian and bat mortality associated with the initial phase of the Foote Creek Rim Windpower Project, Carbon County, Wyoming: November 1998–June 2002. Report to Pacificorp Inc., Portland, Oregon, SeaWest Windpower Inc., San Diego, California, and Bureau of Land Management, Rawlins District Office, Rawlins, Wyoming, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.

YOUNG JR., D. P., W. P. ERICKSON, K. BAY, S. NOMANI, AND W. TIDHAR. 2009. Mount Storm Wind Energy Facility, phase 1 post-construction avian and bat monitoring, July–October 2008. Report to NedPower Mount Storm LLC, Houston, Texas, USA. Western EcoSystems Technology Inc., Cheyenne, Wyoming, USA.