Applicant Ex. 33

BEFORE THE OHIO POWER SITING BOARD

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In the Matter of the Application of Icebreaker Windpower Inc., for a Certificate to Construct a Wind-Powered Electric Generation Facility in Cuyahoga County, Ohio.

) Case No: 16-1871-EL-BGN

TESTIMONY OF

Wallace Erickson

Senior Biometrician Western EcoSystems Technology, Inc.

> on behalf of Icebreaker Windpower Inc.

> > September 6, 2018

1	1.	Please state your name.
2		Wallace Erickson.
3		
4	2.	Please state your business address.
5		415 W. 17 th St. Suite 200, Cheyenne, WY 82001.
6		
7	3.	Please summarize your educational background and professional experience.
8		I have a Bachelor of Science degree in Statistics from Winona State University and a
9		Master of Science degree in Statistics from the University of Wyoming. I began working
10		for Western EcoSystems Technology Inc. ("WEST") in 1991 and have been with WEST
11		for my entire career with the exception of a one-year period that I took off and did some
12		consulting on my own. I have worked on hundreds of projects and studies with funding
13		from a variety of sources including industry, state and federal wildlife and other agencies,
14		and non-governmental organizations. For example, I worked on a project contracted
15		through the State of Alaska to design studies and collect data to understand the impacts of
16		the Exxon Valdez Oil Spill on intertidal organisms, as well as seabirds. I have worked on
17		several projects with the United States ("U.S.") Fish and Wildlife ("USFWS") and U.S.
18		Geological Survey ("USGS") on bird population size estimation, moose population
19		estimation and wildlife habitat selection. I am currently working with the USGS on a
20		study of the impacts of solar energy on birds. I have over 30 peer-reviewed publications
21		including several related to the impacts of wind energy on wildlife. My resume is
22		attached as Attachment WE-1.
23		
24	4.	What is your current position with WEST?
25		I am a Senior Biometrician.
26		
27	5.	On whose behalf are you offering testimony in this case?
28		Icebreaker Windpower, Inc. ("Icebreaker" or "Applicant").
29		
30		
31		

1	6.	Please describe the history of your involvement with the project.
2		I have been a Senior Technical Advisor for the project. I helped co-author the Risks to
3		Birds and Bats dated November 29, 2016 ("2016 Risk Assessment") that is attached to
4		Icebreaker's February 1, 2017 application ("Application") in this case as part of Exhibit J
5		with Dr. Caleb Gordon. I have reviewed and provided input on the Aerial Waterfowl
6		Survey ("Aerial Waterfowl Survey"). ¹
7		
8	7.	Please describe the studies that you and your firm undertook on behalf of the
9		Applicant.
10		Our firm completed the Aerial Waterfowl Survey for waterfowl and waterbirds for the
11		project that was required by the Aerial Study Plan, ² the Assessment of Nocturnal Bird
12		Migration Activity from Weather Radar dated January 23, 2017 ("2017 NEXRAD
13		Analysis") that is attached to Icebreaker's February 1, 2017 application ("Application")
14		in this case as part of Exhibit J, a bat acoustic survey for bats ("Bat Acoustic Survey
15		Plan"), and the 2016 Risk Assessment for birds and bats.
16		
17		I worked closely with Dr. Caleb Gordon in development of the 2016 Risk Assessment for
18		the project. This risk assessment used a mixture of site-specific data, other regional data,
19		and knowledge about impacts to birds and bats from over two decades of monitoring and
20		research at wind projects to assess risk of the Icebreaker project. Development of risk
21		assessments for wind energy is greatly aided by a very large database of studies of
22		impacts at existing wind projects found in a variety of environments and habitats and
23		perceived risk levels for birds and bats.
24		
25	8.	What was your role in the studies conducted for the Application?
26		I was a co-author on the 2016 Risk Assessment, as well as the Aerial Waterfowl Survey,
27		providing senior input and review for both of these documents.

¹ The Aerial Waterfowl Survey was filed by Icebreaker on March 22, 2018, as part of Attachment 4 to the Fourth Supplement to the Application.

² The Aerial Study Plan was filed by Icebreaker on August 18, 2017, as an attachment to the Third Supplement to the Application.

1	9. Please state the purpose of your testimony.	
2	My testimony, together with the other Icebreaker witnesses testifying this this case, wi	i11
3	confirm that the Joint Stipulation and Recommendation ("Stipulation"), which was file	ed
4	in the docket on September 4, 2018, and is being offered in this proceeding as Joint	
5	Exhibit 1, supports a finding by the Board that the Stipulation represents the minimum	1
6	adverse environmental impact, considering the state of available technology, and is in	the
7	public interest.	
8		
9	10. Have you reviewed the Staff Report of Investigation that was filed in this docket	t on
10	July 3, 2018 ("Staff Report")?	
11	Yes. I have reviewed the parts of the Staff Report that address ecological impacts on b	ird
12	and bats from the project.	
13		
14	11. Why do you believe that collision mortality statistics from onshore wind farms	are
15	relevant and can be used to predict mortality at offshore wind farms?	
16	Nocturnal migrating songbirds ("songbirds and similar birds, a category that includes	the
17	vast majority of bird species that occur within the region; hereafter referred to as	
18	"nocturnal migrants") migrate in large numbers throughout the U.S. and are the most	
19	common bird group with over 400 species and North American population estimates a	re
20	in the billions. The same species that will migrate over and through the Icebreaker	
21	project area migrate over and through existing land-based wind projects. There have	
22	been hundreds of monitoring and research studies conducted in the U.S. and Canada.	
23	These studies have allowed us to develop a quantitative range of expected mortality for	or
24	most bird groups, and especially nocturnal migrant songbirds. The hundreds of studie	s in
25	a diversity of locations and perceived risks for birds have allowed us to understand risk	k
26	for various bird groups and species.	
27		
28	In addition, several factors likely contribute to onshore fatality rates being conservativ	e
29	(overestimating fatality rates for the Icebreaker project) which we acknowledged in the	e
30	2016 Risk Assessment. Onshore small passerine fatality rates include mortality of	
31	resident and wintering passerines, which should not be at risk at the Icebreaker project	[

due to lack of habitat for those species 8 to 10 miles offshore. To illustrate, the following figure from my publication Erickson et al. (2014) (See Attachment WE-2) shows the distribution of the timing of carcass finds by month.³



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Figure 2. Monthly timing of small-passerine fatalities caused by collision with turbines and documented in 79 studies. The date for collision was provided in 79 studies on mortality of birds at wind energy facilities. A total of 2,285 fatalities for species of small passerines (less than 30.5 cm in size) were included and are sorted by month.

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5 6

While this graph shows peaks during the typical migration months (March, April, May,
September, October) approximately 25% of the finds occurred in the months with little
nocturnal bird migration (songbirds and similar birds, a category that includes the vast
majority of bird species that occur within the region; hereafter referred to as "nocturnal
migrants"). That may be a low estimate since many of the studies had more intensive
searches in the migration months resulting in higher detection probabilities in those
months. The regional fatality rates we used as a basis for predicting risk at Ice Breaker

³ This is Figure 2 in Erickson et al. (2014), Attachment WE-2.

1	included bird fatalities of nocturnal migrant passerine species that would not occur at the
2	Icebreaker project in any measurable numbers during non-migration seasons
3	
4	In addition, the Diehl study (Diehl et al. 2003, Attachment WE-3) and the 2017
5	NEXRAD Analysis indicate higher migration intensity over land than over water. In
6	addition, a recent study Archibald 2017 (See Attachment WE-4) investigated mean flight
7	heights of birds from the KCLE weather radar and found slightly higher flight altitudes of
8	migrants over water than land at both dawn and at peak migration (Attachment WE-4,
9	Table 1, p. 196).
10	
11	The weight of evidence from all of this information suggests that fatality rates from onshore
12	projects are relevant for assessing bird risk for the Icebreaker project, and may be
13	conservative (overestimate). In addition, overall impact, even cumulatively across wind
14	projects within a region and nationally appears low for nocturnal migrants (Attachment
15	WE-2). The level of wind turbine mortality when compared to each species population
16	sizes is extremely low even when considering all wind projects that have been built.
17	
18	12. What makes you think nocturnal migrant birds behave the same over land as over
19	water?
20	Empirical data from two studies have estimated lower nighttime migration intensity over
21	water than land in the Great Lakes Region (Attachment WE-3, 2017 NEXRAD
22	Analysis). In addition, a recent study (Attachment WE-4) analyzed and presented data
23	from the KCLE weather radar and this information suggested higher mean altitudes of
24	birds over water than land in Lake Erie.
25	
26	13. Based on your experience, what is the correlation between radar target passage rates
27	collected pre-construction and bird mortality rates at wind projects?
28	Studies that utilize pre-construction radar to provide indices to the number of biological
29	targets migrating through a wind project have not demonstrated significant positive
30	correlations with post-construction fatality (e.g., Stantec 2017, Attachment WE-5; Tidhar
31	et al. 2012, Attachment WE-6). While I would expect some correlation between the actual

1	number of birds passing through the rotor swept area and actual fatality rates if both are
2	collected after the project is built, pre-construction only provides indices to migration
3	activity and limitations in radar methodology and variation in methods have limited pre-
4	construction radar for predicting impacts. Other factors to consider are that most of the
5	nocturnal bird migration occurs at altitudes above the turbine heights, and the actual
6	probability of collision of birds that are passing through a wind project is influenced by
7	other factors such as the large amount of "safe" space between the turbines, underneath
8	the rotor swept area, and even through the swept area as well as a bird's ability to avoid
9	structures.
10	
11	14. Have you reviewed the 2012 Lake Erie Report prepared by the USFWS ("2012
12	USFWS Report").
13	Yes.
14	
15	15. Was the 2012 USFWS Report peer reviewed?
16	The report does not list any outside peer reviewers. I cannot confirm whether this means
17	no peer review occurred, but it is typical to list peer reviewers.
18	
19	16. Do you have any concerns about 2012 USFWS Report?
20	Yes
21	
22	17. What methods were used to collect and analyze the vertical radar information in the
23	2012 USFWS Report?
24	
25	The USFWS utilized a Merlin Avian Radar System. The methods used in the 2012
26	USFWS Report (Attachment WE-7) appear similar to the methods utilized by other
27	researchers who have used a Merlin Avian Radar System with one primary difference.
28	The primary difference is that the USFWS applied a correction factor that assumed the
29	volume the radar theoretically sampled at different altitude bands was proportional to the
30	probability of detecting biological targets at those bands.

The correction was largest for targets flying low to the ground. The target count in each
altitude band was adjusted up by the theoretic estimate of volume sampled (see Figure 6,
page 10, Attachment WE-7 below for illustration of the theoretical volume sampled).
The adjustments for low flying targets is quite large, with density multipliers of
approximately 4 to 6, based on the tables in Appendix 4 of Attachment WE-7 (p 49 -56)



Figure 6. Graphical representation of the structural volume of the vertical scanning radar within the standard front. In this graphic, the radar unit is located at the origin and the radar beam extends to 500 m on either side of the radar unit (x-axis) up to a maximum height of 2800 m (z-axis). The y-axis represents the spread of the radar beam as it extends away from the origin. The orange semi-transparent points represent the volume contained by the radar beam. Dark gray points represent the volume within the box but not included in the radar beam.

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The USFWS did not attempt to correct for other factors that may influence probability of detection such as distance from radar, and side lobes, which would enhance volume sampled and decrease corrections for low flying targets. The authors acknowledged this issue on page 37 (Attachment WE-7) "Furthermore, beam propagation was not consistent over time because it was affected by side lobes, target size and distance, and atmospheric conditions." They go on to say: "We were not able to correct for the loss of detection with distance from the radar (Schmaljohann et al. 2008), and our vertical scanning radars lost detection at a range of approximately 1,400 – 2,000 m, which was where the radar

transitioned from the short to medium pulse. For these reasons, our estimates likely under-represented the density as altitude increases."

4 I have attended training on the use of the Merlin systems for target data collection and 5 have participated in other studies that have used Merlin radar systems so am familiar with 6 the equipment and output from their systems. One challenge with automatic detection 7 systems is in the ability of the system to accurately identify and count the number of 8 tracks. It has been my experience that automated detection systems tend to result in a lot 9 higher target counts than non-automated systems. I have seen results of studies that 10 implement Merlin equipment in a region have much higher target counts than non-11 automated systems. One source of potential bias is for automated systems tendency to 12 split tracks of single objects into more than one track. This bias becomes larger when 13 there are an increasing number of simultaneous echoes. Thus, an overestimation of the 14 number of tracks can occur.

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16 18. What has been your experience in how vertical altitude data from avian radar is 17 typically analyzed and how is that different than the approach used in the 2012 18 USFWS Report to correct the data for probability of detection?

Avian radar studies I have participated in or reviewed, with the exception of the USFWS
 Great Lakes Studies, have not adjusted vertical passage rates for volume sampled. These
 studies are based on the assumption that detection is similar at different altitude bands.

23 There are many factors that could influence detection and these factors may interact and 24 counter each other as altitude changes. To the best of my knowledge, the approach used 25 by the USFWS in their Great Lakes radar studies for adjusting the data for potential 26 volume differences has not been used by other researchers. I have participated in several 27 avian radar studies using a variety of radar equipment, including Merlin System, and 28 none of these studies including a volume correction in the vertical mode. Several of 29 those studies were conducted by the manufacturer of the Merlin System and they also do 30 not employ a volume correction.

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I believe this correction for volume sampled is not accurate and results in an overestimate of biological target rates at lower altitudes and overestimates the percentage of target counts at lower altitudes for three primary reasons: 1) targets (bird, bats, and insects) are moving through the beam (not stationary targets) and, therefore, their probability of detection by the radar would not be proportional to the volume of the theoretic area sampled; 2) the actual sampled area by the radar is likely larger near the radar (outside theoretic beam) due to side lobes (Attachment WE-8), increasing the actual amount of airspace sampled near the radar, and 3) probability of detection of targets, similar to human visual surveys, likely decreases with distance from the radar, which would have the opposite effect of any correction for low flying targets.

13

14 20. What degree of confidence do you have in the 2016 Risk Assessment?

19. Do you believe the volume correction is biased and if so why?

15 I am very confident in our 2016 Risk Assessment. With such a small project, variation in 16 total mortality estimates is going to be small. In addition, nocturnal migrant mortality 17 estimates on a per megawatt ("MW") basis have shown relatively low variability across 18 projects in a variety of habitats and locations and migration passage rates. Projects in 19 perceived higher migration areas like the Texas Gulf Coast have not shown high mortality. 20 Projects close to the Great Lakes have been in the range of mortality levels for projects 21 farther from the Great Lakes. In addition, the fatality rates we used for predicting impacts 22 at the Icebreaker project are likely conservative because they include resident passerine 23 species and wintering passerines, which would not occur at the Icebreaker project.

24

25 21. How many risk assessments have you performed for wind projects?

26 27 I have worked on well over 100 wind projects in various capacities, including designing pre-construction studies, assessing risk, and monitoring impacts post construction.

- 28
- 29 30

22. Do you believe the 2016 Risk Assessment is adequate for addressing risk to birds and bats for the Icebreaker project?

31 Yes.

1	
2	23. Do you agree with the assumption that higher numbers of birds flying through the
3	rotor swept zone would result in higher mortality? Why or why not?
4	It depends on species or groups of birds of interest and many other factors such as
5	collision avoidance, weather, and turbine and project characteristics. If comparing two
6	projects with the same configuration of turbines of exactly same height and size, and more
7	birds of the same type fly through the moving rotor of one compared to the other, I would
8	expect on average, that the project with more birds would have more mortality. However,
9	it is impossible to get an exact number of birds that will fly through the rotors since risk
10	assessments are conducted prior to the project getting built and data collect methods for
11	nighttime surveys generally provide indices of overall activity during the time frame
12	studied.
13	
14	24. What is the value of pre-construction marine radar survey data at wind farm sites?
15	
16	Marine radar if conducted both pre- and post- construction can add to an understanding of
17	factors such as displacement of birds and quantification of avoidance rates. Those
18	specialty studies are referred to as Tier 5 studies in the USFWS land-based wind energy
19	guidelines and are conducted as research to further our understanding of interactions of
20	birds and wind energy.
21	
22	Pre-construction marine radar surveys that have been conducted have not shown a
23	correlation with post-construction fatality rates as previously mentioned. We now have
24	hundreds of post-construction monitoring studies conducted at projects throughout the
25	U.S. that are the best information to predict mortality at new projects. Marine radar
26	studies provide an index to actual individual bird/bat passage and have many limitations
27	and challenges.
28	
29	Past marine radar studies as well as NEXRAD radar have provided information that has
30	helped us gain a better understanding of patterns of nocturnal bird migration and those
31	studies have confirmed that most of the migrating songbirds fly at high altitudes, above

the typical turbine heights. Those studies have demonstrated that nocturnal migration
occurs over a very broad front and that weather conditions and wind conditions can
influence timing and altitude of migration. In my opinion, the large number of fatality
studies at existing wind projects, coupled with what we know about nocturnal migration
from many sources of information, as well as an understanding of the negligible impacts
wind energy has on their species populations (Attachment WE-2) has lessened the overall
concerns regarding nocturnal migrant mortality at wind energy projects.

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25. The USFWS radar studies of migration along the shore show higher numbers of birds in the rotor swept zone than previously assumed. Does this concern you?

12 This does not concern me because I do not believe the data from USFWS show higher 13 numbers of birds in the rotor swept area than previously assumed. Based on the 14 information provided in Appendix 4, page 52, of Attachment WE-7, the uncorrected 15 percentage of targets detected below 150 m at night was 10.8%. That value is similar to 16 estimates in other studies and indicates, as other studies have, that a very high percentage 17 of birds are flying above the rotor heights of turbines. As an example, colleagues of mine 18 at WEST reviewed 14 avian radar studies in New York and estimated an average of 14% 19 of the targets were below rotor swept height based on an average across those studies 20 (Attachment WE-5).

21

22 I also reviewed all of the final USFWS Great Lakes Radar studies

23 (https://www.fws.gov/radar/factsandfiles/index.html) and put together the following 24 summary that includes target passage rates, mean altitude and % of targets below the 150 25 meters (Table 1). These numbers do not include the unique volume correction applied to 26 the USFWS data since that correction was the same for each study and other studies do 27 not apply such a correction. The results, when looked at as a whole, are consistent with 28 our understanding of nighttime bird migration. Nocturnal bird migration occurs 29 throughout the Great Lakes Region and beyond, and most of the birds are flying above the 30 rotor heights.

31

Site	Great Lake	Season	sampling vear	pub vear	State	targets /km/hr	mean altitude (m)	% targets below 150 night
Erie County, Ohio	Lake Erie	Spring	2012	2016	ОН	640	587	10.8
Erie County, PA	Lake Erie	Spring	2012	2016	PA	513	447	14.3
Jefferson County, NY	Lake Ontario	Spring	2013	2016	NY	555	816	3.5
Wayne County, NY	Lake Ontario	Spring	2013	2016	NY	732	946	5.1
Niagara County, NY	Lake Ontario	Spring	2013	2016	NY	582	992	2.3
Genesse County, NY	Lake Ontario	Spring	2013	2016	NY	555	774	8.9
Average								
Oceana County, MI	Lake Huron	Fall	2011	2015	MI	442	500	11.8
Huron County, MI	Lake Huron	Fall	2011	2015	MI	340	380	25.4
Jefferson County, NY	Lake Ontario	Fall	2016	2018	NY	427	779	1.8
Wayne County, NY	Lake Ontario	Fall	2016	2018	NY	338	521	11.5
Niagara County, NY	Lake Ontario	Fall	2016	2018	NY	413	675	8.7
Lake County, MN	Lake Superior	Fall	2014	2017	MN	398	612	14.3
Bayfield County, WI	Lake Superior	Fall	2014	2017	WI	450	664	9.6
Keweenaw County, MI	Lake Superior	Fall	2014	2017	MI	266	605	8
Delta County, MI (West	Lake							
Delta)	Michigan	Fall	2012	2017	MI	407	580	10.8
Delta County, MI	Lake							
(Garden Peninsula)	Michigan	Fall	2012	2017	MI	392	526	11.1
losco County, MI	Lake Huron	Fall	2012	2017	MI	664	522	8.5
Huron County, MI	Lake Huron	Fall	2012	2017	MI	344	505	6.4
Average						470	635	9.6

Table 1. Avian radar metrics from 6 USFWS reports posted online.

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26. Has there been a study that correlated radar passage with bird and bat fatality data?

A few studies have investigated whether radar passage rates collected pre-construction correlated with post-construction fatality rates and those studies have not demonstrated a significant correlation (Attachments WE-5 and WE-6).

- 3 4 5 6 7 8 9
- 10

1	27. In your experience, is it typical to see most nocturnal migrants in the \sim 50-150 m
2	above ground level ("agl"). Typical estimates of the percentage of targets at or below
3	turbine heights are 10-20% from radar studies, so a majority of the targets (80 to 90%) are
4	above the heights of the turbines, including the USFWS Great Lakes Radar Studies
5	(https://www.fws.gov/radar/factsandfiles/index.html). The USFWS uncorrected data on
6	average show 90% of the targets above turbine heights and their correction they use for
7	volume is not used by others and has not been validated.
8	
9	28. Are your opinions and conclusions in your testimony made with a reasonable degree
10	of scientific certainty?
11	Yes.
12	
13	29. Does this conclude your testimony?
14	Yes.
15	

CERTIFICATE OF SERVICE

The Ohio Power Siting Board's e-filing system will electronically serve notice of the filing of this document on the parties referenced in the service list of the docket card who have electronically subscribed to this case. In addition, the undersigned certifies that a copy of the foregoing document is also being served upon the persons listed below via electronic mail this 6th day of September, 2018.

<u>/s/ Christine M.T. Pirik</u> Christine M.T. Pirik (0029759)

Counsel:

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Icebreaker Windpower, Inc. Case No. 16-1871-EL-BGN Testimony September 6, 2018

Attachment WPE-1 CV/Resume

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Attorneys for Icebreaker Windpower Inc.



EDUCATION

M.S. University of Wyoming Laramie, Wyoming 1992 Statistics

B.S.

Winona State University Winona, Minnesota 1989 Statistics and Mathematics

SCIENTIFIC ORGANIZATION MEMBERSHIPS

The Wildlife Society

National Audubon

Wallace P. Erickson, Senior Biometrician

PROFESSIONAL EXPERIENCE

2018-Present	Senior Biometrician, Western EcoSystems Technology, Inc., Cheyenne,
	Wyoming
2017-2018	President and Senior Scientist, Erickson Environmental Consulting, Inc.
2016-2017	Chief Executive Officer, Western EcoSystems Technology, Inc., Cheyenne,
	Wyoming
2012-2015	Chief Operating Officer/Senior Biometrician, Western EcoSystems
	Technology, Inc., Cheyenne, Wyoming
1991-2012	Senior Biometrician/Senior Manager, Western EcoSystems Technology, Inc.
	Cheyenne, Wyoming
1990-1991	Research Assistant, University of Wyoming, Laramie, Wyoming
1990-1991	Field Scientist, University of Alaska, Fairbanks, Alaska
1989	Research Assistant, Alumni Office, Winona State University, Winona,
	Minnesota

SPECIALTY AREAS

Wallace P. Erickson has been a statistician with WEST since 1991. He currently serves as a Senior Biometrician/Scientist to deliver on the company's long term visions and goals to provide excellent environmental consulting services to clients while maintaining the highest scientific standards.

Mr. Erickson is a statistician with over 28 years of experience in applying statistical solutions to a wide variety of natural resource problems. Has worked for state and federal wildlife agencies and industry throughout the U.S. Authored/co-authored over 50 professional publications on statistical applications in wildlife and other related fields. He has past served as WEST's COO and CEO.

Statistical Design and Analysis of Monitoring and Risk/Impact Assessment Studies: Numerous projects in designing and analyzing data collected to estimate or monitor the impacts of potential environmental perturbations or general monitoring programs. Was a principal Biometrician responsible for design and analysis of studies of impacts of the Exxon Valdez oil spill on marine organisms for the state of Alaska. Has had similar responsibility working for the States in several other NRDA studies, mainly involving mining impacts. Has participated in studies designed to assess impacts of energy development, including wind and solar energy development on birds, bats and other wildlife in over 35 states and has developed collision risk models and approaches to take estimation a variety of taxa and species. Has worked with numerous National Wildlife Refuges in Alaska and other states designing monitoring programs for wildlife and plant species. He was recently part of a team, including the USGS, and Bard University in a California Energy Commission Grant to evaluate the potential attraction of PV Solar facilities on birds.

Resource/Habitat Selection: Numerous projects in the study of resource selection by animals. Has participated in teaching workshops on resource selection. Experience includes the study of resource selection by moose in Alaska, study the effect of salvage logging on passerines in Oregon, study of brown bear habitat selection on the Kenai Peninsula in relation to development, study of brand habitat selection in wintering areas in Mexico, the study of habitat selection by bighorn sheep in Idaho and the study of resource selection by golden eagles in relation to wind projects. Co-author of book entitled "Resource Selection by Animals."

Wildlife Population Estimation: Knowledgeable in many techniques for estimation of abundance, demographic parameters, survival and mortality of wildlife. Participated in studies using mark/recapture techniques, line transect techniques, quadrat/plot methods, point counts surveys, etc. Designed studies to estimate moose populations in Alaska using line transect sampling. Participated in studies to estimate polar bear numbers, spotted owls and brant populations using capture/recapture techniques; neotropical migrants using point count/variable circular plot methods; walrus using adaptive sampling techniques. Developed numerous techniques for estimating mortality.

Conducting Statistical Workshops for Biologists: Has developed material for, and conducted statistical workshops for biologists on the topics of general statistical methods, biological sampling and animal abundance estimation, resource selection, computer intensive statistics and spatial statistics.



SELECTED PROFESSIONAL PUBLICATIONS

- Bay, K., K. Nasman, **W. Erickson**, K. Taylor and K. Kosciuch. 2016. Predicting eagle fatalities at wind facilities. JWM:80(6).
- D.H. Johnson · S.R. Loss · K.S. Smallwood · and **W.P. Erickson**. 2016. Avian fatalities at wind energy facilities in North America: A comparison of recent approaches. Human-Wildlife Interactions 10(1):7-18
- **Erickson, W.P.**, K. Bay, M. Wolfe, D. Johnson, and J. Gehring. 2014. A Comprehensive Analysis of Small Passerine Fatality Due to Collisions at Wind Energy Facilities with Comparisons to Fatalities from Communications Towers and Other Sources. PLOS ONE. September 2014.
- Huso, Manuela, M.P., W.P. Erickson. 2013. A Comment on "Novel Scavenger Removal Trials Increase Wind Turbine-caused Avian Fatality Estimates". Journal of Wildlife Management; 77(2):213-215.
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Attachment WPE-2

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A Comprehensive Analysis of Small-Passerine Fatalities from Collision with Turbines at Wind Energy Facilities



Attachment WPE-2

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Abstract

Small passerines, sometimes referred to as perching birds or songbirds, are the most abundant bird group in the United States (US) and Canada, and the most common among bird fatalities caused by collision with turbines at wind energy facilities. We used data compiled from 116 studies conducted in the US and Canada to estimate the annual rate of small-bird fatalities. It was necessary for us to calculate estimates of small-bird fatality rates from reported all-bird rates for 30% of studies. The remaining 70% of studies provided data on small-bird fatalities. We then adjusted estimates to account for detection bias and loss of carcasses from scavenging. These studies represented about 15% of current operating capacity (megawatts [MW]) for all wind energy facilities in the US and Canada and provided information on 4,975 bird fatalities, of which we estimated 62.5% were small passerines comprising 156 species. For all wind energy facilities currently in operation, we estimated that about 134,000 to 230,000 small-passerine fatalities from collision with wind turbines occur annually, or 2.10 to 3.35 small birds/MW of installed capacity. When adjusted for species composition, this indicates that about 368,000 fatalities for all bird species are caused annually by collisions with wind turbines. Other human-related sources of bird deaths, (e.g., communication towers, buildings [including windows]), and domestic cats) have been estimated to kill millions to billions of birds each year. Compared to continent-wide population estimates, the cumulative mortality rate per year by species was highest for black-throated blue warbler and tree swallow; 0.043% of the entire population of each species was estimated to annually suffer mortality from collisions with turbines. For the eighteen species with the next highest values, this estimate ranged from 0.008% to 0.038%, much lower than rates attributed to collisions with communication towers (1.2% to 9.0% for top twenty species).

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Introduction

Wind energy production in the United States (US) and Canada has increased greatly in recent years. More so than for any other industry, monitoring the effects of wind turbines on wildlife has been an integral part of this development. For example, the US Fish and Wildlife Service (USFWS) provided guidelines to wind energy developers and identified the following species of concern that could be affected by development: "migratory birds; bats; bald and golden eagles and other birds of prey; prairie and sage grouse; and listed, proposed, or candidate endangered and threatened species" [1]. Research is on-going regarding the effect of wind turbines on bats, raptors, and grouse (e.g., [2–8]). In addition, several efforts have been made to broadly quantify the effects on birds [9–13], and statistical methods associated with these efforts have evolved.

In this paper we use new methods to quantify effects for birds known as passerines (sometimes referred to as songbirds or perching birds). Many passerine species are migratory and protected by the Migratory Bird Treaty Act (MBTA) [1]. Passerines are the most common type of bird observed both during surveys prior to construction and as fatalities resulting from collisions with turbines after construction [14]. The populationlevel effect for most small-passerine species may be smaller compared to other bird types, in part because they are shorterlived and typically reproduce at a higher rate than other taxa, such as raptors [15], [16]. However, we are not aware of any existing comprehensive analyses specifically addressing the interactions of passerine species with wind turbines. This analysis will provide federal and state regulatory agency personnel, the wind industry, and other stakeholders with a better understanding of the overall rate of passerine fatalities from collisions with wind turbines and identify research and monitoring needs.

Our objectives for this evaluation were to 1) identify monitoring studies from wind energy facilities in the US and Canada that contained adequate information for evaluation of small-bird fatality rates; 2) derive estimates for rates of annual mortality for small birds in studies that did not include small-bird mortality rates but rather reported mortality rates for all birds combined; 3) adjust all small-bird rates for bias and derive biome-level and continentwide rates; 4) determine the seasonal timing of fatalities for small



Figure 1. Locations of studies included for analysis of small-bird fatalities at wind energy facilities. The locations of wind energy facilities associated with 116 studies that were appropriate for inclusion in an analysis of fatalities of small passerines due to collisions with wind turbines. See details of studies in Appendix S1. Biomes adapted from Rich et al. [19] [58] [59] [60]. doi:10.1371/journal.pone.0107491.g001

passerines; and 5) estimate the population-level effect for species of small passerines in the US and Canada.

Methods

"Fatality" refers to birds colliding with turbines unless otherwise indicated. While the term fatality is used throughout the paper, cause of death of carcass finds is typically not identified easily, especially for small birds. We defined small passerines as bird species belonging to the taxonomic order Passeriformes [17] but excluded birds that are 30.5 cm or greater in length according to the Sibley Guide to Birds [18]. This was done to decrease variability associated with bird size. Excluded types are larger species in the Corvidae family (crows, etc.). Because some monitoring data did not distinguish species of passerines from other species of small birds, we use the term "small bird" to define all bird species that belong in the same above-defined size class. We estimated rates of fatality for small birds, and although some fatalities were small but not passerines, most of the fatalities were passerines.

Studies of Bird Fatality at Wind Energy Facilities

We used studies from the United States and Canada that were conducted after wind energy facilities were constructed; they report results of surveys conducted to monitor the number of birds killed by striking turbines and the resulting estimated annual fatalities rates. Some studies were conducted at wind energy facilities that were built in phases rather than being built all at once. Most studies also included results from experimental trials (hereafter bias trials) that assessed searcher efficiency and the influence of scavenger activities on detection of carcasses. Bias trials measured how effective observers were at finding dead birds on the ground and how long it would take for scavengers to remove the bird carcasses, which could occur before an observer had the opportunity to find it.

Data from 116 studies at more than 70 wind energy facilities were appropriate for analysis (see "Selection Process, Assumptions and Potential Biases" section below for details on how studies were chosen for inclusion). We identified, described, and mapped each study and its location with ArcGIS software; we further categorized each study according to regions called avifaunal biomes which are broad areas of ecologically similar lands (Figure 1) [19]. Biomes are made up of bird conservation areas (BCRs), defined as "ecologically distinct regions in North America with similar bird communities, habitats, and resource management issues." [20]. Two related studies on bird fatalities due to communication towers in the eastern US used groupings of BCRs as an organizing unit [21], [22]. We organized our data by biomes to reach a better sample size, as the study locations were distributed across the United States and southern Canada and our focus was continent-wide. We gathered facility-specific information including number of turbines, turbine model, turbine tower height and blade length, nameplate megawatt (MW) capacity, and vegetation cover (Appendix S1). We obtained information about study methodology including duration, the interval between searches for carcasses, plot size, number and type of carcasses used in bias trials, and the type of estimator used to correct for bias. Study results included species composition and counts of fatalities, searcher efficiency, carcass removal rates, and other information regarding carcasses (e.g., date found, state of carcass, nearest turbine, evidence of scavenging, etc.). Although more than one study was included for some locations, each study represents independent searches and trials. For our calculations we used the rate of bird fatalities/MW/year provided in each report based on bird fatalities found during standardized searches. For our analysis of timing and taxonomic composition of bird fatalities we included bird fatalities found within the standardized search plots both during standardized searches and incidentally.

Estimator Types

Scientists use mathematical equations referred to as estimators to adjust rates of fatality for detection and scavenging biases because not all birds killed by colliding with wind turbines can be detected during surveys. Most studies of turbine-related fatalities include standardized carcass searches that are conducted at regular intervals along transects at a subset of turbines. Searcher efficiency measures the proportion of carcasses present that are found by observers; searcher efficiency is usually is less than 1, because observers are typically unable to discover all carcasses. Carcass removal rates quantify the rate at which carcasses are not detectable because of scavenging (e.g., an animal picks up the dead bird and carries it off), or cannot be detected because of weathering, decomposition, or other means (e.g., plowing in a field). Thus, the basic formula for estimators of fatality rates is equal to the observed mean number of carcasses found per turbine, divided by the estimated average probability that a carcass is both available to be found during a search (i.e., one minus the carcass removal rate) and is in fact found (i.e., searcher efficiency).

To date, the four most prevalent estimators used to calculate fatality-rate estimates are the Shoenfeld [23], Jain [24], Huso [25], and Naïve estimators [25], [26]. Seventy-four of our chosen studies reported estimates calculated using the Shoenfeld estimator, 22 studies used the Jain estimator, 10 used the Naïve estimator, nine used the Huso estimator, and one used the unique estimator developed by Environment Canada (Appendix S2). The Naïve estimator in Huso [25] was originally used in studies with long search intervals where bias was relatively small, but was later inappropriately applied to studies using methods that violated the assumptions of the method [14]. The Naïve estimator typically is not used in more-recent monitoring studies. The Jain estimator accounts for removal and searcher efficiency bias by dividing the observed-fatality rate by the product of the proportion of trial carcasses not removed after half the search interval, and the proportion of carcasses found by searchers. In contrast, both Huso and Shoenfeld estimators calculate the probability of availability and detection by use of equations involving the average removal time in days, based on an exponential distribution of carcass decay, the searcher efficiency proportion, and the average search interval.

The Shoenfeld and Huso estimators generally produce similar results when search intervals are long and carcass persistence times are short [25]. However, Shoenfeld and Huso estimates may be quite different when search intervals are short and carcass persistent times are long. In general, the Shoenfeld estimator tends to be biased low with respect to the true fatality rate and the Huso estimator tends to be biased high [9]. Due to the exponential component in each formula, both estimators are sensitive to changes in average removal time. The Huso estimator may also overestimate fatality rates unless methods for obtaining searcherefficiency rates allow for multiple opportunities to find a carcass. However, most studies conducted to date have used a single search for searcher efficiency, which can inflate estimates calculated using Huso's method. Because the Shoenfeld estimator assumes equal probability of detection for each search, multiple searches for searcher efficiency trials are not needed.

In a simulation study that compared accuracy of the Jain, Huso, and Shoenfeld estimators, results indicated the Jain estimator slightly underestimated rates of fatality, whereas the Huso estimator tended to overestimate rates but to a lesser extent when carcass removal was rapid and/or the efficiency of searchers declined substantially over time [27]. The Shoenfeld method underestimated fatality rates, especially with rapidly declining searcher efficiency over time, which is logical because constant searcher efficiency over time is one of its assumptions. For this analysis, we assumed that the Naïve estimator is about 20% worse than the Shoenfeld estimator, i.e., it underestimates or overestimates fatality rates even more than Shoenfeld.

Selection Process, Assumptions and Potential Biases

We assumed that the results of studies available to us were representative of unsampled or unreported sites and the studies included in our analysis were standardized to the extent possible. We did not include some studies because they 1) lacked the capacity to be standardized, 2) used older methods, 3) used inappropriately long search intervals, or 4) were conducted at older-generation wind energy facilities that are not representative of current facilities. The data we used were selected from reports representing over 100,000 surveys at turbines. While only two Canadian facilities are included here, Bird Studies Canada maintains a Wind Energy Bird and Bat Monitoring database of fatality studies, of which summary data are available. We excluded reports for older generation turbines because they are not representative of current turbine design and the search interval for these studies tended to be longer (e.g., 30 days), decreasing the likelihood that a small bird would be detectable. Older generation turbines are included in the total MW of current generating capacity used to calculate our estimate of small-bird fatality rates for all biomes and the US and Canada combined, making these estimates more conservative. In addition, many of the turbines in the older facilities are being repowered with newer generation turbines.

Several biases might exist in our analyses. We assumed that all dead birds were observed on standardized search plots and deaths were caused by collision with turbines and not caused by other sources (i.e., background mortality). Additionally, scavenging levels may vary within season and from one season to the next, making it more difficult to measure true scavenging effects. Species typically used in searcher efficiency and carcass removal trials (e.g., house sparrows [*Passer domesticus*] and *Coturnix* species of quail) may not be representative of fatalities found (e.g., they differ in size or coloration). Estimation of species-specific fatality rates with the scaling method explained below assumes equal detection rates among the species of small passerines, which is unlikely. For example, a brightly colored male warbler likely has higher detectability than a drab-colored sparrow. This assumption may cause some bias, but it is likely not large enough to substantially detract from the value of these estimates. Finally, some bird fatalities fall outside of search plots.

Deriving Small-Bird Fatality Rates from All-Bird Fatality Rates

We used the estimated fatality rate for small birds (number of fatalities/MW/year) reported by each study to calculate estimates of fatality rates for the US and Canada and for each avifaunal biome. Eighty-one studies specifically reported estimates for small-bird fatality rates, which ranged from zero to 7.67 birds/MW/ year (Appendix S2). The remaining 35 studies reported estimated rates for all bird fatalities combined, regardless of size. To make all studies comparable, we derived a small-bird-only estimate from the reported estimate for all birds (see below).

Deriving estimates of small-bird fatality rates required data on the number of dead birds observed, the estimated searcher efficiency rate, the estimated carcass removal rate, and the average search interval. In addition to tallies of large- and small-bird fatalities, differences in searcher efficiency and carcass removal times between large and small birds need to be accounted for when attempting to determine the estimate of the small-bird fatality rate from an all-bird estimate. We derived the estimate of the small-bird fatality rate $(m_{\rm SB})$ from the all-bird fatality rate estimate $(m_{\text{all birds}})$ with the following calculation, where m is the estimated average number of fatalities per turbine per year, adjusted for removal and searcher efficiency bias; %compLB and %compSB are the proportions of fatalities that are large birds and small birds, respectively; and $\hat{\pi}_{LB}$ and $\hat{\pi}_{SB}$ are the estimated probabilities that a large carcass and small carcass are both available to be found during a search and actually are found, as estimated from the removal trials and the searcher efficiency trials.

$$m_{SB} = m_{allbirds} \div \left(1 + \frac{\% compLB}{\% compSB * \frac{\hat{\pi}_{LB}}{\hat{\pi}_{SB}}} \right)$$

When some of the necessary information was not available, we used a general conversion method. When this was the case, available data for each biome were used to calculate an average regional (biome-specific) carcass removal time (range is 4.51-24.52 days) and searcher efficiency rate for small and large birds (range is 0.48-0.89), and average search interval (range is 1-28 days), and probability of detection (range is 0.08-0.97; Appendix S3). Prior to analysis, we tested the quality of the conversion equation by calculating estimated small-bird rates for studies containing both all-bird and small-bird rates. We compared the calculated value with the small-bird rate reported in the study, and the resulting R² was 0.93 (Figure S1).

Searcher Efficiency Values. Searcher efficiency rates for small birds were available for 98 studies, and ranged from 16.6% to 86.6% (the percent of trial carcasses that are detected by searchers in the searcher efficiency trials; Appendix S4). Some studies using the Huso estimator calculated searcher efficiency based on placing and leaving a carcass in the survey area for several days, providing multiple opportunities for the carcass to be detected by an observer. When possible, searcher efficiency values estimated in this way were adjusted to reflect single-search values to make comparisons to other studies that provided values from a

single search. When multiple years of study were conducted, all data were combined into a single searcher efficiency value estimate for that project. For projects that did not report searcher efficiency rates, we attempted to determine searcher efficiency from data in the report. All searcher efficiency values in each biome were combined to obtain regional searcher efficiency rates. Regional rates were used instead of a single continental rate to account for regional differences in searcher efficiency (and carcass removal, below) due to differences in topography and vegetation characteristics.

Carcass Removal Values. We estimated the average number of days for the removal of small-bird carcasses in 70 studies; this ranged from 1.64 to 27.8 days (Appendix S4). For projects that did not report mean removal rates, we attempted to determine the average duration of carcasses remaining from the data in the report. Regional carcass removal rates were calculated using all values for each avifaunal biome.

Probability of Detection. With the bias-trial values for each avifaunal biome, the probabilities of availability and detection were calculated for search intervals of 1, 3, 7, 14, and 28 days. The proportions of large- and small-bird fatalities in each biome were then combined with the probability of availability and detection to calculate a multiplier for each search interval. For each biome we averaged the results for the five search interval values to calculate a multiplier, which we used to convert all-bird estimates of fatality rates to small-bird estimates for all projects in that biome that did not include a small-bird rate estimate in their report (Appendix S5). Although this method probably overestimated small-bird fatality rates for projects with daily searches and underestimated fatality rates for projects with long search intervals (e.g., 14 days), it likely provides a better adjustment than the proportion of small birds alone as it accounted for differences in detectability and carcass removal rates between large and small birds.

Bias Adjustments

After we calculated estimates of small-bird fatality rates for the 35 studies that only reported estimates for all birds, we adjusted small-bird rates of all studies for bias based on the type of estimator used [27]. Each study design was different (although studies conducted during different phases at the same wind energy facility tended to have similar methods), so we created a customized adjustment factor for each study based on 1) estimator method used, 2) search interval (e.g., weekly, bi-weekly, etc.), and 3) classification of both bias trial results (Appendix S6). If a project had a search interval different from any category then the two surrounding bias adjustment categories were used, e.g., if the project used 3-day search intervals, the 1-day and 7-day bias adjustments were investigated. It is not possible to determine the rate at which the efficiency of searchers may change over time at each project, e.g., between searcher efficiency trials. Therefore, searcher efficiency rates (proportion found) within each study were averaged and categorized as low (0-0.375), moderate (0.375-0.65), or high (0.65-1). We classified the overall average value for carcass removal as fast (0–10 days), moderate (11–23 days), or slow (24 or more days). For each combination of these four factors, we determined the lowest and highest bias adjustment values, based on trial simulations presented in Erickson et al. [27]. The bias adjustment value was relative to 1: if the value was equal to 1 no adjustment was made, indicating no bias in the estimator; for other values, the further they were from one, either higher or lower, the more they adjusted the original estimate. These two bias adjustments were multiplied by the estimated small-bird fatality rate for each project, resulting in two fatality rates, one using the lowest bias correction and one using the highest. For each biome the project rates were then averaged and resulting values were further multiplied by the current operating capacity to generate an estimate of the number of small bird fatalities using both bias correction values.

Estimation of Species-Specific Numbers for Small Passerines

For each species in each biome its proportion of the total small passerine fatalities was multiplied by the total number of small-bird fatalities estimated using adjustments with the lowest and highest values. The results were summed across biomes. To adjust for the absence of data from the southwest biome, all estimates for species were multiplied by seven percent, which is the proportion of continent-wide operating capacity that the southwest biome represents. Finally, the number of continent-wide fatalities estimated for each species was compared to the overall population size estimated for each species.

An *a posteriori* examination of the timing of fatalities (see Timing of Small-Passerine Fatalities Results below) and range maps of individual species [18] reflected that several species, especially warblers, consist of populations with a distinctive migration pattern. Thirty-three species have ranges that extend from eastern to western Canada and in autumn the more western individuals of several species travel east first and then south, in essence retracing the route of their hypothesized evolutionary breeding-range expansion [28]. Therefore many more individuals migrate through the eastern US than actually breed within biomes in this area or directly to the north in eastern Canada. Consequently, it was more logical to compare effects of turbine-related fatality on individual species for continent-wide populations than to those associated with individual biomes.

Estimation of Bird Population Sizes

Estimates of population sizes for species of small passerines were obtained from the Partners in Flight (PIF) Land Bird Population Estimates Database [29], which is based on annual Breeding Bird Surveys (BBS) coordinated by the US Geological Survey and Canadian Wildlife Service. Breeding Bird Surveys are roadside counts designed to "estimate population trends and relative abundances at various geographic scales" [30], and the PIF database can be used to estimate population size for a specific species across the continent or at a biome level [31]. The PIF population estimates were based on data collected between 1998 and 2007, and raw data are adjusted for factors such as assumed average detection distances, pair occurrence, and time of day [31], [32].

Some population estimates have relatively large standard errors associated with the BBS count average rate, due to high variance in counts and/or small numbers of BBS routes surveyed [31]. In addition, several potential sources of bias exist in these estimates. Potential sources of bias include non-random sampling of landscapes. Also, species detected near habitats altered by roads may not represent the species composition of areas away from roads. For example, traffic may affect the presence of birds or detectability, and some naturally secretive species may be present but not detectable [31] [33], [34]. However, McCarthy et al. [35] evaluated species distribution models from unpaved roadside counts similar to BBS counts in a control-impact study, finding that roadside counts do provide adequate model accuracy compared to the off-road data if an adequate range of environmental gradients is sampled. Reasonable concerns regarding bias exist, however, a measure of population sizes for small passerines is required to discuss the effects of small-passerine fatalities and the PIF population database currently provides the

best estimates of breeding bird population sizes in the US and Canada.

The following describes migration strategies relevant to this analysis: resident birds are present year-round in a particular location or region; breeding birds reproduce in a given location or region; wintering birds remain in a location or region for an extended period of time during the winter months and travel elsewhere to breed; migrant birds are birds in the process of traveling between breeding and wintering locations, typically at regular times, and often over long distances; and nocturnal migrants are birds that migrate at night, often over long distances. Most small passerines that breed in the US and Canada are nocturnal migrants that spend the winter in more southern latitudes [16].

Results

Most of the 116 available monitoring studies that were appropriate for our analyses were conducted in the northern third of the contiguous United States (Figure 1). Agriculture was the only land use identified in 30 studies (Table 1). Ninety-seven monitoring studies occurred in either agricultural, grassland, or forested land cover, or some combination thereof. The remaining 19 studies reported land covers of desert, shrub-steppe, or rocky embankments (Table 1).

Fatality Rate Estimates for Small Birds

We calculated estimates of fatality rates for small birds for 35 studies in which only estimates combining all birds were reported. The resulting calculated values ranged from 0.18 to 9.65 fatalities/MW/year (Table 2). These were derived using the small-bird multiplier values, which ranged from 0.67 to 0.88 depending on region (Appendix S5).

Bias-Corrected Estimates of Fatality Rates for Small Birds

After we determined values for all studies, we adjusted estimates of fatality rates for small birds for bias based on the type of estimator used. Values used for bias adjustment ranged from 0.39 to 2.77, resulting in revised rates from 0 to 18.54 small-bird fatalities/MW/year (Appendix S7).

Composition of Fatalities by Bird Type, Passerine Family, and Small-passerine Species

Small passerines accounted for 62.5% of the 4,975 observed fatalities at wind energy facilities; this included birds found incidentally, outside of standardized surveys (Table 3). Upland game birds (8.2%) and diurnal raptors (7.8%) were the next most commonly found bird types. Each of the other identifiable bird types accounted for less than 4% of all bird fatalities (Table 3). Some avifaunal biomes are represented by more studies than others (Figure 1), so the fatality composition for all biomes combined may not reflect that of individual biomes.

At the level of passerine families, six of 24 taxa made up about half (47.5%) of all bird fatalities from wind energy developments in our analysis (Table 3): Alaudidae (larks; 13.7% of all fatalities), Parulidae (wood-warblers; 10.8%), Vireonidae (vireos; 6.5%), Icteridae (blackbirds/orioles; 6.1%), Emberizidae (sparrows; 6.0%) and Regulidae (kinglets; 4.4%). These taxa combined also made up over three-quarters of all small-passerine fatalities. All other families of passerines each made up 2.5% or less of the total number of turbine-related fatalities.

The studies documented fatalities of 246 identifiable avian species, of which 156 were unique species of small passerines (Appendices S8, S9). The most common species of small passerine **Table 1.** The land cover type associated with studies of collisions of birds with wind turbines at wind energy facilities in geographically distinct avifaunal biomes, for studies that reported small-bird and all-bird only estimates of fatality rates.

Avifaunal biome	Land cover type	#Projects with small-bird estimates	#Projects with all-bird estimates only
Eastern	Agriculture	1	3
	Agriculture/forest	3	3
	Forest	3	4
	Forest/pasture/grassland	0	1
	Grassland	0	2
Intermountain West	Agriculture	4	2
	Agriculture/grassland	13	1
	Desert grassland/forested	2	0
	Grassland	4	1
	Grassland &shrub steppe	3	1
	Grassland/shrub steppe & agriculture	6	1
	Grassland/shrub steppe, agriculture & forest	0	1
	Shrub steppe & agriculture	2	0
Northern Forest	Agriculture	1	0
	Agriculture/forest	6	0
	Forest	1	5
	Grassland, forest, rocky embankments	1	1
Pacific	Agriculture	1	0
	Agriculture/grassland	1	2
	Desert	1	0
	Grassland	1	0
	Shrub/scrub & grassland	1	0
	No habitat listed	1	0
Prairie	Agriculture	13	5
	Agriculture/forest	1	0
	Agriculture/grassland	6	2
	Forest	1	0
	Grassland	4	0
Total	116 projects	81	35

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found as a fatality was horned lark (*Eremophila alpestris*; 21.9% of small passerines), followed by red-eyed vireo (*Vireo olivaceus*; 8.5%), western meadowlark (*Sturnella neglecta*; 5.1%), and golden-crowned kinglet (*Regulus satrapa*; 5.1%; Table 4).

Timing of Small-Passerine Fatalities

Seventy-nine fatality studies provided the date for each bird fatality identified; all of these studies reported data collection in spring, summer, and fall for at least one year. For some studies data were not collected for a short time in the summer or winter, and we considered this acceptable for inclusion here. A peak in fatalities of small passerines occurred in fall, and a smaller peak occurred in spring (Figure 2). The fewest fatalities were found in December and January. Timing of fatalities for small-passerine families and species of interest to this analysis generally follow this same temporal pattern, but to a lesser extent when fewer individual fatalities comprised the group (Figures S2–S27).

Continent-wide and Biome-level Fatality Rates based on Operating Capacity

Across all biomes, the yearly fatality rate estimated for small birds was about 3.35/MW installed capacity when adjusted by the bias value that was the lowest (Table 5). The rate was 2.10 when adjusted by the bias value that was the highest. The studies in our analysis represent about 15% of the 63,023 MW of installed wind energy across all avifaunal biomes that have both wind energy development and data herein (as of January 2013) [36], [37]. At the biome level, studies in this analysis represented from about 18%-40% of the current operating capacity for all biomes except for the prairie and southwest biomes (7% and zero percent, respectively; Table 5). The average fatality rate calculated for small birds was lowest for the northern forest biome (1.43 birds/ MW/year) and highest for the prairie biome (3.96 birds/MW/ year), based on the most conservative bias adjustment. The most conservative rate for the eastern biome (3.83) was similar to that of the prairie biome.

Table 2. Estimated fatality rate (birds/megawatt(MW)/year) and confidence interval calculated for small birds in studies of bird collisions at wind energy facilities that provided all-bird estimates only in their report, along with estimator, all-bird rate and confidence interval, and multiplier value^a.

Project name by	Ectimator	All-bird fatality	All-bird		Calculated small-bird	Calculated small-bird
avifaunal biome	used	(MW/year)	interval	Multiplier	(MW/year)	interval
Eastern Biome						
Buffalo Mountain (2000–2003)	Naïve	11.02		0.88	9.65	
Buffalo Mountain (2005)	Naïve	1.10		0.88	0.98	
Casselman (2008)	Shoenfeld	1.51	0.90-4.00	0.88	1.33	0.53–2.34
Casselman (2009)	Shoenfeld	2.88	2.67–6.44	0.88	2.52	1.56–3.76
Cohocton/Dutch Hill (2009)	Jain	1.39		0.88	1.20	
Cohocton/Dutch Hills (2010)	Jain	1.32		0.88	0.69	
Locust Ridge II (2009)	Shoenfeld	0.84		0.88	0.74	
Locust Ridge II (2010)	Shoenfeld	0.76		0.88	0.66	
Mountaineer (2003)	Shoenfeld	2.69	2.41-8.33	0.88	2.36	1.41–4.87
Munnsville (2008)	Jain	1.48		0.88	1.30	
Ripley (2008)	Environment Canada	3.09		0.88	2.70	
Sheldon (2010)	Shoenfeld	1.76	1.66–3.88	0.88	1.54	0.97–2.27
Sheldon (2011)	Shoenfeld	1.57	1.46–3.36	0.88	1.38	0.85–1.96
Intermountain West Biome						
Big Horn	Huso	2.54	2.59–7.54	0.78	1.97	1.34–3.90
Harvest Wind (2010–2012)	Huso	2.94	4.93-10.00	0.78	2.28	1.66–3.37
Leaning Juniper	Huso	6.66	6.19–15.66	0.78	5.17	3.20-8.10
Pebble Springs	Huso	1.93	2.34-8.89	0.78	1.50	0.86-3.29
Summerview (2006)	Environment Canada	1.06		0.78	0.82	
Tuolumne (Windy Point I)	Shoenfeld	3.20	4.89–11.57	0.78	2.49	1.72–4.08
White Creek (2007–2011)	Huso	4.05	7.64–12.12	0.78	3.14	2.58-4.09
Northern Forest Biome						
Lempster (2009)	Shoenfeld	3.38	3.75–9.78	0.81	2.73	1.52–3.96
Mars Hill (2007)	Jain	1.67		0.81	1.33	
Mars Hill (2008)	Jain	1.76		0.81	1.43	
Stetson Mountain I (2009)	Jain	2.68		0.81	2.17	
Stetson Mountain I (2011)	Jain	1.18	1.54–1.99	0.81	0.96	0.83–1.07
Stetson Mountain II (2010)	Jain	1.42	1.91–2.37	0.81	1.15	1.03–1.28
Pacific Biome						
High Winds (2004)	Shoenfeld	1.62		0.67	1.08	
High Winds (2005)	Shoenfeld	1.10		0.67	0.73	
Prairie Biome						
Barton I and II	Shoenfeld	5.50	8.00–16.09	0.68	3.73	2.71–5.46
Kewaunee County	Shoenfeld	1.95		0.68	1.33	
Moraine II	Shoenfeld	5.59	3.58–15.22	0.68	3.79	1.62–6.88
Pioneer Prairie I (phase II)	Shoenfeld	0.27	0–1.35	0.68	0.18	0–0.55
Prairie Winds ND1/Minot (2010)	Shoenfeld	1.48	1.74–3.33	0.68	1.04	0.82–1.56
Top of Iowa 2003	Shoenfeld	0.42		0.68	0.29	
Top of Iowa 2004	Shoenfeld	0.81		0.68	0.57	

^aReferences for the studies listed in this table may be found in Appendix S1. doi:10.1371/journal.pone.0107491.t002

Effects on Bird Populations

Using the biome-specific rates, the number of fatalities for each species was calculated and summed (Appendix S8). These values were then multiplied by 7% to account for operating capacity in

the southwest biome for a total of 229,765 small-passerine fatalities using the bias adjustment value that was lowest and 133,993 with the bias adjustment value that was the highest (Appendix S9), indicating a range of about 134,000 to 230,000 small-passerine **Table 3.** Observed number of fatalities (including incidental finds) and percent composition of total for each bird type and passerine sub-type (family) for 116 studies at wind energy facilities in the United States and Canada.

Bird type	#Fatalities	% Composition
	2 110	62.5
Passenines	5,110	02.5
Woodwarblere (Parulidae)	536	10.8
Vireos (Vireonidae)	300	65
Blackbirds/Orioles (Icteridae)	302	61
Sparrows (Emberizidae)	299	60
Kinglets (Regulidae)	222	44
Unidentified Passarings	126	25
Thrushes (Turdidae)	120	2.5
Starlings (Sturnidae)	103	2.5
Flycatchers (Tyrannidae)	79	16
Swallows (Hirundinidae)	69	14
Wrens (Troglodytidae)	61	12
Tanagers/Grosbeaks/Cardinals (Thraunidae/Cardinalidae)	32	0.6
Finches/Crossbills (Frincillidae)	30	0.6
Small Corvids (Corvidae)	25	0.5
Mimids (Mimidae)	23	0.5
Nuthatches (Sittidae)	23	0.5
Old World Sparrows (Passeridae)	15	0.3
Waxwings (Bombycillidae)	15	0.3
Creepers (Certhiidae)	10	0.2
Shrikes (Laniidae)	6	0.1
Longspurs/Buntings (Calcariidae)	5	0.1
Titmice/Chickadees (Paridae)	4	0.1
Gnatcatchers (Polioptilidae)	1	<0.1
Upland Game Birds	407	8.2
Diurnal Raptors	386	7.8
Unidentified Birds	260	5.2
Doves/Pigeons	192	3.9
Waterfowl	133	2.7
Vultures	71	1.4
Owls	62	1.2
Rails/Coots	54	1.1
Woodpeckers	52	1.0
Shorebirds	49	1.0
Large Cuckoos	45	0.9
Large Corvids	38	0.8
Swifts/Hummingbirds	37	0.7
Goatsuckers	25	0.5
Gulls/Terns	24	0.5
Loons/Grebes	18	0.4
Waterbirds	9	0.2
Kingfishers	3	0.1
Overall	4,975	100

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fatalities that occur annually in the US and Canada from collisions with turbines.

Using the most conservative estimates, we determined the continent-wide effect from collisions with turbines for each species to be much less than one percent annually, ranging from less than **Table 4.** Number of fatalities caused by collision with wind turbines and percent of all small-passerine fatalities (n = 3,110) for the 25 most commonly found species of small passerines in 116 studies conducted at 71 wind energy facilities from 1996–2012.

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Common name ^a	Species	#Fatalities ^a	% Small-passerine fatalities
horned lark	Eremophila alpestris	681	21.9
red-eyed vireo	Vireo olivaceus	265	8.5
western meadowlark	Sturnella neglecta	159	5.1
golden-crowned kinglet	Regulus satrapa	158	5.1
unidentified passerine		120	3.9
European starling	Sturnus vulgaris	103	3.3
red-winged blackbird	Agelaius phoeniceus	70	2.3
magnolia warbler	Setophaga magnolia	60	1.9
yellow-rumped warbler	Setophaga coronata	57	1.8
ruby-crowned kinglet	Regulus calendula	55	1.8
dark-eyed junco	Junco hyemalis	52	1.7
blackpoll warbler	Setophaga striata	50	1.6
Townsend's warbler	Setophaga townsendi	38	1.2
savannah sparrow	Passerculus sandwichensis	37	1.2
white-crowned sparrow	Zonotrichia leucophrys	37	1.2
tree swallow	Tachycineta bicolor	34	1.1
unidentified warbler		34	1.1
American robin	Turdus migratorius	28	0.9
black-throated blue warbler	Setophaga caerulescens	27	0.9
Wilson's warbler	Cardellina pusilla	27	0.9
common yellowthroat	Geothlypis trichas	26	0.8
unidentified sparrow		25	0.8
wood thrush	Hylocichla mustelina	25	0.8
Brewer's blackbird	Euphagus cyanocephalus	24	0.8
bobolink	Dolichonyx oryzivorus	22	0.7
ovenbird	Seiurus aurocapilla	22	0.7
house wren	Troglodytes aedon	20	0.6
red-breasted nuthatch	Sitta canadensis	20	0.64

^aUnidentified small-passerine types are also included in order of abundance. A full list of species is provided in Appendix S9. doi:10.1371/journal.pone.0107491.t004



Figure 2. Monthly timing of small-passerine fatalities caused by collision with turbines and documented in 79 studies. The date for collision was provided in 79 studies on mortality of birds at wind energy facilities. A total of 2,285 fatalities for species of small passerines (less than 30.5 cm in size) were included and are sorted by month.

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0.001% to 0.043% (Appendix S10). This means that less than one-tenth of one percent of the continent-wide population for each species is estimated to be killed annually by collisions with wind turbines (Table 6, Appendix S10). For about 20% of all species of small passerines in our study this value was less than 0.001%.

An Example

Two fatalities of Acadian flycatcher (*Empidonax virescens*) were documented in all 116 studies; both were found in the eastern biome and represented about 0.26% of all fatalities (762) in that biome (Appendix S8). This composition was multiplied by the two values (based on the adjustments using the bias value that was lowest and the bias value that was highest) for total number of fatalities estimated for the eastern biome based on operating capacity (25,010, and 16,853, respectively; Table 5) to generate two estimates of the annual number of fatalities for Acadian flycatcher from collisions with wind turbines, 66 and 44, respectively. If fatalities of Acadian flycatchers were found in other biomes, values for all biomes would be summed for a continent-wide estimate. To adjust for the absence of data from the southwest biome, all cumulative estimates for species were

		Average estimate	Average estimat	e			Number of estimated annual	Number of
Avifaunal biome	Unadjusted average small-bird estimate (MW/Year)	(MW/year) adjusted by lowest bias value	(MW/year) adjusted by highest bias value	Sum of MW for available data	Total MW in biome ^a	Percent of total MW represented by available data	fatalities adjusted by lowest bias value ^b	estimated annual fatalities adjusted by highest bias value ^b
Eastern	2.34	3.83	2.58	1,139.48	6,523.85	17.47	25,010	16,853
Intermountain West	2.12	3.35	2.09	3,799.80	9,500.93	39.99	31,871	19,896
Northern Forest	1.56	1.43	1.15	854.25	3,694.00	23.13	5,293	4,257
Pacific ^c	2.44	3.27	2.55	686.46	1,857.32	36.96	6,082	4,743
Prairie	2.29	3.96	2.15	2,513.31	37,027.83	6.79	146,477	79,478
Southwest ^c					4,419.13			
All biomes	2.15	3.35	2.10	8,993.30	63,023.05	14.27		
^a Provided by [36], [3								

Table 5. Comparison of the average fatality rate (birds/megawatt [MW]/year) for small birds for each associated avifaunal biome and all biomes combined, total MW produced in each biome. Droportion of total MW represented by wind energy facilities with available fatality monitoring reports, and estimated number of small-bird fatalities annually.

^bSee values for all biomes combined in Appendix S9. ^CThe Dillon Project was the only project in the southwest biome represented by a fatality report that was available. Due to its singularity and since it is located very close to the Pacific biome; it was combined with the Pacific biome data for these estimates. See project characteristics in Appendix S1. doi:10.1371/journal.pone.0107491.t005

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Species	Scientific name	#found	% composition	Ave est i (lowest value) ^b	Ave est (highest value) ^c	Pop est for North America ^d	% pop affected (lowest value) ^e	% pop affected (highest value) ^f
black-throated blue warbler	Setophaga caerulescens	27	0.87	895	610	2,100,000	0.043	0.029
tree swallow	Tachycineta bicolor	34	1.09	7,390	4,102	17,000,000	0.043	0.024
homed lark	Eremophila alpestris	681	21.9	30,591	18,029	80,000,000	0.038	0.023
brown thrasher	Toxostoma rufum	3	0.10	1,722	935	4,900,000	0.035	0.019
yellow-throated vireo	Vireo flavifrons	4	0.13	1,218	670	3,500,000	0.035	0.019
spotted towhee	Pipilo maculatus	7	0.23	716	402	2,200,000	0.033	0.018
sedge wren	Cistothorus platensis	S	0.10	1,722	935	6,200,000	0.028	0.015
bushtit	Psaltriparus minimus	-	0.03	574	312	2,300,000	0.025	0.014
western meadowlark	Sturnella neglecta	159	5.11	6,147	3,790	30,000,000	0.020	0.013
rose-breasted grosbeak	Pheucticus ludovicianus	6	0.29	826	486	4,100,000	0.020	0.012
American tree sparrow	Spizella arborea	7	0.23	4,019	2,181	20,000,000	0.020	0.011
purple martin	Progne subis	S	0.10	1,183	647	6,000,000	0.020	0.011
field sparrow	Spizella pusilla	7	0.23	1,324	741	7,600,000	0.017	0.010
grasshopper sparrow	Ammodramus savannarum	5	0.16	2,322	1,262	14,000,000	0.017	0.009
brown creeper	Certhia americana	10	0.32	1,356	767	8,500,000	0.016	0.009
Bell's vireo	Vireo bellii	-	0.03	574	312	3,600,000	0.016	0.009
barn swallow	Hirundo rustica	11	0.35	5,222	2,844	33,000,000	0.016	0.009
Cape May warbler	Setophaga tigrina	13	0.42	966	595	7,000,000	0.014	0.009
Le Conte's sparrow	Ammodramus leconteii	2	0.06	1,148	623	8,000,000	0.014	0.008
European starling	Sturnus vulgaris	103	3.31	7,892	4,563	57,000,000	0.014	0.008
^a includes carcasses found during ^b Average estimated number of fa	scheduled carcass searches and talities each year adjusted by th	incidentally. Ie bias value t	hat was the lowes	t and for operating cap	acity (see text and Apper	.(92).		

^cAverage estimated number of fatalities each year adjusted by the bias value that was the highest and for operating capacity (see text and Appendix S9). ^dPopulation estimates obtained from the Partners in Flight Landbird Population Estimates Database [29]. ^ePercent of population affected annually, adjusted by the bias value that was the lowest. ^fPercent of population affected annually, adjusted by the bias value that was the highest. Two values are presented for both percentage and number, representing the extreme values of the range of adjustments applied for each species. Also included are the number of dead birds found and the percent composition by species for the 116 studies. Results for all species are presented in Appendix S10^a.

multiplied by seven percent, which is the proportion of continentwide operating capacity that the southwest biome represents. This results in estimates of 70 and 47 annual fatalities of Acadian flycatchers, respectively. Finally, the proportion of the North American population of Acadian flycatchers (4.5 million) that these two estimates represent was determined: 0.002% and 0.001%, respectively.

Discussion

There are factors that make our analysis different from other estimates of rates of bird fatality at wind energy facilities. First, we calculated estimates of small-bird fatality rates for studies where only all-bird estimates were presented. Second, we attempted to remove bias in fatality rate estimation associated with four different estimators, further increasing the accuracy of the continent-wide small-bird fatality rates. Third, our analysis drew upon a much larger set of monitoring efforts at wind energy facilities compared to other similar reviews. Finally, no other study of this type presented fatality rates for small birds both continentwide and for avifaunal biome regions. All the studies that we included covered the periods of migration for most passerines and used relatively uniform methods of data collection. While we did not incorporate more-specific variables to further refine the effects on bird populations (e.g., population growth rate), we think the population effects we calculated allow comparisons to be made among species of small passerines. Some amount of uncertainty is inherent in all studies on bird mortality related to human activity and it is unclear to what extent these fatalities compensate for deaths from sources not related to humans [38]. Other considerations for assessing the effect of turbine-related mortality include: 1) small passerines most likely make up an even larger percentage of actual fatalities because they are harder to detect than larger birds; 2) as mentioned earlier, passerine species tend to be shorterlived with higher rates of reproduction than other bird taxa [15], [16]; and 3) even though the location and timing of fatalities may suggest which particular populations for a given species are being affected, this information may be confounded because migrants, breeders, wintering birds, and year-round residents may overlap in their presence at a wind energy facility, particularly for species with large geographical distributions, distinctive migration patterns, and/or unique life history characteristics. Ideally, we would like to address the effects of turbine-related mortality at a moretargeted, regional level. For example, Loss et al. [39] describes regions of catchment as "the portion of a species' breeding range that is represented by mortalities at a site, assuming straight northto-south migration" which may be evaluated through geolocator and mark-recapture data. We are not aware of the current availability of this type of data for small passerines in general.

Other Analyses of Collisions with Turbines and Unknown Factors

By combining the lowest and highest bias-adjusted rates estimated in our analysis for the annual number of small birds killed by turbines (133,993 and 229,765; Table 5) with the proportion of all fatalities that were passerines (62.5%), we calculated that about 214,000 to 368,000 turbine-related deaths occur each year for all birds. These numbers are less than those presented by Smallwood [12] and Manville [10], 573,093 and 440,000, respectively, but slightly more than the values presented by Loss et al. [13], which averaged 234,000 (range: 140,000 and 328,000). Our study differs from that of Smallwood [12] because we used the fatality rate provided in individual studies as opposed to independently recalculating these rates from the raw data using a single common estimator. In addition, we did not use national averages for bias adjustments. We eliminated studies that we believed were inadequate for estimating fatality. Also, we did not correct results based on turbine tower height or search radius in part because there are some confounding factors between the heights of the turbines and the size of the rotor swept area. We were unable to determine how Manville [10] calculated his estimate.

There are factors that may influence any per year estimate of bird fatalities. First, taller turbines may be related to an increase in bird mortality, as suggested by Loss et al. [13]. We found no linear correlation between turbine tower height and the fatality rates we estimated, but other factors such as geographic location or turbine age may confound the effect of tower height. Second, the size of the search plot may influence how many actual fatalities are found by searchers. Guidelines provided by the USFWS recommend that search plots for birds have a width that is twice the length of the turbine tower height to the ground [1], while another recommendation is that the length of the radius of search plots for birds match the height of the highest point of the rotor swept area of the turbine (the area that the blades pass over when moving), which may be about 90–120 m or more for modern turbines [14]. Not all plot sizes in studies for our analysis conformed to these guidelines, and some studies may underestimate the number of bird fatalities found due to the bird carcasses landing outside the search plot. Smallwood [12] and Loss et al. [13] both adjusted their estimate of bird fatalities per year based on the proportion of all fatalities found for classes of turbine tower height paired with plot size derived by Smallwood [12] from raw data contained in previous studies. While we recognize this as a potential bias, we also recognize that background mortality (evidence of carcasses found that are not caused by collision with wind turbines) is likely an important positive bias, and limited studies suggest this bias may partially or even completely offset any bias associated with plot size. Background mortality is an issue with these studies because observers may incorrectly identify a carcass found within the survey area as a fatality caused by colliding with a turbine when it actually may have died from another cause. We found two studies on this phenomenon (one conducted in Tennessee and one in Minnesota) in which plots away from turbines were monitored simultaneously with regular plots at turbines. For these, researchers determined the rate of background mortality as 0.22 and 1.10 birds/reference plot/year for circular plots with a 50-m radius and 126 m by 126 m plots, respectively [40], [41], which accounted for about 4% or 33% of the total estimated fatality. Additional evidence of background mortality was found during a study in Montana for a proposed wind energy facility, where four dead birds were found along linear transects totaling a distance of about 290 km over a two-year period [42]. The extent of background mortality, while not known, is likely an important bias in estimating turbine collision fatalities and probably varies according to location. In addition, assuming background mortality is proportional to area searched; larger plots that are searched would be expected to have more mortality associated with factors independent of collision. This suggests the plot size models of Smallwood [12] may have an increasing bias with increasing plot size. Zimmerling et al. [43] estimated 23,300 bird deaths/year in Canada (8.2±1.4 fatalities/turbine/year) based on 2,955 operating turbines from studies at 43 wind projects in eight provinces in Canada. The authors stated that in Canada passerines typically comprise 80% of all fatalities at turbines and they found population effects of less than 0.01% for species of small passerines that made up the most overall fatalities. Unlike other analyses discussed here, the authors appear to have applied a single set of correction factors to all carcasses regardless of size and search conditions, making comparisons to other studies questionable (M. Huso, personal communication).

To explore the potential greater effect of older-generation facilities on small-passerine fatalities [44] we estimated potential fatalities from older generation turbines that are currently in operation, based on our overall estimate. We know of three current facilities with older generation turbines: Altamont Pass, San Gorgonio, and Tehachapi, all located in California. About 317 MW of 454 total MW at Altamont Pass are from older turbines [45]. At San Gorgonio about 300 MW out of about 550 total MW are from older turbines [46], and about 800 MW of capacity from a total of over 3,000 MW are estimated to be derived from older turbines at Tehachapi [47]. The combined total, 1,417 MW, is about 2.25% of the continent-wide operating capacity in our analysis (Table 5). Smallwood and Karas [48] compared fatality rates at Altamont between modernized (repowered) and older turbines, finding notable reductions at the repowered facilities compared to older generation. For horned lark, loggerhead shrike, and western meadowlark, the authors noted reductions of 83%, 44%, and 44%, respectively. Applying the highest reduction in their study to the 2.25% of capacity from older generation turbines in our study results in a fatality rate of roughly 30,400 small-passerine fatalities per year. Adding this value to our most conservative rate of 225,000 (after adjusting for the remaining 97.75% of total capacity from modern turbines) results in a total of 255,000 total small-passerine fatalities per year. When extrapolated to all birds this results in a total of 408,000 allbird fatalities per year.

Comparison to Other Sources of Avian Fatalities

Longcore et al. [22] reported on species composition for birds that collide with communication towers. They documented over a quarter-million bird fatalities consisting of 239 bird species, of which about 97% were passerines (corvids made up 0.01% of all fatalities while our study excluded large corvids), and over half of these were warblers. These fatalities were found at 107 communication tower locations in central and eastern North America. In a similar study, Longcore et al. [21] stated that 6.8 million birds die annually from collisions with communication towers in the United States and Canada. The authors derived this number from 38 studies of communication towers such as cellular towers, television towers, radio towers, microwave towers, and public safety communication system towers. Adjustments for searcher efficiency and scavenger bias were made. Combining these findings indicates that about 6.6 million passerines are killed by communication towers per year. Annual mortality from communication towers was estimated to be at least one percent of the total population size for 26 passerine species. The estimated effect on populations from wind turbines is far less than for communication towers, which ranged up to nine percent/year and was at least one percent for 29 species of birds [22]. In our analysis two of the top 20 species for population effects were warblers (Table 6), while about half of the top 20 species were warblers in the other study.

An estimated 1.4 to 3.7 billion bird fatalities per year were attributed to cats in the contiguous US [49]. Two-thirds of these fatalities were linked to cats that were not owned by people as pets (e.g., barn cats and feral cats). In Canada 100–350 million bird deaths were estimated to be caused by predation by cats [50].

In Canada 269 million bird deaths each year were estimated to be from human-related sources; over 95% of these were attributed to predation by cats and collisions with road vehicles, houses, and transmission lines, while annual mortality from wind turbines was estimated to be 23,300 birds [51], [43].

Passerine Species

Our analysis shows the species composition for small passerines whose populations will most likely be affected by collisions with turbines (Table 6, Appendix S10). In general, a species with a small population size and high numbers of casualties from collisions with turbines would be affected the most, and a species with a large population would be influenced much less, particularly when the number of casualties is small.

In our study the continent-wide population of the blackthroated blue warbler (Dendroica caerulescens) was affected the most in comparison to other species of small passerines (0.029%-0.043% annual loss due to collisions with turbines). In comparison, the effect from communications towers presented by Longcore et al. [22] for this species was 4.9%, more than two orders of magnitude higher. Interestingly, Arnold and Zink [52] identified the black-throated blue warbler as the one that collides most frequently with towers and buildings. However, these authors have been criticized for concluding that bird population trends were not affected by collisions because the authors did not adjust for other population factors and had a limited dataset [53], [54], [22]. In contrast, horned lark comprised the highest proportion of smallpasserine fatalities in our data, at least twice as many fatalities as any other species, but the estimated population effect ranged from 0.023% to 0.038%, less than that of the black-throated blue warbler, because of the large size of the continental population for horned lark.

Passerine Families

Of the passerine families with the most fatalities, a single species was sometimes disproportionally represented, even though several species are members of the taxa in North America. For example, about 82.3% of collisions in Vireonidae were red-eyed vireos, and 52.6% of found fatalities of Icteridae were western meadowlarks. Regulidae is comprised of two species in North America, and of these the golden-crowned kinglet made up 71.5% of fatalities for that family (Table 3 and Appendix S9). Parulidae comprised a much smaller percent of overall fatalities with wind turbines (10.8%) as compared to communication towers (58.4%;), while a similar percent of fatalities from Emberizidae were killed by turbines (6.0%) compared to communication towers (5.8%) [22].

Timing of Fatalities

Fatalities for most small-passerine families – notably Hirundinidae (swallows), Turdidae (thrushes), Vireonidae, and Parulidae followed a pattern where most fatalities occurred in fall followed by a smaller peak in spring (Figures S2–S27). For Emberizidae and Alaudidae combined, a bird grouping typically assessed in biological studies for wind energy facilities, spring was the time of most collisions overall. Male horned larks sing while flying at heights up to 250 meters during courtship displays in spring [55] and could encounter blades from wind turbines during their performance. This demonstrates how effects to small passerines cannot be generalized, but perhaps should be assessed on a species level or by the suite of species associated with the type of habitat present, depending on the study.

Species of Conservation Concern

Species of conservation concern [56] identified as fatalities in our analysis included bay-breasted warbler (*Setophaga castanea*), Bell's vireo (*Vireo bellii*), Bewick's wren (*Thryomanes bewickii*), blue-winged warbler (*Vermivora cyanoptera*), Canada warbler (*Cardellina canadensis*), cerulean warbler (*Setophaga cerulea*), dickcissel (*Spiza americana*), gray vireo (*Vireo vicinior*), Kentucky warbler (*Geothlypis formosa*), loggerhead shrike (*Lanius ludovicia-nus*), prairie warbler (*Setophaga discolor*), tricolored blackbirds (*Agelaius tricolor*) and wood thrush (*Hylocichla mustelina*). Continental populations for all of these species were estimated to be affected by 0.016% or less (Appendix S10).

Biome-level Rates

Adjusted fatality rates for small birds at wind energy facilities for each biome ranged from 1.43 birds/MW/year in the northern forest biome to 3.96 in the prairie biome, based on the most conservative bias-adjusted rates (Table 5). The ability to discuss turbine-related fatalities at a biome level may contribute to coordinated, cooperative conservation planning and management efforts, at the very minimum by providing an understanding of the actual measured and bias-corrected effect of wind turbines on populations of small passerines. Comparison of rates between regions may not be as useful due to differences in the availability of habitats and the quantity and geographic location of studies among regions. In many cases it is also not possible to determine whether an individual killed by a turbine was breeding in that area, migrating through it, or wintering there.

Our analysis indicated that fatalities from collisions with turbines are fewer than fatalities from other anthropogenic sources, including individual and cumulative effects to listed sensitive species of small passerines. Those species protected by the Migratory Bird Treaty Act [57], which includes passerine species, are likely to continue to be of concern to federal and state regulatory agencies, the wind industry, and other stakeholders.

Further Research

Our work is a major advance in assessing the accumulated data available from many individual fatality monitoring studies, and provides preliminary insight into the effects of wind energy turbines on populations of small passerines. As more studies are conducted and their results made available, they will help refine the current understanding overall and at the level of avifaunal biomes, which will contribute to a better ability to make decisions about effects, turbine siting, and possible avoidance and mitigation strategies. This analysis and future analyses of these data can provide information that could be used to better predict small passerine mortality on future projects, and focus monitoring efforts on more specific unanswered questions or possibly avoidance and mitigation. Our analysis suggests overall mortality of small passerines from wind energy is minor compared to passerine mortality from other anthropogenic sources, and development of solutions for reducing mortality from those other sources may provide more benefit to passerine populations than concentrating efforts on reducing impacts of wind energy. Efforts towards understanding the consequence of wind energy on small passerines should focus primarily on understanding effects on listed species as well as other species of concern such as birds that breed in grasslands.

All appropriate data were included in our analysis, but for some areas of the continent only limited data were available. For example, only 7% of the installed capacity of the prairie biome was included in this study. As mentioned above, only one report was available to us that represented the southwest biome, even though this region contains over 4,400 MW of operating capacity. Additional insight could be gained on the effect of wind energy on small passerines in this biome as more studies are conducted and become available.

Supporting Information

Figure S1 Regression between calculated estimates of small-bird fatality rates and reported small-bird rates for studies at wind energy facilities in the United States and Canada for which both all-bird and small-bird estimates are provided.

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Figure S2 The monthly timing of fatalities for blackbirds and orioles (Icteridae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S3 The monthly timing of fatalities for small corvids (Corvidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided.

Figure S4 The monthly timing of fatalities for creepers and nuthatches (Certhiidae and Sittidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S5 The monthly timing of fatalities for finches and crossbills (Fringillidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S6 The monthly timing of fatalities for flycatchers (Tyrannidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided.

Figure S7 The monthly timing of fatalities for gnatcatchers and kinglets (Polioptilidae and Regulidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S8 The monthly timing of fatalities for grassland species and sparrows (Alaudidae/Emberizidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and

⁽TIF)

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species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S9 The monthly timing of fatalities for mimids (Mimidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided.

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Figure S10 The monthly timing of fatalities for shrikes (Laniidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided.

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Figure S11 The monthly timing of fatalities for swallows (Hirundinidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S12 The monthly timing of fatalities for tanagers, grosbeaks, and cardinals (Cardinalidae), from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S13 The monthly timing of fatalities for thrushes (Turdidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided.

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Figure S14 The monthly timing of fatalities for titmice and chickadees (Paridae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S15 The monthly timing of fatalities for vireos (Vireonidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S16 The monthly timing of fatalities for warblers (Parulidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S17 The monthly timing of fatalities for waxwings (Bombycillidae) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and

Canada for which dates were provided. (TIF)

Figure S18 The monthly timing of fatalities for wrens (Troglodytidae) from 79 fatality studies from which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided.



Figure S19 The monthly timing of fatalities for all unidentified passerines from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S20 The monthly timing of fatalities for the baybreasted warbler (*Setophaga castanea*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S21 The monthly timing of fatalities for the black-throated blue warbler (*Setophaga caerulescens*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided.



Figure S22 The monthly timing of fatalities for the bluewinged warbler (*Vermivora cyanoptera*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S23 The monthly timing of fatalities for the Canada warbler (*Cardellina canadensis*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S24 The monthly timing of fatalities for the golden-crowned kinglet (*Regulus satrapa*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S25 The monthly timing of fatalities for the horned lark (*Eremophila alpestris*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S26 The monthly timing of fatalities for the redeyed vireo (*Vireo olivaceus*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Figure S27 The monthly timing of fatalities for the western meadowlark (*Sturnella neglecta*) from 79 fatality studies for which the date when each fatality was found was provided. Timing of fatalities for small passerine families (presented alphabetically), unidentified passerines, and species of interest for 79 of 116 fatality monitoring studies in the United States and Canada for which dates were provided. (TIF)

Appendix S1 Description of fatality studies conducted at wind energy facilities, including project location, number of turbines, size (megawatts [MW]), and height of turbines; and post-construction study information, divided into avifaunal biome regions for the United States and Canada. Blank spaces indicate that data was not available. (DOCX)

Appendix S2 Bird fatality monitoring studies at wind energy facilities with estimates of fatality rates for small birds, confidence intervals (CI) and estimator used, if known, for avifaunal biomes in the United States and Canada. Blank spaces indicate that data was not available. (DOCX)

Appendix S3 Variables used to calculate a multiplier value used to determine estimates of small-bird rates of fatality for wind energy fatality studies providing only all-bird estimates, in the United States and Canada, grouped by avifaunal biome. (DOCX)

Appendix S4 Percent of trial carcasses found in experimental searcher efficiency (SEEF) bias trials and average removal time (days) in carcass removal (CRT) bias trials for small birds and all birds for postconstruction fatality monitoring studies conducted at wind energy facilities in the United States and Canada, categorized by avifaunal biome. Blank spaces indicate that data was not available.

(DOCX)

Appendix S5 Additional variables used to calculate a multiplier value used to determine estimated rates of fatality for small birds and the calculated multiplier for wind energy fatality studies providing only all-bird estimates for each associated avifaunal biome in the United States and Canada. See equation in methods section of main document.

(DOCX)

Appendix S6 Variables used to determine which bias adjustment factors to apply to the fatality estimate for small birds in 116 studies of bird collisions at wind energy facilities conducted in the United States and Canada. Search interval, percent of small birds found during searcher efficiency trials and categorization [low (0–0.375), medium (0.375–0.65), and high (0.65–1)], average carcass removal times (days) and carcass removal classification [fast (0–10 days), moderate (11–23 days), and slow (24 or more days)]. (DOCX)

Appendix S7 Fatality studies conducted at wind energy facilities in the United States and Canada, sorted by avifaunal biome region, with associated small-bird fatality rate estimates (birds/megawatt/year), for which the estimator type is identified, the applied low and high bias adjustment factors, followed by the resulting low and high bias-adjusted fatality rates for small birds.

(DOCX)

Appendix S8 The number and percent composition of fatalities of small passerines found during 116 studies of bird collisions with wind energy turbines, geographically separated into avifaunal biomes, along with the estimated annual number of fatalities using the lowest and highest bias adjustment value. Blank spaces indicate no fatalities were recorded. See Appendix S10 for scientific names of each species. Column A = number of fatalities found in studies in biome, B = % composition in biome, C = estimated number of fatalities each year adjusted by the bias value that was the lowest, D = estimated number of fatalities each year adjusted.

Appendix S9 The cumulative values for analysis of small-passerine fatalities in 116 studies at wind energy facilities from all associated avifaunal biomes* in the United States and Canada. Total number and percent composition of fatalities of small-passerines, estimated number of fatalities using for the lowest and highest value of bias and the biome-specific rate (bird fatalities/megawatt/year) from studies and total megawatts of operating capacity, and the adjusted number of fatalities by species. (DOCX)

Appendix S10 Annual fatality rates compared to population sizes for species of small passerines found as fatalities in 116 available studies conducted at wind energy facilities in the United States and Canada. The estimated average number and percent of population killed each year after low and high bias adjustments were applied and

⁽DOCX)

adjusted for operating capacity (see Appendix S9); estimated population size, and the proportion of the population that these estimates represent. Based on actual fatalities found both during scheduled searches and incidentally.

(DOCX)

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Author Contributions

Conceived and designed the experiments: WPE KJB DHJ JLG. Analyzed the data: WPE KJB MMW. Wrote the paper: WPE MMW KJB DHJ JLG.

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Icebreaker Windpower, Inc. Case No. 16-1871-EL-BGN Testimony September 6, 2018

Attachment WPE-3

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RADAR OBSERVATIONS OF BIRD MIGRATION OVER THE GREAT LAKES

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ABSTRACT.—The Great Lakes and nearby agricultural midwestern United States together represent a geographical challenge to migratory land birds during flight and stopover. We explored large-scale migratory responses of land birds encountering the Great Lakes as revealed by weather surveillance radars (WSR-88D) and two smaller specialized radars. Those responses reveal comprehensive landscape- or regional-scale migratory patterns that would otherwise have been difficult to infer. Analysis of radar echoes showed birds crossed the Great Lakes in large numbers, although we also found evidence of birds avoiding lake crossing in some locations. Around dawn, birds over water in numerous locations frequently exhibited an increase in migratory height (dawn ascent) and often an accompanying reorientation toward nearest land if they were within ~28 km of shore. Those behavioral responses to the Great Lakes influence the resulting distribution of birds stopping over in the intervening terrestrial landscapes. *Received 23 August 2001, accepted 14 December 2002.*

RESUMEN.— Los Grandes Lagos y las áreas agrícolas cercanas del medio oeste de los Estados Unidos representan un desafío geográfico para las aves migratorias terrestres durante el vuelo y las escalas de migración. Exploramos las respuestas migratorias a gran escala de aves que se encuentran con los Grandes Lagos mediante radares de vigilancia climáticos (WSR-88D) y dos radares especializados más pequeños. Dichas respuestas nos permitieron observar patrones generales a la escala de paisaje o región que de otra manera hubieran sido difíciles de inferir. Análisis de los ecos de radar mostraron que grandes números de aves cruzaron los Grandes Lagos, aunque también encontramos evidencia de aves que evitaron cruzarlos en algunas localidades. Alrededor del amanecer, en numerosas localidades las aves frecuentemente exhibieron un aumento en la altura de migración (ascenso del alba) a menudo acompañando por una reorientación hacia la tierra más cercana si se encontraban a menos de ~28 km de la costa. Estas respuestas conductuales ante los Grandes Lagos influencian la distribución de las aves que realizan escalas migratorias en los paisajes terrestres que se encuentran entre ellos.

STUDIES OF BIRD migration across large bodies of water have illuminated our understanding of the mechanisms and evolution of migration and stopover, partly because water represents poor stopover habitat in extremis (Moore and Simons 1992). The five Great Lakes constitute ~250,000 km² of open water and stretch 1,400 km east to west (Government of Canada and U.S. Environmental Protection Agency 1995). Here, we consider the propensity for land birds to cross the Great Lakes during migration, and whether those that cross engage in dawn ascent and reorientation. Those behaviors, operating together, determine in part how birds variously encounter coastal habitats at the end of nocturnal migration.

Bruderer and Liechti (1998) observed reduced tendency for nocturnal migrants approaching the Mediterranean Sea to cross as night progressed, suggesting that birds reaching the coast later were less energetically prepared for a potentially lengthy crossing. Alerstam and Pettersson (1977) theorize and then support empirically that the tendency for migrating birds to avoid crossing parts of the North Sea is driven by a combination of factors including wind direction and the angle between the track of birds and orientation of the approaching coastline.

Myres (1964) noticed "dawn ascent and reorientation" over the North Sea in fall, in which radar echoes from distant birds over water increased in number or appeared where none had been before. The birds (especially *Turdus* thrushes), well out of sight of land, appeared

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to ascend around sunrise and then assume a new direction of travel, frequently one that had the effect of increasing the chance of birds encountering land rather than continuing into the open Atlantic Ocean. Birds departing the northeastern coast of North America in fall, on the other hand, sometimes turn back toward land at dawn only if they are within sight of land (Myres 1964; reviewed in Richardson 1978).

The behavior of migratory birds aloft through the Great Lakes region is poorly understood (see Hussell et al. 1992, Ewert and Hamas 1995) largely because the indirect means of observation are often technically demanding. Such methods include flight-call monitoring (Evans and Rosenberg 2000, Larkin et al. 2002), radio telemetry (Cochran et al. 1967, Cochran and Kjos 1985, Diehl and Larkin 1998), passive infrared (Liechti and Bruderer 1995), and radar (Eastwood 1967, Gauthreaux 1971, Larkin 1994, Bruderer 1997).

In the past 10 years, new doppler radar technology has become available for use in studies of bird movements in the United States. This system of 154 radars (Crum and Alberty 1993), widely known as "NEXRAD" (NEXt generation RADar)—or more properly WSR-88D (Weather Surveillance Radar, 1988 Doppler)—is capable of revealing large-scale patterns of bird migration. In recent years, S. A. Gauthreaux and colleagues have uncovered some of the potential of WSR-88D for studying bird movements (Gauthreaux and Belser 1998, Gauthreaux et al. 1998, Russell and Gauthreaux 1998; see also Larkin 1984, 1991a) resulting in renewed interest in radar ornithology in the United States. These large radars are particularly useful for studying patterns of migration over and around the Great Lakes, because the lakes are narrow enough that favorably situated land-based radars operating simultaneously can obtain a panoramic picture of migrating birds (Fig. 1). The surrounding glacially scoured landscape is also generally free of topography that can obstruct the radar's beam.

Care is needed in interpreting WSR-88D imagery, in part because over large lakes, refraction (or bending) of the radar's beam may strongly influence the apparent strength of radar echoes of birds at some times of the day



FIG. 1. Ten radars capture a migration primarily composed of land birds on 3 May 2000 between 2235 and 2245 hours. Black dots show radar locations and white polygons mark where regions of echo were sampled for quantification. Color scales relate to quantifiable densities of birds in this heavy migration (see text). The bulls-eye pattern of decreasing echo strengths around radars in this composite is an artifact of the way the WSR-88D beam gradually passes over the migratory layer as the earth (and birds) curve out from beneath the beam at longer ranges. That explains the absence of echo due to birds over some geographic locations and does not indicate where birds are absent. White polygons delimit sampling regions used in comparing bird densities over water and over land at three different radars, KGRB, KCLE, and KBUF. The 5×30 km white rectangle along the Wisconsin coast (near KMKX) marks the sampling region used in quantifying dawn ascent. Courtesy of WeatherTAP.com

and year. The approximation of four-thirds of the earth's radius often used over land to account for standard refraction may not apply (for review see Ko et al. 1983), and some closer higher-flying birds may be missed because the beam has been refracted downward. We have observed cliffs and other ground-clutter echoes on WSR-88D at great distance across the Great Lakes in April and early May, when both empirical data (Bean and Emmanuel 1973) and theory (Paulus 1985) suggest refraction should be strongest.

By quantifying differences in WSR-88D bird echoes, we examined the degree to which birds engaged in movements consistent with lake crossing (bird densities over land not significantly different than bird densities over water) versus lake avoidance (bird densities over land significantly greater than bird densities over water). Because even the large radars of the WSR-88D system offer poor coverage of birds crossing Lake Superior, we present data from a small tracking radar located near the center of the Upper Peninsula of Michigan. We also examined whether dawn ascent and reorientation was common over the Great Lakes by quantitatively examining temporal changes in bird-echo strength and doppler velocity in the time before, during, and after dawn. Finally, we consider how those movements may influence subsequent stopover patterns by migratory land birds in Great Lakes coastal habitats (see Barrow et al. 2000). Throughout, we illustrate some of WSR-88D's capabilities and consider methodological issues in using that system for biological research.

METHODS

Estimating bird density.—Our analysis focuses on WSR-88D data collected when the radar's beam is at its lowest elevation angle of 0.5° measured up from the horizon. Radars in the WSR-88D system emit microwaves in pulses along a narrow conical beam that is nominally 0.95° across but that also spills some energy in directions outside the 0.95° beam. For that reason, objects near the ground close to the radars often produce strong echoes even though they may not lie directly in the beam. Echoes from such so-called ground clutter were suppressed using custom internally written software.

Results presented here are in units of birds per cubic kilometer. However, radars within the WSR-88D system show the amount of echo from a large volume of airspace reflected back to the radar, or reflectivity, in logarithmic units of reflectivity (dBZ). Logarithmic units allow concise description of a large range of reflectivity from a few small droplets of rain or a few small insects to numerous large drops in an intense storm or a large movement of waterfowl. The linear measure of reflectivity used in deriving birds per cubic kilometer is calculated as $Z = 10^{dBZ/10}$. This is not a measure of echo from a single target (one bird or one hailstone), but rather of numerous targets distributed throughout the volume of airspace being measured by the radar. Black and Donaldson (1999; see also Gauthreaux and Belser 1998, 1999) showed that, when targets such as birds are well distributed in space, *Z* follows the relationship, $28.0 \cdot Z = average$ target density × average radar cross-section per target for a given volume of airspace at a given range from the radar. The average density is in units of targets per cubic kilometer. The average radar cross section, or echoing area of a target (Vaughn 1985), is in units of square centimeters × target⁻¹. Density of birds in units of square centimeters per cubic kilometers is reflected by 28.0Z. We calculate average bird density aloft as 28.0Z divided by a representative cross-section for a migratory land bird, 17.5 cm² (Larkin 1991b).

Bird cross-sections used to calculate bird density were empirically estimated by regressing bird reflectivities from WSR-88D with actual bird densities aloft using a portable 3 cm wavelength radar. In the spring of 1997, 1998, and 1999, one of us (J.E.B.) operated a small, dedicated 3-cm wavelength radar at Brock University, 46 km north west of the Buffalo WSR-88D (Fig. 2, KBUF; unless otherwise indicated, refer



FIG. 2. Locations of 10 radars in the WSR-88D system offering Great Lakes coverage. Arrows at each radar location indicate the general direction of migration near midnight on 3 May 2000, depicted in reflectivity on Figure 1. Each radar is identified by a four-letter call sign: KGRB = Green Bay, Wisconsin; KMKX = Dousman, Wisconsin; KLOT = Romeoville, Illinois; KAPX = Gaylord, Michigan; KGRR = Grand Rapids, Michigan; KIWX = North Webster, Indiana; KDTX = White Lake, Michigan; KCLE = Cleveland, Ohio; KBUF = Buffalo, New York; KTYX = Montague, New York. Direction data were unavailable at the time this research was conducted.

to Fig. 2 to identify locations of WSR-88D radars by their four-letter call signs). The center of the KBUF radar beam at 0.5° elevation lies 600 m above Brock at that distance, and the 3-cm radar counted individual birds overhead in the same range of heights as those detected in the WSR-88D's beam, permitting direct comparison between data from the 3-cm unit and *Z* from WSR-88D (Fig. 3). Because the 3-cm radar operated in conical mode (Eastwood 1967) it was possible to obtain velocities of birds and therefore to calculate a bird density overhead on the basis of velocity and numbers of birds passing through the airspace swept out by the 3-cm radar's beam.

Bird density measured by 3-cm radar at heights of 500–700 m (Black 2000) was compared with a 5 × 5 km square of WSR-88D *Z* centered above the 3-cm unit between 2215 and 2345 hours local time (all times expressed in text are local time). The slope of a linear regression on bird density measured by 3-cm radar and *Z* was forced through the origin and gave an estimate of mean cross-section (σ) on WSR-88D ranging from 9 to 34 cm² across the three seasons, reasonable values for σ of birds (Fig. 3; Vaughn 1985, Larkin 1991b). The slope (σ = 17.5 cm²) is typical for a small passerine and the measured bird density explained much of the variance in WSR-88D reflectivity *R*² = 0.75.

These results are important for two additional reasons: (1) migrating birds can account for the strong echoes in WSR-88D data quantitatively, and (2) at least in situations where the unobstructed WSR-88D beam intersects migrating birds at a favorable range and other factors are held constant, the reflectivity from a WSR-88D bears a direct, quantifiable relationship to the volumetric density of migrating birds.

Identifying lake crossing and avoidance.-Biological processes such as lake avoidance are seen on radar as departures from symmetrical radar reflectivity patterns typified by that around KMKX and other radars in Figure 1. Variation in geography, topography, and vegetation generates an uneven distribution of birds in the landscape during stopover that translates into asymmetries in the pattern (Pearson and Gardner 1997) of radar echoes shortly after takeoff (e.g. Fig. 4). As migration progresses, individual birds of many species assume courses in varying winds and spread out in the airspace (Fig. 5). Through that spreading, small features of the landscape reflected in the echo pattern at takeoff eventually blur and disappear (compare KCLE on Figs. 1 and 4). As time passes, larger structures in the echo pattern either vanish as spreading homogenizes the migratory layer or persist as such structures continue to influence migratory behavior.

In identifying departures from symmetry that are consistent with lake avoidance, we quantitatively compared bird densities sampled over land and water using WSR-88D. Image data used in that analysis occurred as snapshots of migration at each radar site



FIG. 3. Mean bird density between 500–700 m above ground level explains most of the variance in WSR-88D reflectivity ($R^2 = 0.75$) where the slope of the linear regression is the WSR-88D cross-section, σ , a measure of the target's echoing area. That relationship is based on bird-density data collected with a small, 3-cm wavelength radar (see text) around 2300 hours between 20 April and 16 May 1999 at Brock University, St. Catharines, Ontario.

and updated every 5 to 10 min. For each of three radar sites (KGRB, KCLE, and KBUF), we used the closest image to 2330 hours for each migration day included in the analysis between 20 April and 21 May 2000 and 1 September and 30 September 2000. By 2330 hours, migration is near peak intensity and birds have had ample time to migrate over water in large numbers. Images selected for analysis excluded those dominated by weather echoes, radar artifacts such as those caused by refraction, weak migration (<1 bird km⁻³), and widespread insect activity. We identified migrations dominated by insects by calculating airspeed from the vector difference between wind and ground velocities using nearest radiosonde (wind profile) data and WSR-88D velocity, respectively (see below). We considered WSR-88D targets exhibiting airspeeds less than 6 m s⁻¹ to be insects (Larkin 1991b) and culled images dominated by them. For this analysis, we chose coastal radars offering the best lake coverage (KCLE, KBUF). We did not analyze data from KTYX and KMQT (Marquette, Michigan; not shown on Fig. 2) because beam blockage apparently caused by relief in terrain biased estimates of radar reflectivity. We included KGRB, although further from a coast, to broaden sampling to represent more western lakes.

We assumed each nocturnal exodus included in the analysis represented an independent sample of migratory behavior involving mostly different birds. For each migration, we sampled bird echoes around three lakes—Michigan, Erie, and Ontario (see Fig. 1



FIG. 4. Takeoff on 18 September 2000 as seen by radar in Cleveland, Ohio, and Buffalo, New York, ~1.3 h after local civil sunset. Images were combined to highlight habitat use patterns revealed at takeoff. The takeoff pattern at Buffalo (1934 hours) occurred 19 min before that at Cleveland (1953 hours) because of the sun setting later further west. Concentrations appear along the southern coast of both lakes Erie and Ontario. Pelee Island, Point Pelee, Rondeau, and Long Point along the northern coast of Lake Erie give rise to particularly strong bird echoes. Extremely weak echoes over water at that time are of unknown origin but are probably not birds. White patches showing no echo south of Buffalo (KBUF) result from ground clutter (e.g. topography) causing the radar to automatically reject all echoes from those areas. Courtesy of WeatherTAP.com



FIG. 5. Detailed structure of a takeoff on 15 May 1999 around the Buffalo, New York radar 57 min after local civil sunset. In a map view (left), northward migrating birds are seen moving out over the southern rim of lakes Erie (left) and Ontario (top) in large numbers. Ground clutter causes gaps in the echo pattern to the south and southeast of KBUF. Two line segments on the map view delineate cross sections (right) showing the vertical distribution of migrating birds as they take off over Lake Erie (AB) and over land (CD). These vertical cross-sections are assembled from multiple radar scans at different elevations of the beam. The cross-sections are slightly "U" shaped because the radar's beam is closer to the ground when sweeping across the middle part of the line segment nearer the radar. Maximum height of the migratory layer (~2000 m above ground level) is similar in both AB and CD.

for layout of sample regions). We chose location and size of sample regions to minimize accidental sampling of ground clutter or areas influenced by beam blockage while maximizing the area sampled. Echo sample regions were delineated in polar coordinates (range and azimuth) at identical ranges within each radar (Fig. 1) to avoid bias introduced by the earth (and therefore the migratory layer) curving out from beneath the radar's beam with increasing range. The width of Lake Ontario constrained the range depth of sample regions to 30 km (see Fig. 1). We applied that sampling range at all radars for consistency. Minimum and maximum ranges sampled varied between radars (75-105 km at KGRB, 40-70 km at KCLE, 55-85 km at KBUF) to ensure adequate sampling over water. However, because sampling ranges varied between radars, we did not compare or combine reflectivities measured at different radars.

Land samples composed of separate regions around a radar were pooled (Fig. 1). We computed mean bird density over land and water and tested their differences using paired sample tests. Because spring KGRB data violated assumptions of normality and symmetric distribution about the median, we used conservative nonparametric sign tests to test differences between over-water and land samples.

For analysis of birds crossing Lake Superior in fall, we back-extrapolated points of departure of from tracks of individual migrating birds taken in 1983 and 1984 with a modified tracking radar in Michigan's Upper Peninsula. We verified those radar targets as birds and not insects by examining wing-beat signatures (for details see Larkin and Frase 1988). Birds were assumed to take off 48 min past civil sunset (Diehl and Larkin 1998) and travel straight at constant speed. In the back-extrapolation, we used all straight, nocturnal tracks that were at least 10 s in duration and aloft at least 0.25 h. See Larkin and Frase (1988) for further details.

Dawn ascent and reorientation.—We defined dawn reorientation on WSR-88D as a geographically widespread and consistent change in velocity compared with WSR-88D images before dawn, occurring at the time of maximum over-water reflectivity and not attributable to changes in winds with time or height. We measured the spatial extent of reorientation directly from WSR-88D doppler velocity except when available doppler velocity values were corrupted by artifacts in the velocity data (Rinehart 1997).

We identified dawn ascent by examining 100 consecutive mornings around Milwaukee, Wisconsin (KMKX, 8 April through 22 May, and 17 August through 10 October 2000). To determine if that phenomenon occurred throughout the Great Lakes, we examined 34 additional nonconsecutive mornings at other radars (Fig. 2; KAPX, KCLE, KBUF, KGRR) during days of known bird migration. Over land, distant echoes of nocturnal migrants diminish in reflectivity around dawn as landing birds descend below a height detectible by radar. In this context, we define "dawn ascent" as increased reflectivity at civil sunrise compared with 50 min earlier. We calculated mean bird density at KMKX in a 5×30 km region over Lake Michigan (Fig. 1; again chosen to minimize effects of beam blockage), and as above, omitted mornings dominated by weather echoes, radar artifacts such as obvious refraction, or widespread insect activity.

Dawn reorientation was identified from WSR-88D doppler base velocity which measures the component of velocity of the bird toward or away from the radar (Rinehart 1997). For a bird moving perpendicular to the radar beam, the doppler speed is zero, whereas for a bird moving directly toward (Fig. 6; velocity, dark green) or away (Fig. 6; velocity, dark red) from the radar, the doppler speed is almost exactly the bird's speed over the ground. When all birds are flying in the same direction there is a doppler region (here light red in color, velocity component 0 m s⁻¹; e.g. Fig. 6, velocity) perpendicular to the direction of flight. Base velocity images often exhibit complicated patterns, with birds flying in different directions and speeds at different ranges and bearings from the radar.

Velocity values are helpful in deciding if targets detected are insects or birds. One needs to know the wind velocity aloft (obtainable from radiosonde or wind profile data taken at sunset and sunrise). Insects fly at very low air speeds (Larkin 1991b) and as a consequence their velocity relative to the radar will be close to that of the wind in both speed and direction. Birds fly at higher air speeds and may be flying in directions that are different from the wind direction. If indeed the doppler velocities differ substantially in direction or magnitude from the wind speeds aloft, then one can be reasonably sure the targets on the WSR-88D are birds (or bats) and not insects.

RESULTS

Birds crossed the Great Lakes in large numbers. Trans-lake migration was common (Table 1), and repeated occurrence of patterns typified by those around radars in Figure 1 showed birds regularly crossing lakes. The structure of bird movement over water early in migration is illustrated in Figure 5. In the crosssection of migratory bird echoes over eastern Lake Erie, higher birds seen at increasing distance from the coast reveal patterns of climb shortly after takeoff. Similar cross-sections over Lake Erie 3 h later showed climb patterns absent and birds distributed uniformly throughout the airspace similar to segment CD.

In both spring and fall 2000, mean bird densities over land were always greater than or approximately equal to those over water. Ratios of

tests were M, is repo	used to evaluate orted with <i>P</i> value	differer s. An ast	ices betweer terisk (*) ma	n paired land- rks significanc	and water- e and a plu	bird densit	ties. The sign	test statistic, t $\alpha < 0.05$.
Radar	Lake	п	Over	land	Ove	r water	М	Р
				Spring 2000				
KBUF	Erie	9	11.79	(7.84) ^a	8.79	(6.53)	-2.5	0.1797
KBUF	Ontario	9	11.79	(7.84)	6.44	(3.74)	-4.5	0.0039*
KCLE	Erie	5	31.78	(13.47)	10.50	(4.94)	-2.5	0.0625+
KGRB	Michigan	11	14.98	(15.12)	3.80	(1.78)	-4.5	0.0117*
				Fall 2000				
KBUF	Erie	6	18.51	(16.47) ^a	12.97	(16.34)	-2.0	0.2188
KBUF	Ontario	6	18.51	(16.47)	12.65	(9.76)	-1.0	0.6875
KCLE	Erie	13	22.60	(19.16)	9.40	(8.99)	-6.5	0.0002^{*}
KGRB	Michigan	5	9.81	(4.88)	3.49	(3.64)	-2.5	0.0625+

TABLE 1. Bird density (birds km-3) over land versus over the Great Lakes during spring and fall 2000. Each radar-lake combination identifies a location where bird densities were compared (see Figs. 1 and 2). Sign

^a We compare the same land densities are compared against densities against lakes Erie and Ontario at KBUF (see Fig. 1).

land bird to water bird densities varied from 1.3 to 3.9. In spring 2000, bird densities over water were significantly or nearly significantly lower than those over land around all lakes except the east end of Lake Erie (Table 1). This pattern of significance (or near significance) varied seasonally only around Lake Ontario where land and lake densities differed statistically in spring but not fall (Table 1). The more eastern samples (KBUF Erie and KBUF Ontario) exhibited higher bird densities in fall, whereas the more western samples (KCLE Erie and KGRB Michigan) showed higher densities in spring.

Wing-beat signature data from tracking radar stationed in Michigan's Upper Peninsula showed that the tracked animals were migrating birds (Larkin and Frase 1988). Estimated takeoff points from birds' tracks (n = 520) were concentrated north and south of Lake Superior establishing that direct crossing of that part of Lake Superior was common (Fig. 7).

Dawn ascents were always located over the Great Lakes except for occasional localized morning movements at, for example, Lake Winnebago, Wisconsin. At KMKX, ascent occurred on 28 of the 60 mornings free of weather and radar artifacts (Table 2), sometimes taking on the appearance of birds materializing from nowhere over open water. Birds in a dawn ascent were more often concentrated near shore than spread uniformly over the 5×30 km area used in the analysis (Fig. 1). Even among the mornings in which migration density over the water never reached 1 bird km⁻³, a dawn ascent was sometimes measured. Because birds depicted in Figure 8 were high, those over southwest Lake Michigan were observed by both the KMKX (Wisconsin) and KLOT (Illinois) radars, enabling confirmation of birds' actual flight behavior. The doppler velocity vectors from the two radars together reveal the birds were heading almost directly toward shore, with their resultant track toward ~170° and ground speed ~14 m s⁻¹ in winds from the northwest. The concentration of migrants just offshore in Figure 8 (reflectivity) was typical and such patches of echo near or on the shoreline always appeared denser toward the direction the birds were migrating (that is, denser along the south shore in fall, and along the north shore in spring). The apparent increase in bird density possibly resulted from an aspect effect, where birds' bodies are oriented so as to present their broad sides to the radar causing stronger echoes than when oriented directly toward or away from the radar (Edwards and Houghton 1959, Buurma 1995).

TABLE 2. Dawn ascent, measured as bird densities (birds km⁻³) over Lake Michigan 50 min before sunrise and at sunrise (means with SD in parentheses; medians behaved the same).

	п	Sunrise – 50 min	Sunrise
Ascent	28	4.18 (3.72)	6.43 (6.36)
No ascent	11	3.19 (4.88)	0.82 (0.89)
No migration	21	0.04 (0.06)	0.08 (0.18)

At KMKX, we observed 14 clear instances and 7 probable instances of dawn reorientation; on other radars within the WSR-88D system around the lakes (34 mornings), 5 clear examples and 5 probable examples were observed. Changes in doppler velocity up to 12.2 m s⁻¹ occurred within a few minutes when directions at dawn changed by >90°; flight speeds often exceeded those values because birds seldom happened to be flying directly toward or away from the radar. Reorientation occurred over water simultaneously with dawn ascent and was never observed inland or >39 km from land (minimum distance from shore 6.5 km, median 28 km). An inshore region of reoriented birds (Fig. 8) was always visible as part of a dawn ascent except when insufficient migrants, radar anomalies, or weather prevented us from observing it. Sometimes birds showed a thin stripe of mixed or very low velocities centered between two close shores, which seems to represent either a collection of birds vacillating in their orientation or different nearby individuals or flocks flying toward different shores.

Birds over the narrower Great Lakes (Lake Erie, Lake Ontario, west Lake Superior) or near isolated land features regularly reoriented toward the closest land. For example, by their prominence, Lake Erie's Point Pelee, Rondeau, and Long Point (see Dunn and Nol 1980) may draw dawn reoriented birds from disproportionately large airspaces relative to their land areas. Nocturnal migrants following coasts and diurnally mobile individuals may also be channeled into those peninsular areas. Those forces acting together will tend to concentrate birds, perhaps in the manner portrayed in Figure 4 where the northern coast of Lake Erie shows distinct areas of strong bird echoes at takeoff associated with geographically unique peninsular features of Lake Erie's northern coast.

DISCUSSION

Lake crossing and avoidance.—The proportion of birds engaging in lake crossing when encountering Great Lakes coasts determines in part the relative abundance of birds arriving over and perhaps concentrating in near or far shores (but see Smith et al. 1998). The decision of whether to cross likely reflects an "adjustable compromise" by the birds (Bruderer and Liechti 1998) between fitness benefits of early arrival at the final destination and the risks of assuming hazardous routes in expediting travel to that destination. Assuming the final destination is static, that compromise adjusts to changing risk conditions that vary with endogenous state, direction of travel with respect to the orientation of the coast, and weather—particularly wind conditions (Alerstam and Pettersson 1977, Bruderer and Liechti 1998). Furthermore, different sexes, age classes, or taxa likely respond differently when encountering coasts during migration (Dorst 1962, Dunn and Nol 1980).

Lake avoidance may occur as a matter of convenience. As the direction of travel increasingly parallels the coast, birds may increasingly favor slightly altered courses to remain over land and avoid lake crossings (Alerstam and Pettersson 1977). Gauthreaux (1980) reported that directions of travel near lakes Michigan, Erie, and Ontario tend to parallel the long axis of those lakes in spring and run more perpendicular to them in fall, especially lakes Erie and Ontario. Radiotracking studies of Catharus thrushes approaching Lake Michigan during migration show most of those birds either initiated or engaged in lake crossing (Cochran et al. 1967, Cochran 1972). The one clear exception portrays the track of a low-flying Veery (C. fuscescens) that followed along the western coast of Lake Michigan after intercepting the shore at an acute angle (Diehl and Larkin 1998). By contrast, birds encountering coasts perpendicular to their direction of travel may be more inclined to cross. If so, we would expect a tendency toward greater lake avoidance in spring and less in fall. Our results are consistent with that prediction around Lake Ontario, the eastern-most lake.

Lake avoidance assumes birds can detect the coast during nocturnal flight. Whether a coast is perceived may depend on the height of bird, the amount of moonlight, or presence of whitecaps (Griffin 1969).

Apparent decreases in bird density over water may also occur if birds change height as they move out over water, flying above or below the radar's beam in the process. Assuming standard refraction (see above), only birds flying lower over water might be consistent with our data. Although we cannot specifically exclude that possibility, birds that decreased height when flying over water would exhibit changes in height opposite that observed during dawn ascent. Bruderer and Liechti (1998) show no evidence that migrating birds altered their heights as they approached or left the Mediterranean coast.



Fig. 6. Fall land-bird migration over the Lower Peninsula of Michigan, northern Lake Michigan, and eastern Lake Huron 1.7 h after civil sunset on 12 September 2000 as seen in reflectivity (2035 hours) and radial velocity. In reflectivity (left), birds from the Upper Peninsula of Michigan and Door County Peninsula, Wisconsin, are crossing Lake Michigan in large numbers (arrows). Note the relative absence of bird echoes along the western shore of Michigan as Lake Michigan casts its "shadow" on the migratory layer. Radial velocity (right) shows the migration moving toward ~135° with peak speeds at 20 m s⁻¹. Doppler shift is depicted as speed toward the radar (green) or away from the radar (red). Courtesy of WeatherTAP.com



FIG. 7. Estimated takeoff areas show that targets verified as birds cross Lake Superior in fall. Takeoff locations were estimated by backward-extrapolating bird flight tracks collected using tracking radar, located here as a white plus. Highest density takeoff areas were delineated using a kernel-based density estimator (Arcview GIS, version 3.2; cell size = 1 km, search radius = 15 km). Targets estimated to have taken off from pelagic Lake Superior probably represent a combination of water birds and birds that took off at times other than sunset, changed course, or whose back-extrapolations were erroneous.

Because birds and insects fly at low altitudes and often in layers in the atmosphere (Vaughn 1985), variations in beam height produced by refraction can have a pronounced influence on the resulting reflectivity pattern and its interpretation. Unfortunately, radar beam refraction over the lakes remains poorly understood. Refraction may be more pronounced at Cleveland and Buffalo owing to those radars' close proximity to lakes. On some days, differences in bird density consistent with lake avoidance may also be consistent with birds over water flying largely above a radar beam refracted downward over water. However, if refraction accounted for most of the difference between apparent bird densities measured over land and water, we would also not expect dawn ascent to be visible on radar as frequently as it is, unless the refractory conditions also change frequently and suddenly at dawn, which is unlikely. Furthermore, refraction should be strongest in spring, yet patterns of statistical difference in bird densities over land versus over water were similar at three of the four locations measured in spring and fall.

Dawn ascent and reorientation.-Dawn ascent



FIG. 8. Ascent and reorientation of migratory birds over Lake Michigan 9 to 10 min after civil dawn over southeastern Wisconsin in fall following passage of a cold front the preceding night. Reflectivity (left) shows the remnants of nocturnally migrating birds still aloft over land, mostly at low heights, but dense concentrations of migrants still aloft over Lake Michigan. Dawn ascent is seen on radar as echoes appearing at greater height (and therefore greater range) than any time during the preceding night, a pattern best depicted through time (see Acknowledgments for a website URL showing this dawn ascent). Radial velocity (right) shows that diminishing migration over land is toward the southeast, the same direction as birds over both land and Lake Michigan had maintained during the preceding night. Far from shore over Lake Michigan, velocities of distant birds are also toward the southeast or east. However, velocities of closer birds—those within 39 km of land—were more toward the radar and therefore show birds reoriented toward the lakeshore. A distinct discontinuity in doppler velocity occurs at the shoreline. Patches of strong echo inland appeared suddenly ~15 min prior to these images and represent terrestrial birds departing their nocturnal roosts. Courtesy of WeatherTAP.com

is an increase in height of migrating birds (reviewed in Richardson 1978), and measured reflectivities of postdawn echoes provide further strong evidence for the reality of dawn ascent. Because low-flying birds may not be visible on WSR-88D radars, we cannot tell whether all migrating birds ascend at dawn over the Great Lakes. Many or most birds certainly ascend often enough to produce reflectivity over water equal to the most intense reflectivity observed over land during the preceding night.

Reorientation that accompanies dawn ascent constitutes a sudden change in vectors of travel that cannot be explained as a coincidental change in wind and whose magnitude is greater than that exhibited by migrating insects (Larkin 1991b). As such, reorientation confirms that echoes over the Great Lakes and, by extension, contiguous echoes over land, are predominantly migrating birds. (Migrating bats [Chiroptera] probably contribute to those echoes as well.) Results from the tracking radar and characteristics of the WSR-88D echoes (reflectivity and velocity) further support the target identity as birds.

Reorientation involves birds turning toward land when land is close and becomes visible in the dawn light. Celestial and large-scale geophysical cues can be ruled out to explain reorientation because neighboring birds that happen to be over a relatively narrow stretch of water fly toward opposite shores depending on which is nearer. Because reorientation can occur on calm mornings up to 39 km from shore, ordinary local acoustic cues such as waves against the shore (Griffin 1969) cannot explain reorientation. We rule out olfaction because migrating birds are usually traveling roughly with the wind, with any land-based odor source behind them. Thus, although the mechanism of other published occurrences of dawn reorientation can be difficult to determine (Drury and Keith 1962, Alerstam 1990), we conclude that birds in the present study oriented visually. Further supporting that idea is the assumption that dawn ascent functions to gain a high vantage from which to look for land. Dawn ascent may also serve other ultimate functions such as seeking cooler air or predator avoidance (Bourne 1980).

Our radar data clearly show Great Lakes crossing is common, and evolution has presumably equipped migratory land birds with behavioral adaptations that specifically permit birds to survive long flights over hazardous terrain (Biebach 1995). Nonetheless, direct indications of the Great Lakes as selective agents on migrating birds have been reported (Segal 1960, Janssen 1976), although that mortality is often poorly documented and difficult to quantify. As with larger bodies of water, the Great Lakes are large enough to kill birds and certainly add to existing selection pressures posed by other barriers to migration.

A large percentage of land birds confront the Great Lakes as they migrate through North America. As a consequence, millions of land birds find themselves aloft over the surface of the Great Lakes. For birds stranded over water near sunrise, the coasts of the Great Lakes represent first landfall. Reorientation and lake avoidance will tend to direct more birds along the near (or departing) shores of lakes whereas nonreoriented crossing will tend to direct birds toward the far shore. However, the geographic characteristics of each lake and how birds respond to the lakes during migratory flight tell only part of the story of how land birds come to occupy specific stopover habitats in the intervening landscape of the Great Lakes region. The finer scale process of habitat selection after migration remains largely unknown.

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Attachment WPE-4

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RESEARCH ARTICLE

Migrating birds reorient toward land at dawn over the Great Lakes, USA

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ABSTRACT

Most landbirds migrate at night and typically make landfall in suitable stopover habitat before dawn. However, when birds find themselves over large water bodies at dawn, they must continue flying into the day and either finish crossing the water body and land on the far shore or backtrack to the near (i.e. first encountered) shore to land. Their collective decisions will influence how migrants are distributed among shoreline stopover habitats on either side of the water crossing. We studied birds during 4 spring migration seasons from 2010 to 2013 in the Great Lakes region, USA. We used 3 weather surveillance radars to observe migrating landbirds' behavior at dawn and subsequent terrestrial distributions during stopover. Mean flight heights over land and water were higher and mean flight directions were more oriented toward the closest shore at dawn when compared to peak migration earlier in the night. The wider the lake crossing, the higher that birds along the lakeshore flew at dawn. Seasonal mean stopover densities of migrants on land within 3 km of shorelines were 48% higher on the near shores of lakes (based on the seasonal mean direction of migration) than on the far shores. There was a moderate positive correlation (r = 0.584, P < 0.001, n = 358) between the seasonal mean density of birds aloft over water at dawn and the stopover density of birds in adjacent shorelines. Thus, birds over the water. As a result, shoreline habitats on the near shores of lakes harbor greater densities of migrants and are thus critical stopover sites for migrating landbirds in the Great Lakes region.

Keywords: flight behavior, Great Lakes, migration, radar, shoreline, stopover

Aves migratorias se reorientan hacia la tierra al amanecer sobre los Grandes Lagos

RESUMEN

La mayoría de las aves terrestres migran durante la noche y típicamente paran en hábitats adecuados antes del amanecer. Sin embargo, cuando las aves se hallan sobre grandes cuerpos de agua al amanecer, deben seguir volando entrado el día y terminar de cruzar el cuerpo de agua y aterrizar en la orilla del lado opuesto o dar marcha atrás hasta la orilla que encontraron en primera instancia para aterrizar. Sus decisiones colectivas van a influenciar el modo en que las aves migratorias están distribuidas entre los ambientes de parada en las orillas a cada lado de las aguas atravesadas. Estudiamos aves durante cuatro estaciones migratorias de primavera desde 2010 a 2013 en la región de los Grandes Lagos. Usamos tres radares de vigilancia climática para observar el comportamiento de las aves terrestres migratorias al amanecer y las subsecuentes distribuciones terrestres cerca de la orilla durante la parada. Las alturas promedio del vuelo sobre la tierra y el agua fueron más elevadas y las direcciones promedio de vuelo estuvieron más orientadas hacia la primera orilla encontrada al momento del amanecer en comparación con el pico de migración que ocurre más temprano en la noche. Cuanto más ancho fue el lago que cruzaron, más alto volaron las aves a lo largo de la orilla del lago al amanecer. Las densidades estacionales promedio en los sitios de parada a menos de 3 km de la orilla fueron 48% más altas en la orilla primeramente encontrada de los lagos usando la dirección estacional promedio de los migrantes en comparación con el lado opuesto de los lagos. Encontramos una correlación positiva moderada (r=0.584, n=358, p<0.001) entre la densidad estacional promedio de las aves sobre el agua al amanecer y la densidad de aves en los sitios de parada en las orillas adyacentes. Por ende, las aves sobre el agua al amanecer tienden a regresar a las orillas encontradas en primera instancia de los Grandes Lagos para parar, más que seguir a través del agua. Como resultado, los hábitats de las orillas encontradas en primera instancia de los lagos albergan densidades mayores de migrantes y son por ende sitios críticos de parada para las aves migratorias terrestres en la región de los Grandes Lagos.

Palabras clave: comportamiento de vuelo, Grandes Lagos, migración, orilla, radar, sitio de parada

INTRODUCTION

The Great Lakes region of the United States is an important stopover area for migrating landbirds in both spring and fall (Bonter et al. 2009). High concentrations of birds are generally present in stopover habitat along the shores of the lakes and have been linked to the presence of abundant food sources in these habitats (Smith et al. 2007, Ewert et al. 2011). The majority of research in this area has focused on characteristics of stopover habitat use (e.g., Ewert and Hamas 1996, Smith et al. 2004, 2007, Rodewald and Matthews 2005, Bonter et al. 2009, Ewert et al. 2011). The link between flight behaviors of migrating landbirds aloft over the lakes and distributions within stopover habitat is less well understood.

The U.S. network of weather surveillance radars, comprising model Weather Surveillance Radar-1988 Doppler (WSR-88D) or Next Generation Radar (NEX-RAD), is a powerful tool to study birds in the air (Gauthreaux and Belser 1998). Diehl et al. (2003) used NEXRAD to observe a flight behavior they dubbed "dawn ascent" in the Great Lakes region. Dawn ascent is characterized by migrating birds over the water, increasing their flight height and often reorienting themselves toward shorelines as dawn approaches. Diehl et al. (2003) reported the median range over which reorientation occurred as \sim 28 km from the shore, although increased flight heights were observed over longer distances. Dawn ascent and reorientation has also been observed along the North Sea (Myres 1964). Dawn ascent could be a response to migrating birds' reluctance to continue a water crossing, regardless of the crossing distance, into daylight hours; nocturnal migrants typically end their flights at dawn (Diehl et al. 2003). Birds may gain altitude in an effort to locate the nearest shoreline or evaluate how far they must travel to complete a water crossing. If birds are returning to shore at dawn, this could contribute to the higher concentrations of birds along shorelines first encountered by birds when approaching the lake from the dominant seasonal migratory direction (hereafter "near shores"). Non-reoriented crossing will tend to direct birds toward shorelines encountered after crossing the lake in the dominant seasonal migratory direction (hereafter "far shores"). However, no studies have yet linked stopover distributions to the dawn-ascent flight behavior of migrants along the Great Lakes. Additionally, there have not been detailed studies of broad-scale variability in dawn flight behavior, nor of stopover use along shorelines that may depend on whether birds need to turn back or continue forward to reach the nearest shoreline.

In the present study, we used NEXRAD data from the Great Lakes region of the United States to compare the flight behaviors (height and direction) of migrating landbirds aloft over land and over water at peak migration and at dawn. We

also measured the density of birds aloft over stopover habitat within 3 km of the shores of the Great Lakes at dawn over water and during exodus over land and tested whether differences between densities on the near and far shores of the lakes are linked to dawn flight behavior.

We hypothesized that migrating birds would show differences in flight behavior at dawn compared to peak migration earlier in the night. We expected birds at dawn to show (1) increased flight heights and (2) flight directions more oriented toward the near shores of the Great Lakes, compared to the patterns at peak migration (Diehl et al. 2003). We further hypothesized that migrating birds over water at dawn might show additional differences in flight characteristics-increased height and reoriented flight direction-with respect to birds over land at dawn. The hypothesized changes in flight behavior might indicate that birds at dawn are looking for stopover habitat on the near shores of the lakes, which should result in measureable differences in stopover patterns of emigrants at flight exodus on following nights. Accordingly, we expected to see increased densities of birds at exodus on the near shores of the Great Lakes, as well as positive correlations between densities of birds over water at dawn and densities of birds over land at exodus the following night.

A more complete understanding of dawn ascent in the Great Lakes region illuminates the relationship between the behavior of birds aloft and stopover habitat selection, especially in habitat on the near shores. This information can inform decisions about the preservation of stopover habitat and the conservation of migratory birds in the Great Lakes.

METHODS

We used data collected from 3 NEXRAD stations across the Great Lakes region of the United States: Cleveland, Ohio (KCLE: 41.413°N, 81.859°W); Grand Rapids, Michigan (KGRR: 42.893°N, 85.544°W); and Green Bay, Wisconsin (KGRB: 44.498°N, 88.111°W) (Figure 1). These radars were selected because they observed significant amounts of Great Lakes shoreline (i.e. Lake Michigan and Lake Erie). We analyzed data collected by each radar during the spring migration season, April 1 to June 15, from 2010 to 2013. For each sampling day, we analyzed radar data from each station collected at 3 time points: (1) the onset of nocturnal migration exodus, hereafter "exodus"; (2) \sim 3 hr after sunset during the typical peak of migratory flight (Gauthreaux and Belser 1998, Diehl et al. 2003), hereafter "peak migration"; and (3) at dawn (sun elevation at the horizon). For sampling at peak migration and at dawn, we used the single radar volume scan closest in time to the desired time point. For sampling at migration exodus, we interpolated radar data in between volume scans using simple distance-weighted averaging for



FIGURE 1. Locations and names of the 3 NEXRAD stations in the Great Lakes region, USA, that were used in the study. Radar coverages of data are within the black rings. The shoreline for which data were collected is highlighted in white. The inlay shows how the shoreline was broken into polygons of 3 km parallel by 3 km perpendicular to shorelines to cover the area of water (dark gray) and an adjacent area of land (light gray) to compare reflectivity at dawn over water and at exodus over land.

every radar sampling volume to the time when the sun's elevation angle reached 7° below the horizon (i.e. just after the end of evening civil twilight; *sensu* Buler and Dawson 2014). When comparing data gathered at these time points, "peak migration" refers to the evening prior to a dawn sample and "exodus" refers to the evening following a dawn sample.

We constructed a shapefile in a geographic information system (GIS) to delineate shoreline segments of large lakes near each radar station. The shapefile consisted of polygons that were each 3 km parallel and 3 km perpendicular to the shoreline, covering a 9 km^2 area of either land or water on either side of the shoreline boundary (see inset of Figure 1). This shapefile was intersected with polar coordinate polygon basegrids of radar sampling volumes extending in a 100 km radius around each radar station to identify the portions of specific sampling volumes within each shoreline segment. The basegrid for each radar station is a GIS shapefile that delineates the two-dimensional boundaries of individual radars' sampling volumes within the coverage area of the radar, allowing the reflectivity data collected by the radar to be transformed into a geographic state space. Sampling volumes of radar basegrids have an azimuthal resolution of 0.5° and range resolution of 250 m, corresponding with the resolution of NEXRAD. We also characterized each shoreline segment by side of the lake, such that "near shores" are the shorelines typically encountered by birds before crossing a lake while flying along their mean peak migration track (Table 1) during the spring migration season, and "far shores" are the shorelines typically

encountered by birds after crossing a lake. Near shores were those on the eastern and southern sides of the Great Lakes; far shores were those on the western and northern sides. The domain of the Grand Rapids radar covered only near shores, while the Green Bay and Cleveland radars had a mix of near and far shores.

Radar Data Processing

Radar volume scans measuring birds aloft went through a two-stage screening process to determine suitability. First, we visually screened radar imagery compiled at the Surveillance of the Aerosphere Using Weather Radar (SOAR) website (http://soar.ou.edu/legacy.html) to achieve a coarse filter for contamination. SOAR provides a fast and easy-to-access look at the radar data but is limited by a coarse resolution and overlapping data from adjacent radar stations. The 2 main sources of contamination were precipitation and anomalous propagation, in which certain atmospheric conditions cause excessive refraction of the radar beam. We excluded from further analyses scans with precipitation within 100 km of the radar, or with obvious anomalous propagation of the beam. We downloaded radar sweeps that passed this first round of screening from the National Climatic Data Center (http://has.ncdc.noaa.gov/pls/plhas/has.dsselect), a service of the National Oceanic and Atmospheric Administration. Radar sweeps were visually screened at their native resolution for precipitation and anomalous propagation a second time with the program Integrated Data Viewer (Murray et al. 2003) to verify their suitability for analysis.

Flight characteristic						
Metric	Time	Location	KCLE	KGRB	KGRR	All radars pooled
Height above surface (m)	Peak migration	Land	574 ± 57.9	489 ± 38.6	615 ± 70.2	542 ± 30
		Water	681 ± 79.2	441 ± 45.5	522 ± 36.1	525 ± 34.7
	Dawn	Land	565 \pm 15.9	$734~\pm~14.7$	980 ± 7.2	704 ± 17.2
		Water	664 ± 15.5	812 ± 14.4	$1022~\pm~4.6$	785 ± 15.4
Track direction (°)	Peak migration	Land	$27.6~\pm~0.2$	349.7 ± 0.1	345.2 ± 0.1	-
		Water	$24.7~\pm~0.3$	329.9 ± 0.2	332.9 ± 0.2	-
	Dawn	Land	$83.0~\pm~1.3$	16.1 ± 1.0	54.1 \pm 0.5	-
		Water	89.1 ± 1.3	2.4 ± 0.9	65.3 ± 0.4	-

TABLE 1. Mean values (\pm SE) for flight characteristics of migrating birds in the Great Lakes region, USA, at dawn and at peak migration earlier that night as detected by 3 radars, 2010–2013.

We used the Weather Decision Support System– Integrated Information (WDSS-II), a suite of algorithms for weather radar data analysis (available at http://www. wdsii.org), to convert raw radar files into netCDF format containing reflectivity and radial velocity measures. We used data from the 0.5° beam tilt-angle sweep because this was the angle at which most birds were observed by the radar and because data at higher tilt angles were too sparse to be useful.

We used a Matlab program written by Dan Sheldon of the University of Massachusetts Amherst and NASA's Radar Software Library to de-alias the velocity data (Farnsworth et al. 2014). We then used custom R code to produce a velocity azimuth display (VAD) profile from each range annulus of each 0.5° sweep (sensu Browning and Wexler 1968). The VAD profile fits a sine function through the radial velocity data to give an average ground speed and track direction of flight for animals at the mean height of the radar beam above ground within each range annulus. The accuracy of the VAD assumes that animals are moving in a consistent manner, however variable their directions and speeds, throughout the altitudinal strata being analyzed. We excluded from analyses heights at which $R^2 < 0.25$ for the modeled sine functions. We retrieved VAD profiles separately for data over land and over water for each of our time periods: dawn, exodus, and peak migration.

We computed the mean ground speed and direction of birds across the VAD for each sweep by weighting data from each height using a vertical profile of reflectivity (VPR) following Buler and Dawson (2014). The VPR describes the ratio of the vertical variability of reflectivity at a given height in relation to the mean reflectivity from the ground to 1,750 m above the ground and was also used to determine the mean flight height of birds. These metrics were computed such that we had a measure of mean flight height and direction of birds for each radar sweep. Mean flight height and direction for each sweep were computed across all data within the range of radar, separating only into data collected over land and over water. We applied 3 grouping variables to the data: radar (KCLE, KGRB, KGRR), location (land vs. water), and time (dawn vs. peak migration). To distinguish the dominant biota aloft, we performed VAD analysis of radial velocity from the 3.5° tilt-angle radar sweep sampled at peak migration and subtracted wind vector from winds aloft collected via nearby radiosonde (archived by the University of Wyoming) or from surface winds collected from nearby weather stations when radiosonde data were not available to calculate mean target airspeeds. All nights with mean target airspeeds $<5 \text{ m s}^{-1}$ were considered insect dominated and were eliminated from analyses (Larkin 1991).

We estimated the vertically integrated reflectivity (VIR) within each sample volume in order to directly compare reflectivity measures at different ranges from radars and among radar scans, following previously established methods (Buler and Diehl 2009, Buler and Dawson 2014). This approach is necessary because the radar beam systematically samples increasing heights as it propagates away from the radar and because the vertical profile of bird reflectivity varies among radar scans. Each raw reflectivity measure is divided by the mean VPR ratio within the sampled volume airspace to produce an estimate of the mean reflectivity of birds in the airspace from 0 to 1,750 m above the ground. We converted the original reflectivity factor in units of Z (mm⁶ m⁻³) into more biologically meaningful units (cm² km⁻³; Chilson et al. 2012). We then multiplied reflectivity by the height of 1,750 m to "flatten" the volumetric measure of reflectivity into a two-dimensional measure $(cm^2 ha^{-1})$ representing the total amount of reflected cross-sectional area of birds per hectare above the ground. Unlike the analysis of flight height and direction, for which a mean value was computed for migrants over land and over water at each time point, mean VIR was computed individually within each shoreline polygon.

Statistical Analysis

To investigate the effects of our 3 grouping variables on flight height, we used an analysis of variance (ANOVA)



FIGURE 2. Time series of radar reflectivity from KGRR, Great Lakes region, USA, on May 16, 2010, around sunrise, showing changes in migrating birds' activity. At 4:15 EST, birds are migrating to the northwest. The sun strobe at 5:21 EST indicates sunrise. Bird activity decreases over land as birds end their migratory flight before dawn, whereas birds over water remain aloft after dawn.

with 3 factors: radar (KCLE, KGRB, KGRR), time (dawn, peak migration), and location (over land, over water). We used a Tukey-Kramer post hoc test to investigate differences between individual groups. To investigate the effects of our 3 grouping variables on flight directions, we used a Harrison-Kanji test for the analysis of variance of circular data (Harrison and Kanji 1988). Because the Harrison-Kanji build in Matlab handles only 2 grouping factors, we implemented the test separately for each radar, using time and location as factors.

Area-weighted mean dawn VIR was computed for each shoreline segment over water and for each segment over land at the following exodus for every sampling day. Only days that had data for both dawn and evening exodus were included. We also computed the geometric mean of daily reflectivity for each segment across all seasons. We tested for differences in the magnitude of VIR, using shoreline (near, far) and time (dawn, exodus) as grouping factors. Because there was significant interaction between these factors, we also used independent one-way ANOVA to test the effect of shoreline separately at dawn and at exodus.

We calculated the mean VIR across all seasons for nearand far-shoreline segments with all 3 radars pooled. We used the Pearson correlations between adjacent land and water segments to assess relationships between reflectivity at dawn over water and reflectivity during the following evening exodus over land. We computed correlations between segment pairs for all shorelines together, and also for near and far shorelines separately.

RESULTS

After screening for contamination by precipitation, anomalous propagation, and insects, 15% of total potential days had suitable sweeps at dawn for analysis (KCLE: 52 days, KGRB: 39 days, KGRR: 23 days). KCLE provided data within 104 segments along 312 km of shoreline, KGRB provided data within 174 segments along 517 km of shoreline, and KGRR provided data within 47 segments along 141 km of shoreline. The total sample size pooled across radars was 325 segments along 970 km of shoreline.

Visual inspection of time series of radar scans showed an increase in the extent and magnitude of reflectivities over the water just before dawn (Figure 2), which is consistent with migrating birds increasing their flight heights. This increase in reflectivity over water was typically not matched by a similar increase in reflectivities over land.

Differences in Flight Height and Direction

Birds showed increased flight heights at dawn compared to peak migration at the KGRB and KGRR radars, but not at KCLE (Table 1). The effects of radar and time were both significant, and an interaction between these factors was present. The effect of time (difference between dawn flight heights and peak migration flight heights) is therefore dependent on radar, with increases in dawn flight height seen at KGRB and KGRR but not at KCLE (Figure 3). The estimated mean difference in flight height between birds at dawn and birds at peak migration was 265 m at KGRB and 390 m at KGRR. The mean heights of birds aloft over water at dawn were generally great enough for birds to potentially see the opposite shoreline of lakes they were over (Table 2). In addition, these mean heights increased with increasing width of lake among the radars.

Additionally, the mean flight height over water at dawn was higher than the mean flight height over land at dawn, both at each radar individually and pooled across all samples. This effect was not present at peak migration (Table 1). Overall, the effect of location (land vs. water) was not statistically significant across all grouping variables, but there was a significant interaction term between location and time, indicating that the effect of location on flight height was different at dawn than at peak migration (Table 3).

Flight directions during peak migration were approximately northerly, ranging from 345° at KGRR to 27° at



FIGURE 3. Boxplots of the flight heights for birds at dawn and during peak migration in the Great Lakes region, USA, 2010–2013. Boxes are centered at median and extend from the 25th to the 75th percentiles of the data. Whiskers extend to the extreme data points not considered outliers. Outliers are plotted separately. Sample sizes are given below the boxes. Letters indicate groups based on a Tukey-Kramer post hoc test for significant difference between groups. Boxes with the same letter are not significantly different.

KCLE. The flight directions at dawn were more directed toward the near shore than those at peak migration (Figure 4). At each of the 3 radars, the effect of time on flight direction was significant but the effect of location on flight direction was not significant (Table 4). There were no significant interactions between factors at any of the radars. Birds changed their flight direction at dawn compared to peak migration at each radar, but there was no difference in flight direction over land and over water at either dawn or peak migration.

Differences in Reflectivity for Near and Far Shores

The VIR of migrating birds aloft over water within 3 km of shorelines at dawn was 21% higher at the far shores than at

near shores when data were pooled across all radars (Figure 5). Bird density aloft over land within 3 km of shorelines at flight exodus on subsequent evenings was 48% higher at near shores than at far shores (Figure 5).

There was a significant interaction term (P < 0.001, n = 650) between time (dawn vs. peak exodus) and shoreline (near vs. far shore) factors, indicating that the effect of near vs. far shore on reflectivity is not the same at dawn and exodus. Based on the results of independent ANOVA tests for dawn and exodus data, the differences in near- and far-shoreline reflectivity at dawn over water were marginally significant (P = 0.044, n = 325) and the differences at exodus over land between near and far shores were significant (P < 0.001, n = 325).

The correlation between seasonal mean dawn reflectivity over water and seasonal mean exodus reflectivity over land for pairs of adjacent segments was moderately positive when all shoreline segments were considered together (r = 0.269, P < 0.001, n = 325). When near and far shores were considered separately, the correlation was much stronger for near shores (r = 0.584, P < 0.001) than for far shores (r = 0.280, P < 0.001).

DISCUSSION

Migrating birds showed large differences in aggregate flight behaviors between peak nocturnal migration and dawn. These changes were characterized by increased flight height and changes in flight direction that generally resulted in birds orienting themselves toward the near shores of the Great Lakes at dawn. At dawn, birds showed further increases in flight height over water than over land, but this effect was not present during peak migration.

Dawn reorientation of migrating birds aloft toward the nearest shorelines is consistent with other studies that have documented dawn ascent flights (Myres 1964, Diehl et al. 2003, Bowden et al. 2015, Rathbun et al. 2016). Additionally, as morning approaches, nocturnally migrating birds have been found to reorient toward land along the Atlantic coast of the United States (Horton et al. 2016) and along the Mediterranean Sea (Bruderer and Liechti 1998).

TABLE 2. Approximate distance to the horizon for an observer at the mean flight height of migrating birds, at peak nocturnal migration and at dawn, for 3 radars within the Great Lakes region, USA, during spring migration, 2010–2013. Approximate ranges of lake widths within each radar domain are also presented for comparison.

		Radar			
Parameter	KCLE	KGRB	KGRR		
Distance to horizon at mean height of birds at peak nocturnal flight (km)	93	75	82		
Distance to horizon at mean height of birds at dawn (km)	92	102	114		
Width of lake (km)	50-70	80-90	120–130		

TABLE 3. Results of an analysis of variance for differences in flight height among groups of migrating birds in the Great Lakes region, USA, during spring migration, 2010–2013. Radar (KCLE, KGRB, KGRR), time (dawn vs. peak migration), and location (land vs. water) were included as grouping factors.

Source	Sum of squares	df	Mean square	F	Probability > F
Radar	1,309,990	2	654,995	30.91	<0.001
Time	3,708,900	1	3,708,900	175.03	< 0.001
Location	43,629	1	43,629	2.06	0.15
Radar*time	2,126,251	2	1,063,125	50.17	< 0.001
Radar*location	109,189	2	54,593	2.58	0.078
Time*location	122,932	1	122,932	5.80	0.016
Error	6,738,344	318	21,190		
Total	15,572,854	327	·		

The increase in flight height is presumed to be a response by which birds evaluate the width of the ecological barrier posed by the large Great Lakes (Diehl et al. 2003). Migrants over Lake Michigan increased in height at dawn. Migrants increased their flight heights at dawn enough to appear to allow them to see across the lake. Greater increases in heights occurred with a wider lake crossing. This is somewhat consistent with the results of Bruderer and Liechti (1998), who found that birds flying over the widest part of the Mediterranean Sea flew higher than birds crossing near the Iberian Peninsula. However, they could not rule out topographic relief as a factor in these differences and did not observe significant ascent of birds at dawn. Rather, birds flew at the same heights throughout the night. A return to habitat on the near shore may be the result of birds deciding that the crossing is too wide to attempt until the following evening exodus, after flying high enough to see to the other side. We encourage

further investigation of whether birds seek a higher vantage point at dawn to observe the width of a water crossing. It would be interesting to see if a similar response would be observed when the body of water is too wide for migrants to see the other side, even with the increased flight heights associated with dawn ascent.

We estimated that only birds flying over Lake Erie near KCLE were likely able to see across the entire lake during peak nocturnal migration. Interestingly, no increase in flight height at dawn was observed at the KCLE station. It is possible that the narrower crossing presented by Lake Erie eliminates the need to increase height at dawn. However, birds were already flying higher, on average, at the KCLE station during peak migration than at the other sites.

Our finding of a reorientation response is also consistent with birds at dawn seeking stopover habitat on the near shores of the Great Lakes. Diehl et al. (2003) suggested that



FIGURE 4. Circular histograms showing daily mean flight-track directions for birds in the Great Lakes region, USA, at peak migration (i.e. 3 hr after sunset) and at dawn for each NEXRAD radar station, 2010–2013. Sample sizes are given in parentheses. The mean across all years is indicated by an arrow. Dots represent the observed mean direction for an individual day. A map of the land (white) and water (gray) areas within 100 km of the radar station is shown within the circular histograms for reference.

TABLE 4. Results of a Harrison-Kanji test for differences between groups of migrating birds in flight direction at dawn and during peak migration in the Great Lakes region, USA, during spring migration, 2010–2013. Separate tests were done for each radar, including time (dawn vs. peak migration) and location (over water vs. over land) as grouping factors.

Radar	Factor	df	χ^2	Р
KCI F	Time	2	16,11898	< 0.001
	Location	2	0.290949	0.86
	Interaction	1	0.311419	0.58
KGRB	Time	2	10.89632	0.004
	Location	2	3.127111	0.21
	Interaction	1	2.932581	0.087
KGRR	Time	2	76.47924	< 0.001
	Location	2	1.347019	0.51
	Interaction	1	1.018962	0.31

this response may result from evolutionary pressures posed by the difficulty of lengthy crossings across large water bodies. Although the threat of drowning when crossing the Great Lakes is likely minimal in comparison to larger water crossings within North America, such as the Gulf of Mexico, mass mortality of landbirds attempting to cross Lake Michigan can occur (Diehl et al. 2014).

As a consequence of returning to the near shoreline at dawn rather than continuing across to the far shore, migrating birds concentrate at higher densities on near shores than on far shores. This was evidenced by greater VIR of birds emanating from stopover habitats on the near shores for all radars during evening exodus. The correlation between the density of birds over water at dawn and the density of birds at exodus on adjacent shorelines links dawn activity over water and the subsequent distribution of birds in shoreline stopover habitat. The fact that this relationship was much stronger on near shorelines supports the hypothesis that birds that are generally close to shorelines tend to return to stopover habitat on the near shore at dawn rather than continuing across the lake during the day. Unfortunately, low-flying birds could not be detected far from shorelines by the radars we used, so whether most birds far from shorelines also reorient toward shorelines or not is difficult to evaluate. However, Diehl et al.'s (2003) results suggest that reorientation is likely limited to migrants within 28 km of a shoreline. Additionally, lake avoidance by birds altering their course to remain over land along the long axis of the lakes in spring, which seems less common than lake crossing, will also tend to direct more birds along the near shores of lakes (Gauthreaux 1980, Diehl and Larkin 1998, Diehl et al. 2003). Lake avoidance is more apparent in spring than in fall and may contribute to the higher concentrations of migrants on near shores. Finally, an unmeasured subset of migrants may drop out into shoreline stopover habitat during the night, which also contributes to higher densities



FIGURE 5. Pooled mean values $(\pm SE)$ of vertically integrated reflectivity (cm² ha⁻¹) of migrating birds within 3 km of the shoreline in the Great Lakes region, USA, 2010–2013, for all near and far shores, over water at dawn and over land at exodus.

on the near shore. Dawn ascent is likely one of several behaviors that contribute to the overall importance of the near shore's stopover habitat.

There was no increase in VIR of migrants on near shores compared to far shores at dawn to accompany the large increase observed at exodus. In fact, near shores showed slightly lower VIR over water at dawn than far shores. It is possible that, at dawn, migrants are more likely to drop out into stopover habitat along near shores than on far shores. The increased numbers of birds landing on the near shores of the lake reduced the density of migrants aloft at dawn, despite the general pattern of birds returning to near shores, and contributed to the increased VIR of migrants observed at exodus the following evening. In short, it seems that dawn ascent behaviors in the Great Lakes result in migrating landbirds accumulating in stopover habitat along the near shores of the lakes on the ground, but not in the atmosphere at dawn. We encourage studies using small-scale surveillance radars to better resolve the dynamics of flight behavior as birds approach shorelines and determine how far inland birds travel before making landfall at dawn (e.g., Bowden et al 2015, Rathbun et al. 2016).

The linkage of dawn ascent and reorientation of migrating birds in the Great Lakes with greater shoreline densities of migrants indicates that the stopover habitats on near shores are an important resource for migrating birds. Because the "near shore" of a lake is dependent on the flight direction of the migrating birds, the relative importance of shoreline stopover habitat on northern and southern shores of the Great Lakes is dependent, in part, on the migration season. The dawn flight behaviors of migrating birds that we report here suggest that habitat on the near shores (i.e. the southern side of Lake Erie and the eastern side of Lake Michigan) is important in spring, whereas habitat on the far shore may be important in fall.

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Attachment WPE-5

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Comparison of Preconstruction Bird/Bat Activity and Post-construction Mortality at Commercial Wind Projects in Maine



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Executive Summary

Wind developers are required to conduct pre-construction assessments of bird and bat activity at proposed wind farms. Directly measuring the distribution, abundance, and activity levels of birds and bats through pre-construction surveys is presumed to provide a basis for evaluating the mortality risk of a site. However, for pre-construction bird and bat activity to be a useful predictor of post-construction bird and bat mortality, there must be a strong and consistent relationship between the two. Stantec tested the relationship between pre-construction bird and bat survey results and post-construction mortality estimates from commercial wind farms in Maine, specifically evaluating whether variation in estimated bird and bat mortality rates was correlated with variation in corresponding pre-construction survey results. Our results showed no strong or consistent relationship between bird and bat activity measured prior to construction and post-construction mortality rates. The results in Maine are similar to others conducted at broader regional scales, and challenge the assumption that pre-construction surveys are a meaningful predictor of risk. Wind projects have been operating in Maine since 2006. Stantec compiled all publicly available pre-construction and post-construction bird and bat survey results for proposed and operating wind projects in the state. Pre-construction data included 682 nights of radar surveys at 14 proposed sites, 442 raptor survey days at 13 proposed sites, and 10,644 detector-nights of acoustic bat surveys at 12 proposed sites. Post-construction bird and bat mortality estimates were available from 9 sites, all of which also had corresponding preconstruction data. Where both pre- and post-construction data are available, we assessed relationships between pre-construction bird and bat activity and post-construction mortality rates at the site level (overall and yearly), evaluating radar, bat acoustic, and raptor data separately.

Pre-construction bird, bat, and raptor activity levels and bird and bat mortality rates varied among sites, suggesting differing levels of risk. However, based on evaluation of multiple pairings of variables there is no consistent relationship between pre-construction activity levels and annual mortality estimates at the sites. Of all available pairings of pre-construction and postconstruction results we compared, none showed a statistically significant relationship. As such, existing data representing most operating wind projects in Maine fail to support the assumption that pre-construction bird and bat activity provides a reliable indicator of mortality rates during operation.

Similar attempts to compare pre-construction activity versus post-construction mortality rates in other states and on a national level have also failed to support this assumption. Despite some overall seasonal trends, which have been consistently demonstrated in pre-construction and post-construction surveys throughout North America, variation in overall pre-construction bird and bat activity appears to have no consistent relationship with mortality. Our understanding of other factors (e.g., weather, lighting) influencing mortality at wind projects and other projects (e.g., buildings, communication towers) suggest that risk to birds and bats is anything but static, and is instead influenced by a variety of seasonal, behavioral, and conditions-based factors.



1.0 INTRODUCTION

The reality that commercial wind turbines can kill birds and bats has prompted a substantial effort to identify factors that predict the magnitude of risk for proposed project sites and explain why bird and bat mortality rates are higher at some wind farms than others. Pre-construction bird and bat surveys have been used in and outside of Maine to document distribution, abundance, species composition, and temporal/seasonal activity patterns of birds and bats at proposed wind power sites, and the results of such surveys have been used to evaluate the risks that development of such a site might present. However, for pre-construction bird and bat activity to be a meaningful predictor of risk at wind projects in Maine, the relationship between activity and post-construction mortality rates should be relatively strong and consistent.

Stantec analyzed the relationship between publicly available pre-construction bird and bat survey results and post-construction mortality estimates from commercial wind farms in Maine. We tested whether variation in estimated bird and bat mortality rates was correlated with variation in corresponding pre-construction survey results using straightforward linear regressions at the site level. This report summarizes the methods and results of our analyses, compares our results to similar efforts conducted in other states, and provides a regional context for the variation in mortality rates documented at wind projects in Maine. The results showed no consistent relationship between bird and bat activity measured prior to construction and post-construction mortality rates. The results in Maine are consistent with the results from projects outside of Maine and challenge the assumption that pre-construction surveys are a meaningful predictor of risk.

2.0 METHODS

2.1 PRE-CONSTRUCTION AND POST-CONSTRUCTION DATA SUMMARY AND ANALYSIS

Stantec first compiled publicly available pre-construction bird, raptor, and bat survey results for commercial wind projects in Maine. These included results from projects that have gone through permitting and pre-construction survey results are therefore part of the public record. Because the level of effort and survey methods varied among sites¹, we derived a set of standardized metrics for each survey type based on the raw daily/nightly data to improve comparability of data among sites (Table 1).

We next obtained post-construction mortality estimates from all publicly available survey reports, tracking the survey interval, mortality estimator used, turbine characteristics, and operational parameters. To improve comparability of mortality estimates among sites, we converted per-

¹ For example, in collecting pre-construction data, 13 of the projects analyzed used an X-band radar system and 1 used the MERLINTM radar system.



COMPARISON OF PRE-CONSTRUCTION BIRD/BAT ACTIVITY AND POST-CONSTRUCTION MORTALITY AT COMMERCIAL WIND PROJECTS IN MAINE

turbine bird and bat fatality estimates to per-megawatt (MW) estimates. To account for varying survey lengths among studies, we also adjusted each estimate based on the ratio of the survey period compared to the mean survey period of all projects in Maine. When present, we combined separate seasonal estimates (e.g., spring, summer, fall) and size-specific estimates for birds (e.g., small bird, medium bird, large bird) to generate annual² bird and bat mortality estimates. In cases where multiple mortality estimates existed for a given site/year (e.g., based on different search intervals), we calculated a mean mortality estimate for each year. We also generated a per-site overall average for birds and bats for sites with more than 1 year of post-construction monitoring (Table 1). The intent of calculating these summary statistics was to improve comparability of results among projects.

We plotted post-construction mortality versus pre-construction bird and bat activity rates at the site level and used linear regression to determine whether there were correlations between mortality estimates and pre-construction results. We used separate linear regressions for each pairing of pre-construction and post-construction data, analyzing annual mortality estimates and site-level mean mortality estimates separately. We conducted separate analyses of bat mortality datasets with and without 3 Maine projects (Bull Hill, Oakfield, and Passadumkeag) operating under curtailment; curtailment reduces bat mortality rates and could therefore affect results. Finally, to provide a regional context for bird and bat mortality estimates from Maine projects to those from nearby states. We implemented all data summary, graphing, and analysis using statistical software and reported adjusted R² values for all regressions (R Core Team 2014).

² Mortality surveys in Maine typically occur between April/May and October and therefore do not necessarily reflect the full year, although they cover much of the period during which bats and songbirds are active and are generally presented as annual estimates in the reports.


Survey Type	Raw Data	Calculated Metric(s)
Acoustic bat survey	 Nightly passes per detector-night, grouped by detector and species/species guild 	 Mean/median passes per detector- night, grouped by detector type Percent of surveyed nights with bat activity Overall species composition by detector type
Nocturnal radar survey	 Nightly passage rate Nightly flight height Percent targets below turbine height Flight path direction 	 Mean/median passage rate Mean/median flight height Mean/median percent targets below turbine height
Raptor migration surveys	 Raptors observed per species per day Flight height and behavior Flight path direction 	Mean raptors observed per day
Post-construction mortality surveys	 Estimated bird/bat carcasses per turbine per season Bird/bat carcasses (by species) found per turbine search 	 Estimated bird/bat carcasses per MW, adjusted for length of survey period (annual and overall per site) Mean monthly bird/bat carcasses found per search

Table 1. Description of raw data and derived metrics from typical pre- and post-construction bird and bat surveys conducted at wind projects in Maine.

2.2 REGIONAL CONTEXT

To put the Maine results in context, we also compiled data from publicly available postconstruction mortality monitoring reports for wind projects in 6 northeastern states (Maine, New Hampshire, Vermont, New York, Pennsylvania, and West Virginia). For the regional comparison, we excluded mortality estimates from sites implementing curtailment to minimize variation due to factors other than siting. We did not have access to original raw data used to calculate bias estimates and correction factors in all cases. In order to compare similarly reported projects, our regional analyses only includes reported estimates that incorporated bias and correction factors such as searcher efficiency and carcass removal. In most cases, estimates had also been adjusted to account for areas not surveyed. We combined separate seasonal and size-class estimates into overall annual bird and bat estimates, as described above. We converted perturbine estimates to per-MW estimates and incorporated the same scaling factor mentioned above to account for variable survey lengths. If multiple estimates were reported for a site during a year, based on different search intervals or calculation methods, we calculated the mean bird and bat mortality rates for that year to ensure each site/year combination was represented only once in the dataset.



3.0 **RESULTS**

Stantec obtained pre-construction and/or post-construction survey results from 15 proposed or operating wind projects in Maine including nocturnal radar data (14 sites), raptor migration data (13 sites), bat acoustic data (12 sites), and post-construction bird and bat mortality data (9 sites) (Appendix A Table 1). Nine of those sites had both pre-construction and post-construction data readily available. Because analysis focused on site-level relationships, we considered data from multiphase projects (e.g., Stetson I and II) as representative of one site.

3.1 PRE-CONSTRUCTION BIRD AND BAT ACTIVITY SURVEYS

3.1.1 Radar Surveys

Radar surveys and analytical approaches used in Maine have followed consistent methods since the mid-2000s³. All except one radar survey we analyzed were conducted using the same radar technology (x-band 12 kilowatt marine radar operated in horizontal and vertical modes) and using the same analysis methods (randomly selected subsamples of data analyzed by hand to quantify passage rates, flight directions, and flight height). One other survey was conducted using the MERLINTM radar system which uses horizontal and vertical radars simultaneously to automatically and continuously record bird and bat activity. The pre-construction radar survey dataset consisted of 682 nights of radar surveys from 14 sites.

We report radar survey results in terms of "passage rates", which represent the number of "targets" flying through the airspace sampled by the radar in horizontal mode, and the "percent of targets below turbine height" based on vertical operation. "Below turbine height" includes targets at or below the maximum height of the turbines. Among the 14 Maine projects with nocturnal radar data, mean passage rates ranged from 310.5 – 746.2 targets/kilometer/hour, with an overall mean of 438.0 (Figure 3-1). The mean percent of targets below turbine height ranged from 11 – 33% with an overall mean of 23% (Figure 3-2).

³ The first nocturnal radar surveys in Maine occurred in the mid-1990s, and used 25 kilowatt marine radars.





Figure 3-1. Mean radar passage rates from pre-construction surveys at Maine wind projects (proposed and existing).



Figure 3-2. Mean percent of radar targets below turbine height from pre-construction surveys at Maine wind projects (proposed and existing).

3.1.2 Raptor Surveys

Raptor surveys followed consistent methods among sites, based on visual surveys conducted by a single observer equipped with binoculars and spotting scope. Pre-construction raptor survey



results were available for 442 survey days from 13 sites, observing more than 4,053 raptors during the project area surveys. The mean number of raptors observed per survey day ranged from 5.1 – 18.7 raptors/day among sites (mean = 10.3; Figure 3-3).



Figure 3-3. Mean number of raptors observed per survey day from pre-construction surveys at Maine wind projects (proposed and existing).

3.1.3 Acoustic Bat Surveys

Acoustic bat surveys can vary widely in scope and methods, although most pre-construction surveys in Maine have involved deploying "Met High" (>20 m above ground level [agl] in meteorological [met] towers), "Met Low" ($\sim 10 - 20$ m agl in met towers), or "Tree" detectors (~ 2 m agl) in trees. Because multiple detectors may be at different heights each night, the results are tracked as "detector nights" (DN), rather than just nights (i.e., 3 detectors during 1 calendar night equals 3 DN per night). We analyzed nightly pre-construction bat acoustic data to Tree detectors (n = 5,346 DN), Met High detectors (n = 2,676 DN), and Met Low detectors (n = 2,622 DN), resulting in a dataset representing 10,644 detector nights from 121 sites over 9 years (2006 – 2014). In cases where multiple detectors were deployed, we calculated mean nightly activity levels for each detector type (here referring to position as Met High, Met Low, or Tree).

Because mean rate of passes per DN calculated per site varied significantly among detector types ($R^2 = 0.53$, p < 0.001, F(2,26) = 16.66), we plotted and analyzed results separately for each detector type. Mean bat passes per night ranged from 0.10 – 1.96 at Met High detectors (mean = 0.67), from 0.25 – 3.60 at Met Low detectors (mean = 1.12), and from 4.3 – 68.45 (mean = 29.48) for Tree detectors (Figure 3-4).





Figure 3-4. Mean number of bat passes per detector night by detector type from preconstruction surveys at Maine wind projects (proposed and existing). Note the varying y-axis scale for each detector type and the differing detector heights among the 12 sites.



3.2 POST-CONSTRUCTION MORTALITY ESTIMATES

Bird and bat mortality estimates are based on standardized counts of carcasses found by trained observers walking regularly spaced transects within the cleared turbine pad. Because the number of days between turbine searches (search interval), the size of searchable area, the ability of searchers to see carcasses (searcher efficiency), and the rate at which carcasses are removed by scavengers (scavenging rate) vary among sites and years, the total number of carcasses is adjusted upwards by correction factors to generate a cumulative, per-turbine estimate representing the entire survey period (usually encompassing spring, summer, and fall).

Several methods exist to adjust estimates based on search interval, searcher efficiency, carcass removal, and search area. The most commonly applied methods in Maine have been the "Huso" estimator (Huso 2010, Huso et al. 2012), the "Jain" estimator (Jain et al. 2009), and the "Shoenfeld" estimator (Shoenfeld 2004). Each of these estimators results in an annual per-turbine estimate (separate for birds and bats) and associated confidence intervals, although the methods have different biases and would not yield the same results if used on the same dataset. Although this introduces a source of variation when comparing mortality rates, we did not have access to the raw data necessary to recalculate mortality estimates using a common estimator. Our analyses are therefore based on reported estimates. In cases were multiple estimates exist, based on different search intervals or estimators, we calculated mean estimated values.

Bird and bat mortality rates have been estimated for 9 operating wind projects in Maine. Estimates of bat and bird mortality rates and associated confidence intervals varied widely among sites and among years for individual sites. Mean annual bat mortality estimates ranged from 0.12 – 2.95 bats/MW (mean = 0.76; Figure 3-5) and estimated annual bird mortality ranged from 0.54 – 6.95 birds/MW (mean = 2.54; Figure 3-6). Of the 9 sites from which mortality estimates were available, 3 sites (Bull Hill, Oakfield, and Passadumkeag) were implementing feathering below an increased cut-in speed of 5.0 m/s during certain times of year and the remaining 6 sites were operating turbines according to manufactured standard cut-in speed. Appendix C contains site-level post-construction bird and bat estimates on which the plotted mean values were based.





Figure 3-5. Mean bat mortality estimates from Maine wind projects.



Figure 3-6. Mean bird mortality estimates from Maine wind projects.



3.3 COMPARING PRE-CONSTRUCTION AND POST-CONSTRUCTION RESULTS

Paired pre-construction survey results and post-construction mortality estimates were available for 9 sites in Maine.

3.3.1 Radar Surveys

Estimated bat mortality rates (adjusted to account for variable survey periods) showed no apparent trends with pre-construction radar passage rates (Figure 3-7) or the percent of radar targets below turbine height (Figure 3-8)). Linear models comparing estimated bat mortality versus pre-construction radar data indicated that no significant relationships existed between these variables at the site level whether analyses were done using overall averages or annual mortality data (Appendix D Figure 1 and 2). Shown are figures that include 3 sites using curtailment (Bull Hill, Oakfield, Passadumkeag); excluding these sites did not affect the results of the analysis. Some of the highest radar passage rates were associated with the lowest estimated mortality rates, contributing to a low correlation coefficient (R²) and non-significant *P*-value (see equations inset in Appendix D figures).

Comparisons of radar passage rates with bird mortality at the site level using annual mortality estimates also showed no apparent visual pattern (Figure 3-9). Although linear regression suggested a slight positive correlation, this relationship was not statistically significant whether using annual or site-level average mortality estimates (Appendix D Figure 3). Sites with higher estimated rates of bird mortality appeared to also have higher percentages of radar targets below turbine height in pre-construction surveys (Figure 3-10), although linear regression indicated that this trend was not statistically significant whether using site-level average mortality estimates or annual estimates (Appendix D Figure 4).









Figure 3-8. Mean adjusted annual bat mortality rates (gray columns) plotted with percent radar targets below turbine height (yellow dots) for commercial wind projects in Maine.





Figure 3-9. Mean adjusted annual bird mortality rates (black columns) plotted with radar passage rate (orange dots) for commercial wind projects in Maine.



Figure 3-10. Mean adjusted annual bird mortality rates (black columns) plotted with percent radar targets below turbine height (yellow dots) for commercial wind projects in Maine.



3.3.1 Acoustic Surveys

Pre-construction bat acoustic activity rates, whether measured at met high, met low, or tree detectors, showed no discernable relationship with post-construction bat mortality estimates (Figure 3-11). Linear regression of bat mortality estimates as a function of pre-construction bat activity based on annual data (Appendix D Figure 5) or site-level averages (Appendix D Figure 6) also demonstrated no consistent or statistically significant relationships. As with radar data, the results were similar whether or not 3 sites implementing curtailment were included in the analyses.





Figure 3-11. Mean adjusted annual bat mortality rates (gray columns) plotted with acoustic bat activity levels (blue dots) by detector type for commercial wind projects in Maine. Note different secondary y-axis scales for each detector type.



3.3.1 Raptor Surveys

Although raptors are abundant, raptor mortality at wind projects in Maine has been infrequent, preventing calculation of raptor mortality rates and a comparison to pre-construction raptor survey results.

In summary, no pairs of pre-construction and post-construction data had a statistically significant relationship, whether analyzed at the site level or using annual mortality estimates. Considered together, statistical analyses based on both bird and bat pre-construction surveys demonstrate weak relationships (dots in scatterplots do not fall close to a line) and inconsistent relationships (slopes of linear regressions were not all positive or negative). Although only 9 datapoints were available for site-level analyses after combining survey years, 9 points could sufficiently demonstrate a linear relationship where a strong relationship is present.

3.4 REGIONAL MORTALITY PATTERNS

To provide context for the Maine results, Stantec also compiled 131 empirical bat and bird mortality estimates from 46 wind projects in the Northeast to identify consistency or variation. After removing results from sites with curtailment, as explained above, the dataset included 74 mortality studies conducted at 37 total sites; including 16 studies at 6 sites in Maine, 6 studies at 3 sites in New Hampshire, 22 studies at 12 sites in New York, 24 studies at 12 sites in Pennsylvania, and 6 studies at 4 sites in West Virginia (Appendix E).

Mean adjusted bat mortality rates summarized at the state level increased steadily from a low in Maine (mean = 0.9 bats/MW) to a high in West Virginia (mean = 17.3 bats/MW). Bird mortality rates, on the other hand, were less variable among states, ranging from 1.4 birds/MW in Pennsylvania to 3.1 birds/MW in West Virginia (Figure 3-12).





Figure 3-12. <u>Bat (left) and bird (right) mortality estimates</u> from publicly available postconstruction studies at commercial wind farms operating without curtailment in the Northeast.

4.0 **DISCUSSION**

Predicting bird and bat mortality rates based on pre-construction bird and bat activity levels requires a strong link between presence/abundance of birds and bats with the magnitude of mortality. The data from Maine fails to support such a link. Although only 9 paired pre-construction and post-construction datasets exist in Maine (corresponding to the 9 projects for which mortality estimates and pre-construction data are publicly available), the sample size would be sufficient where a strong and consistent relationship would exist between any paired variables. Because we tested each paired dataset using mortality estimates averaged at the site level (which reduces some of the scatter among years) and treating annual mortality estimates from each site as independent datapoints, our analysis was comprehensive yet straightforward. Of all relationships we tested, none were statistically significant.

Overall, bird and bat mortality rates at Maine wind projects showed no consistent relationship to bird and bat activity levels measured before construction. Whether based on mean mortality estimates per site (averaged over multiple years at a site) or separate annual estimates, variation in pre-construction bird and bat activity explained little if any of the variation in mortality rates. The correlation coefficients for linear regressions (labeled as R² in figures in Appendix D), which indicates the strength of the relationship between two variables and typically ranges from 0 (indicating no relationship) to 1 (indicating a very strong relationship), was less than or equal to 0.1 in all relationships we tested. This indicates that variation in preconstruction bird and bat activity explained little if any of the variation in data could sites. In other words, variation in mortality attributable to variation in pre-construction data could



not be distinguished from random variation. The 3 raptor mortalities documented in 20 publicly available Maine post-construction studies involving more than 9,000 turbine searches indicates low magnitude of risk to raptors even at sites with higher pre-construction raptor activity levels.

The lack of strong correlations between pre-construction and post-construction surveys is not unique to Maine. A recently published study comparing rankings of perceived pre-construction risk to bats and post-construction mortality rates from 29 European wind projects documented a marginally significant relationship and concluded that the substantial effort and cost associated with pre-construction assessments was largely unjustified by their analyses (Lintott et al. 2016). Similarly, a study comparing pre-construction raptor abundance at 20 wind projects in Spain documented significant differences among sites in terms of predicted risk, but found no relationship between pre-construction bird activity and post-construction mortality rates (Ferrer et al. 2012). Analysis of results from 12 North American wind projects with pre-construction and post-construction data documented a weak positive relationship between bat activity and bat mortality, although the relationship explained only a small portion of variation in mortality (Hein et al. 2013). The Pennsylvania Game Commission concluded that raptor abundance measured pre-construction at 12 wind farms in Pennsylvania showed no correlation with post-construction mortality rates and indicated that data from the same 12 wind farms with paired data were insufficient for establishing relationships between pre-construction bat activity and bat mortality rates (Taucher et al. 2012). This study further detected no correlation between raptor activity and mortality rates measured concurrently based on post-construction raptor activity surveys.

Several factors could explain the lack of correlation between pre-construction bird and bat activity and mortality rates at wind farms in Maine and elsewhere. Pre-construction metrics do not necessarily reflect the abundance of birds and bats in an area. For example, acoustic bat surveys cannot distinguish individual bats or determine whether individuals are detected more than once (Hayes 1997) and radar cannot reliably and consistently differentiate between individual species or even birds from bats. In addition to characteristics of the data themselves, numerous factors beyond the abundance of birds and bats may affect mortality rates observed at wind projects including turbine characteristics (e.g., height, size of rotor-swept area, lighting arrangements, algorithms controlling turbine operation and startup/shutdown conditions), site conditions (e.g., topography, elevation, habitat types), or behavioral processes (e.g., attraction, avoidance, migratory strategies, species-specific risk factors) (Marques et al. 2014; Cryan and Barclay 2009; Kunz et al. 2007). The presence of the turbines themselves may further manipulate the distribution and behavior of birds and bats, affecting the predictive power of pre-construction surveys.

Since current pre-construction measures of bird and bat activity are not useful predictors of risk, factors such as weather conditions (e.g., temperature and wind speed), the presence of lighting, and details of turbine operation (which can be modified through curtailment) appear to have greater influence on mortality rates.

It is important to evaluate the data in the context of a broader region when evaluating whether the observed variation in mortality, both among Maine wind projects and in total, is ecologically



significant. The difference between the highest and lowest bat mortality estimates in Maine was 3.3 bats/MW (based on site-level average adjusted mortality estimates for sites without curtailment). To put that in a regional context, the highest adjusted annual bat mortality rate documented at any Maine project was lower than the statewide average bat mortality rate for West Virginia, Pennsylvania, and New York. Statewide bat mortality estimates diminish steadily northward from West Virginia to Maine and is likely tied to regional abundance and extended periods of activity in more southern areas. Although this trend has been noted previously, there have been no clear associations between mortality rates and landscape or habitat features in the Northeast (Hein and Schirmacher 2016).

The same geographic trend was not apparent for birds. Mean bird mortality rates and ranges among projects in each state were similar in Northeast states. Comparing mortality rates among states compounds issues related to survey methods, as states often recommend varying levels of effort or use of different mortality estimators (Arnett et al. 2013). Nevertheless, the distinct trend observed for bat mortality estimates among 5 northeastern states is noteworthy, particularly because no such trend existed for bird mortality. Since bird and bat mortality estimates are almost always generated in pairs using the same search and analysis methods, the contrast between the trends is strengthened.

Despite the growing number of paired pre- and post-construction datasets across regions, efforts to link these datasets have not revealed strong relationships. The lack of a clear and consistent relationship between the pre-construction bird and bat activity and mortality rates in our results as well as those of other studies in the U.S. and abroad warrants a re-evaluation of how pre-construction survey data are used in project siting decisions.

Approaching project siting with the idea of differentiating "high" and "low" risk sites based on pre-construction bird and bat activity levels may fail to accomplish the stated goals of avoiding and reducing risk. Our understanding of the factors influencing mortality patterns suggest that risk to birds and bats is dynamic, and is influenced by a variety of seasonal, site-specific, behavioral, and conditions-based factors. Additionally, the relationship between activity and risk may vary dramatically between these two very different taxa and is likely governed by numerous interacting factors. If our current methods do not provide a meaningful tool for evaluating collision risk, more meaningful data may be collected through alternative methods.

Diverting resources away from pre-construction metrics that have shown little utility in predicting bird and bat mortality (e.g., raptor migration surveys, tree-level bat acoustic surveys, extensive radar surveys) and towards efforts to better identify high risk conditions or develop mitigation (e.g., nacelle-mounted acoustic surveys to document wind speed and temperature conditions during which bats are present in the rotor zone; correlate weather conditions with avian mortality; clean up roadkill to reduce vehicle collisions with raptors and eagles; gate known hibernacula; provide research funding for MDIFW or others to mist net for bats and find maternity roosts) would help wind developers and resource agencies better predict and manage impacts. Comparing the extent of high-risk conditions among potential projects would be far more effective at reducing mortality than knowing that pre-construction bat activity was 50% higher



at one site versus another. Accurate characterization of high risk conditions would in turn enable predictions of how frequently such conditions occur and the cost and effectiveness of appropriate management actions.

Although typical pre-construction survey methods do not predict the magnitude of turbinerelated impacts, methods could be revised to focus not only on habitat-related impacts but also determining the relative frequency of high-risk conditions linked to bird and bat mortality. This approach would provide a more comprehensive understanding of the types of impacts expected for a proposed project and could help project developers evaluate and design sitespecific adaptive management measures (e.g., threshold wind speeds, temperatures, and seasons where curtailment would be most effective at reducing bat mortality while minimizing the cost of lost power generation). Traditional meteorological measurements and GIS-based landscape/habitat analyses could play a far greater role in such assessments, supplemented by field surveys to document rare species presence and/or sensitive habitats that could be affected by construction of the projects.

True adaptive management requires a better understanding of not only the relationship between risk and conditions but also the efficacy of varying levels of operational management, which could be achieved through simultaneous comparison of multiple management strategies. Ultimately, the cost of operational management actions could be reduced and effectiveness improved if such measures are focused on the demonstrated periods of highest risk.

5.0 **REFERENCES**

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APPENDICES



Appendix A INVENTORY OF PRE- AND POST-CONSTRUCTION DATA

Site (Region)	Megawatts (# Turbines)	Year	Data (sample size)	Reference
Bold=pre and post data				
Bingham (Western)	250 (119)	2010	 Bat acoustic data from tree (n = 602 DN), met high (n = 390 DN) and met low detectors (n = 517 DN) Nocturnal radar data (n = 40 nights) Raptor migration data (n = 19 days) 	Stantec Consult Survey Report fc Sky East Wind, LL Stantec Consult Survey Report fc Sky East Wind, LL
		2011	 Nocturnal radar data (n = 12 nights) 	Stantec Consult Results and Con Project. Memo t
Bowers (Central)	Proposed	2009	 Bat acoustic data from tree detectors (n = 342 DN) Nocturnal radar data (n = 22 nights) Raptor migration data (n = 15 days) 	Stantec Consulti Surveys for the B Wind Energy, LLC
		2010	 Bat acoustic data from tree (n = 498 DN), met high (n = 143 DN), and met low detectors (n = 143 DN) Nocturnal radar data (n = 20 nights) Raptor migration data (n = 12 days) 	Stantec Consult Spring/Summer I for Champlain V
Bull Hill (Coastal Plain)	34.2 (19)	2009	 Bat acoustic data from tree (n = 426 DN), met high (n = 94 DN), and met low detectors (n = 114 DN) Nocturnal radar data (n = 20 nights) Raptor migration data (n = 18 days) 	Stantec Consulti Avian and Bat Si Blue Sky East Wir
		2010	 Bat acoustic data from tree (n = 307 DN), met high (n = 81), and met low detectors (n = 79 DN) Nocturnal radar data (n = 20 nights) Raptor migration data (n = 25 days) 	Stantec Consulti Survey Report fo East Wind LLC.
		2011	 Nocturnal radar data (n = 20 nights) 	Stantec Consulti Results and Con Bull Hill Wind Pro
		2013	 Bat acoustic data from turbine base detectors (n = 102 DN) Mortality data (19 turbines, survey period = 184 days, interval = daily/weekly by season, Huso estimator) 	Stantec Consult Construction Wil Wind, LLC.
		2014	 Bat acoustic data from tree (n = 217 DN) and turbine base detectors (n = 500 DN) Mortality data (19 turbines, survey period = 184 days, interval = daily/3-day by season, Huso estimator) 	Stantec Consulti Post-Constructio First Wind, LLC.
Hancock (Coastal Plain)	Proposed	2012	Raptor migration data (n = 10 days)	Stantec Consulti Surveys: Memo f

Appendix A Table 1. Inventory of pre-construction and post-construction data compiled for proposed and existing commercial wind projects in Maine.



ing Services Inc. 2012. Spring 2010 Avian and Bat or the Bingham Wind Project. Prepared for Blue .C.

ng Services Inc. 2012. Fall 2010 Avian and Bat r the Bingham Wind Project. Prepared for Blue .C.

ing Services Inc. 2012. Fall 2011 Radar Survey nparison to Fall 2010 Results at the Bingham Wind o Blue Sky East Wind, LLC.

ng Services Inc. 2010. Fall 2009 Avian and Bat owers Wind Project. Prepared for Champlain C.

ng Services Inc. 2010. 2010 Spring Avian and 3at Surveys for the Bowers Wind Project. Prepared Vind Energy LLC.

ng Services Inc. 2010. Summer and Fall 2009 urvey Report for the Bull Hill Project. Prepared for nd, LLC.

ng Services Inc. 2010. Spring 2010 Avian and Bat r the Bull Hill Wind Project. Prepared for Blue Sky

ng Services Inc. 2011. Fall 2011 Radar Survey aparison to Fall 2009 Radar Results: Memo for the fect. Prepared for Blue Sky East Wind, LLC.

ng Services Inc. 2014. Bull Hill Year 1 Postdlife Monitoring Report, 2013. Prepared for First

ing Services Inc. 2015. Bull Hill Wind Project Year 2 in Wildlife Monitoring Report, 2014. Prepared for

ing Services Inc. 2012. Results of Fall 2012 Raptor for the Hancock Wind Project. Prepared for First

Site (Region)	Megawatts (# Turbines)	Year	Data (sample size)	Reference
Bold=pre and post data				
Highland	Proposed	2008	Bat acoustic data from tree (n = 146, met high (n = 144 DN) and met low detectors (n = 142 DN)	Stantec Consulti
(Western)			 Nocturnal radar data (n = 20 nights) 	Survey Report: Re
			 Raptor migration data (n = 15 days) 	Highland Wind P
				Highland Wind Ll
		2009	• Bat acoustic data from met high (n = 300 DN) and met low detectors (n = 254 DN)	Stantec Consulti
			 Nocturnal radar data (n = 40 nights) 	for the Highland
			 Raptor migration data (n = 15 days) 	Prepared for Hig
Kibby (Western)	132 (44)	2005	 Nocturnal radar data (n = 24 nights) 	Woodlot Alterna
				Migration at the
				Skinner Township
		2006	• Bat acoustic data from met high (n = 145 DN) and met low detectors (n = 126 DN)	Woodlot Alterna
			 Nocturnal radar data (n = 25 nights 	Activity at the Pr
				Skinner Township
				Wind Developme
		2011	 Mortality data (22 turbines, survey period = 146 days, interval ~5 days, Shoenfeld estimator) 	Stantec Consulti
				Monitoring Repo
				Maine. Prepared
		2014	• Mortality data (10 turbines, survey period = 122 days, interval = daily [5 days/week], Huso estimator)	TRC. 2015. Post-C
				Report for the Kik
				TransCanada En
Mars Hill	42 (28)	2005	 Nocturnal radar data (n = 18 nights) 	Woodlot Alterna
(Northern)			 Raptor migration data (n = 8 days) 	Acoustic Survey
				Hill Wind Project
				Management, Ll
		2006	 Nocturnal radar data (n = 15 nights) 	Woodlot Alterna
			 Raptor migration data (n = 7 days) 	Acoustic Survey
				Mars Hill, Maine.
		2007	 Mortality data (28 turbines, survey period = 113 days, interval = 2 daily/26 weekly, Jain estimator) 	Stantec Consulti
				Post-construction
				Wind Farm, Main
				Management, Ll
		2008	 Mortality data (28 turbines, survey period = 135 days, interval = weekly, Jain estimator) 	Stantec Consulti
				Monitoring at the
				Unpublished rep
Number Nine	Proposed	2014	 Nocturnal radar data (n = 40 nights) 	Stantec Consulti
(Northern)				Survey Report. Pr



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epared for Number Nine Wind Farm LLC.

Site (Region)	Megawatts (# Turbines)	Year	Data (sample size)	Reference
post data				
Oakfield (Northern)	148 (48)	2007	Bat acoustic data from tree (n = 228 DN) and met high detectors (n = 37 DN)	Stantec Consulti Survey Report. P
		2008	 Bat acoustic data from tree (n = 278 DN), met high (n = 148 DN), and met low detectors (n = 141 DN) Nocturnal radar data (n = 40 nights) Raptor migration data (n = 23 days) 	Stantec Consulti Bird and Bat Mig Bat Surveys for th Prepared for Firs
		2016	Mortality data (29 turbines, survey period=178 days, interval = 3 days, Huso, Shoenfield, Smallwood estimators)	Stantec Consulti Bird and Bat Fate
Passadumkeag (Central)	40 (13)	2011	 Bat acoustic data from tree detectors (n = 691 DN) Nocturnal radar data (n = 40 nights) Raptor migration data (n = 24 days) 	Stantec Consulti Avian and Bat Si in Grand Falls To Windpark LLC.
Record Hill (Western)	50.6 (22)	2007	 Bat acoustic data from tree (n = 43 DN), met high (n = 90 DN), and met low detectors (n = 107 DN) Nocturnal radar data (n = 40 nights) Raptor migration data (n = 14 days) 	Stantec Consulti Visual, Acoustic Conducted at th Maine. Prepared
		2008	 Bat acoustic data from tree (n = 41 DN), met high (n = 90 DN), and met low detectors (n = 84 DN) Raptor migration data (n = 15 days) 	Stantec Consulti Migration Survey Surveys for the R Prepared for Rec
		2012	 Bat acoustic data from tree detectors (n = 639 DN) Raptor migration data (n = 23 days) Mortality data (22 turbines, survey period = 155 days, interval ~ 5 days, Huso estimator) 	Stantec Consulti Post-Constructio Hill Wind, LLC.
		2014	 Raptor migration data (n = 35 days) Mortality data (10 turbines, survey period = 139 days, interval = daily [5 days/week], Huso estimator) 	Stantec Consulti Year 2 Post-Cons Record Hill Wind
Rollins (Central)	60 (40)	2007	 Bat acoustic data from tree (n = 274 DN), met high (n = 95 DN), and met low detectors (n = 106 DN) Nocturnal radar data (n = 21 nights) Raptor migration data (n = 12 days) 	Stantec Consultin Migration Survey the Rollins Wind P
		2008	 Bat acoustic data from tree (n = 50 DN), met high (n = 128 DN), and met low detectors (n = 99 DN) Nocturnal radar data (n = 21 nights) Raptor migration data (n = 15 days) 	Stantec Consultin Migration Survey the Rollins Wind P
		2012	 Raptor migration data (n = 38 days) Mortality data (20 turbines, survey period = 184 days, interval = weekly, Huso estimator) 	Stantec Consultir Construction Mor
		2013	Raptor migration data (n = 25 days)	Stantec Consulti Post-Constructio Wind, U.C.
		2014	Mortality data (20 turbines, survey period = 184 days, interval = weekly, Huso estimator)	Stantec Consulti Post-Constructio First Wind, LLC.



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ng Services Inc. 2015. Rollins Wind Project Year 2 n Wildlife Monitoring Report, 2014. Prepared for

Site (Region)	Megawatts (# Turbines)	Year	Data (sample size)	Reference
Bold=pre and post data				
Spruce	20 (10)	2009	Raptor migration data (n = 21 days)	TetraTech. 2009.
Mountain			 Nocturnal radar data (n = 93 nights) 	Report. Prepared
(Western)			• Bat acoustic data from met high (n = 157 DN), met low (n = 157 DN), and tree detectors (n = 157 DN)	
		2012	Mortality data (10 turbines, survey period = 205 days, interval = weekly, Huso estimator)	TetraTech. 2013. Bird and Bat Fato Prenared for Pat
		2014	 Mortality data (10 turbines, survey period = 199 days, interval =2x/week, Huso estimator) 	TetraTech. 2015. Bird and Bat Fato Patriot Renewab
Stetson I & II	82.5 (55)	2006	• Bat acoustic data from met high ($n = 149$ DN) and met low detectors ($n = 212$ DN)	Woodlot Alterna
(Central)			 Nocturnal radar data (n = 12 nights) 	Bat Miaration at
(,			• Raptor migration data ($n = 6$ days)	Project in Washir
				Wind V. LLC.
		2007	Bat acoustic data from met high detectors (n = 160 DN)	Woodlot Alterna
			• Nocturnal radar data (n = 21 nights)	Bat Miaration at
			• Raptor migration data ($n = 8 \text{ days}$)	Maine. Prepare
		2009	• Bat acoustic data from tree detectors ($n = 407 \text{ DN}$)	Stantec Consulti
		2007	• Nocturnal radar data ($n = 18 \text{ DN}$)	Project, Year 1 P
			 Raptor migration data (n = 12 days) 	Prepared for First
			 Mortality data (19 Stetson I turbines, survey period = 185 days, interval = weekly, Huso estimator) 	
		2010	 Mortality data (17 Stetson II turbines, survey period = 180 days, interval = weekly, Jain estimator) 	Normandeau As Year 1 Post-Cons Prepared for First
		2011	Mortality data (19 Stetson I turbines, survey period = 187 days, interval = weekly, Huso estimator)	Normandeau As and bat casualt Prepared for First
		2012	Mortality data (17 Stetson II turbines, survey period = 184 days, interval = weekly, Huso estimator)	Stantec Consulti Post-Constructio
		2013	Mortality data (19 Stetson I turbines, survey period = 194 days, interval = weekly, Huso estimator)	Stantec Consulti 2013 Post-Constr Prepared for First
		2014	Mortality data (17 Stetson II turbines, survey period = 184 days, interval = weekly, Huso estimator)	Stantec Consulti 3 Post-Constructi Wind, LLC.

Spring 2009 – Bird and Bat Biological Survey d for Patriot Renewables.

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ng Services Inc. 2014. Stetson I Wind Project ruction Wildlife Monitoring Report, Year 5. t Wind, LLC.

ng Services Inc. 2015. Stetson II Wind Project Year ion Monitoring Report, 2014. Prepared for First

Site (Region)	Megawatts	Year	Data (sample size)	Reference
Bold=pre and post data	(# Turbines)			
Weaver (Coastal Plain)	Proposed	2013	 Bat acoustic data from met high (n = 325 DN) and met low detectors (n = 341 DN) Raptor migration data (n = 8 days) 	Stantec Consultin Avian and Bat Su Wind, LLC.
		2014	 Nocturnal radar data (n = 40 nights) Raptor migration data (n = 19 days) 	Stantec Consultir Avian and Bat Su Wind, LLC.



ing Services Inc. 2014. 2014 Pre-Construction urveys – Weaver Wind Project. Prepared for First

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Appendix B PRE-CONSTRUCTION BIRD AND BAT ACTIVITY METRICS

Appendix B Table 1. Pre-construction bird and bat activity metrics derived from publicly available pre-construction survey data from Maine wind projects.

				Rada	ır							
		Radar Pa Rate	ssage e	Passage Below Turbine Height		Met High		Met Low		Tree		Raptor Passage
Site Name	Maine Region	Mean	SD	Mean	SD	Rate	SD	Rate	SD	Rate	SD	Rate
Bingham	Western	738.3	488.6	0.24	0.14	0.32	0.62	0.54	0.75	4.31	7.76	9.2
Highland	Western	524.4	393.4	0.16	0.14	0.29	0.98	0.35	0.61	54.05	64.68	18.7
Kibby	Western	374.7	347.9	0.17	0.16	0.13	0.41	0.25	1.18			
Record Hill	Western	491.4	301.0	0.17	0.12	0.27	0.74	2.01	6.48	28.02	41.53	7.1
Spruce Mountain	Western	436.4	421.7	0.19	0.09	0.20		0.94		2.04		
Bowers	Central	322.5	183.1	0.24	0.16	1.96	5.26	1.06	2.33	14.8		8.4
Passadumkeag	Central	439.6	450.9	0.30	0.19					27.37	51.73	9.9
Rollins	Central	310.5	225.4	0.17	0.10	1.04	4.07	1.33	5.42	68.45	176.37	7.4
Stetson	Central	344.7	316.5	0.20	0.22	1.68	4.09	3.60	5.47	45.77	91.57	7.7
Bull Hill	Coastal Plain	491.9	302.4	0.32	0.20	0.10	0.40	0.48	1.11	7.05	11.93	8.0
Weaver	Coastal Plain	746.2	440.5	0.33	0.17	0.49	1.00	0.48	1.29			9.7
Mars Hill	Northern	432.6	288.0	0.11	0.10							
Number Nine	Northern	323.7	240.6	0.27	0.10							
Oakfield	Northern	499.5	226.0	0.3	0.14	0.44	1.84	1.09	2.20	15.46	48.07	5.1



Appendix C POST-CONSTRUCTION BIRD AND BAT MORTALITY ESTIMATES

Site	Region	Year	Survey Period Length (Days)	Search Interval	Searcher	Estimator	Curtailment	Turbine Specification (MW)	Estimated Bat Mortality per Turbine	Estimated Bird Mortality per Turbine
Bull Hill	Coastal Plain	2013	184	daily	human	Huso	5.0 m/s	1.8	2.5 (1.6 – 4.0)	12.1 (7.3 – 19.5)
Bull Hill	Coastal Plain	2013	184	weekly	human	Huso	5.0 m/s	1.8	0.9 (0.7 – 1.4)	7.7 (4.8 – 13.2)
Bull Hill	Coastal Plain	2014	184	3-day	human	Huso	5.0 m/s	1.8	0.4 (0.1 – 1.1)	1.3 (0.9 – 2.1)
Bull Hill	Coastal Plain	2014	184	weekly	human	Huso	5.0 m/s	1.8	0 (0 – 0)	5.0 (3.3 - 8.4)
Kibby	Western	2011	146	5-day (3 times every 2 wks)	human	Shoenfeld	None	3	0.4 (0.1 – 0.7)	1.6 (0.7 – 3.6)
Kibby	Western	2014	122	daily (5 days/week)	human	Huso	None	3	0.5 (No CI)	4.7 (No Cl)
Mars Hill	Northern	2007	113	weekly	human	Jain	None	1.5	0.4 (0.5 – 0.6)	0.4 (0.4 – 0.7)
Mars Hill	Northern	2007	113	seasonal dog	dog	Jain	None	1.5	4.4 (1.8 – 4.5)	2.5 (2.7 – 8.4)
Mars Hill	Northern	2007	113	daily	human	Jain	None	1.5	2.0 (1.1 – 1.4)	1.0 (-0.2 – 2.9)
Mars Hill	Northern	2008	135	weekly	human	Jain	None	1.5	0.7 (0.6 – 1.1)	2.0 (2.3 – 2.9)
Mars Hill	Northern	2008	135	seasonal dog	dog	Jain	None	1.5	0.2 (0.2 – 0.2)	2.7 (2.1 – 4.7)
Oakfield	Northern	2016	178	3-day	human	Huso, Shoenfeld, Smallwood	5.0 m/s, temperature variable	3.0	1.77 (1.13 – 2.77) 2.11 (0.86 – 3.91) 2.31 (±0.01)	7.60 (5.33 – 10.75) 9.42 (5.87 – 14.23) 9.77 (±0.63)
Passadumkeag	Central	2016	183	3-day	Human	Huso, Shoenfeld, Smallwood	5.0 m/s, seasonally variable temperature	3.3	0.79 (0.14 – 1.79) 0.56 (0.11 – 1.22) 0.87 (0.87 – 0.87)	6.32 (4.06 – 10.13) 4.28 (2.76 – 5.58) 8.15 (6.13 – 10.17)
Record Hill	Western	2012	155	5-day (3 times every 2 wks)	human	Huso	None	2.3	6.8 (3.4 – 49.7)	8.5 (4.5 – 18.8)
Record Hill	Western	2014	139	daily (5 days/week)	human	Huso	None	2.3	1.2 (0.7 – 3.0)	4.2 (2.1 – 8.1)
Rollins	Central	2012	184	weekly	human	Huso	None	1.5	0.2 (0.1 – 0.5)	2.9 (1.6 – 6.0)
Rollins	Central	2014	184	weekly	human	Huso	None	1.5	0.5 (0.3 – 1.0)	5.1 (3.2 – 8.3)
Spruce Mountain	Western	2012	205	weekly	human	Huso	None	2	2.4 (0.5 – 0.5)	1.5 (1.2 – 4.5)
Spruce Mountain	Western	2014	199	2x per week	human	Huso	None	2	0.61 (0.19 – 1.18)	10.06 (5.39 – 15.77)
Stetson	Central	2009	185	weekly	human	Jain	None	1.5	2.1 (1.1 – 3.1)	4.0 (2.8 – 5.2)
Stetson	Central	2011	187	Weekly	human	Jain	None	1.5	0.4 (0.4 – 0.5)	1.8 (1.5 – 2.0)
Stetson	Central	2013	194	Weekly	human	Huso	None	1.5	0.3 (0.2 – 1.1)	10.4 (5.0 – 22.2)
Stetson	Central	2010	180	Weekly	human	Jain	None	1.5	2.5 (2.2 – 2.8)	2.1 (1.9 – 2.4)
Stetson	Central	2012	184	Weekly	human	Huso	None	1.5	2.1 (0.6 – 51.4)	2.8 (0.7 – 8.4)
Stetson	Central	2014	184	Weekly	human	Huso	None	1.5	1.3 (0.5 – 5.9)	4.9 (2.0 – 14.7)

Appendix C Table 1. Post-construction bird and bat mortality estimates and project characteristics used to generate site-level mortality metrics for Maine wind projects.





Appendix D LINEAR MODEL RESULTS

Appendix D Figure 1. Estimated bat mortality rates versus pre-construction rardar passage rate based on site-level averages (left) and annual mortality estiamtes (right) for commercial wind projects in Maine. Shown are regressions including sites with curtailment.



Appendix D Figure 2. Estimated bat mortality rates versus pre-construction percent radar targets below turbine height based on site-level averages (left) and annual mortality estimates (right) for commercial wind projects in Maine. Shown are regressions including sites with curtailment.





Appendix D Figure 3. Estimated bird mortality rates versus pre-construction radar passage rate based on site-level averages (left) and annual mortality estimates (right) for commercial wind projects in Maine.



Appendix D Figure 4. Estimated bird mortality rates versus pre-construction percent radar targets below turbine based on site-level averages (left) and annual mortality estimates (right) for commercial wind projects in Maine.





Appendix D Figure 5. Estimated bat mortality versus pre-construction bat activity levels based on site-level averages.



Appendix D Figure 6. Estimated bat mortality versus pre-construction bat activity levels on annual mortality estimates by detector type.



Appendix E BIRD AND BAT MORTALITY ESTIMATES FROM NORTHEAST STATES

Appendix E Table 1. Bird and bat mortality estimates from publicly available mortality survey reports for wind projects in New Hampshire, New York, Pennsylvania, and West Virginia used to compare statewide mortality rates.

Site	State	Turbine Size (MW)	Year	Estimated Bat Mortality per Turbine	Estimated Bird Mortality per Turbine	Survey Period Length (Days)	Search Interval	Estimator	R
Granite Reliable	NH	3.0	2012	3.0	2.8	189	weekly	Huso	Curry and Kerlinger. 2013. Post-constru- Wind Park, Coos County, New Hampsh for Granite Reliable Power, LLC.
Groton	NH	2.0	2013	2.6	4.9	196	weekly	Shoenfeld	Stantec Consulting Services Inc. 2014. 2 Report. Prepared for Groton Wind, LLC
			2014	3.3	3.0	190	weekly	Shoenfeld	Stantec Consulting Services Inc. 2015. 2 Report. Prepared for Groton Wind, LLC
			2015	3.5	2.0	192	weekly	Shoenfeld	Stantec Consulting Services Inc. 2016. 2 Report. Prepared for Groton Wind, LLC
Lempster	NH	2.0	2009	6.1	6.8	157	daily	Shoenfeld	Tidhar, D., W. Tidhar, and M. Sonnenbe Surveys for Lempster Wind Project. Pre
			2010	7.1	5.3	157	weekly	Shoenfeld	Tidhar, D., W. Tidhar, L. McManus, and Fatality Surveys for Lempster Wind Proje
Altona	NY	1.5	2010	6.5	1.6	173	daily	Jain	Jain, A., Kerlinger, P., Slobodnik, L., Cur
				3.9	2.8		weekly	Jain	Noble Altona Windpark, LLC Post-Cons Prepared for Noble Environmental Pow
Bliss	NY	1.5	2008	7.6	4.3	208	daily	Jain	Jain, A., P. Kerlinger, R. Curry, L. Slobod
				14.7	0.7		3-day	Jain	for the Noble Bliss Windpark, LLC. Postc
				13.0	0.7		weekly	Jain	Prepared by Curry and Kerlinger, LLC.
			2009	8.2	4.5	215	daily	Jain	Jain, A., Kerlinger, P., Slobodnik, L., Cur
				4.5	2.9		weekly	Jain	Noble Bliss Windpark, LLC Post-Construct Prepared for Noble Environmental Pow
Chateaugay	NY	1.5	2010	3.7	2.4	173	weekly	Jain	Jain, A., Kerlinger, P., Slobodnik, L., Curr Noble Chateaugay Windpark, LLC Pos 2010. Prepared for Noble Environment
Clinton	NY	1.5	2008	5.5	1.4	171	daily	Jain	Jain, A., P. Kerlinger, R. Curry, L. Slobod
				4.8	3.3		3-day	Jain	Report for the Noble Clinton Windpark,
				3.8	2.5		weekly	Jain	Study – 2008. Prepared by Curry and K
			2009	9.7	1.5	215	daily	Jain	Jain, A., Kerlinger, P., Slobodnik, L., Cur
				5.2	1.8		weekly	Jain	Noble Clinton Windpark, LLC Post-Cons Prepared for Noble Environmental Pow

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Inik, J. Histed, and J. Meacham. 2009. Annual LLC. Postconstruction Bird and Bat Fatality Cerlinger, LLC.

ry, R., Russel, K. 2010. Annual Report for the struction Bird and Bat Fatality Study - 2009. er, LLC.

Site	State	Turbine Size (MW)	Year	Estimated Bat Mortality per Turbine	Estimated Bird Mortality	Survey Period	Search	Estimator	R																										
Cohocton/	NY	2.5	2009	40.4	4.7	215	daily	Jain	Stantec Consulting Services Inc. 2010.																										
Dutch Hill	Dutch Hill			13.8	2.9	-	weekly	Jain	Post-Construction Monitoring Report, 2 Farms In Cohocton, New York. Prepare Canandaiaua Power Partners II, 11 C.																										
			2010	15.5	2.0	180	weekly	Jain	Stantec Consulting Services Inc. 2011.																										
					36.1	3.2	180	daily & weekly	Jain	Post-Construction Monitoring Report, 2 Farms In Cohocton, New York. Prepare Canandaigua Power Partners II, LLC.																									
			2013	8.0	4.0	100	5-day	Jain	Stantec Consulting Services Inc. 2014. Post-ConstructionWildlife Monitoring Re Partners, LLC and Canandaigua Powe																										
Ellenburg	NY	1.5	2008	8.2	2.1	169	daily	Jain	Jain, A., P. Kerlinger, R. Curry, L. Sloboc																										
				6.9	1.4	-	3-day	Jain	Report for the Noble Ellenburg Windpo																										
				4.2	1.2		weekly	Jain	Study – 2008. Prepared by Curry and k																										
			2009	8.0	5.7	215	daily	Jain	Jain, A., Kerlinger, P., Slobodnik, L., Cur																										
				3.7	2.3		weekly	Jain	Noble Ellenburg Windpark, LLC Post-Co Prepared for Noble Environmental Pow																										
Hardscrabble	NY	2.0	2012	21.3	6.9	184	daily	Shoenfeld	Jain, A., Kerlinger, P., Slobodnik, L., Cur Noble Ellenburg Windpark, LLC Post-Co Prepared for Noble Environmental Pow																										
Howard	NY	2.1	2012	20.1	2.5	215	daily & weekly	Shoenfeld	West. 2013. 2012 Post-Construction M Projgect Steuben County, New York. F																										
			2013	4.3	0.8	185	daily & weekly	Shoenfeld	West. 2014. 2013 Post-Construction Me Projgect Steuben County, New York. F																										
Maple Ridge	NY	1.7	2006	24.5	9.6	152	daily	Jain	Jain, A., P. Kerlinger, R. Curry, and L. Sla																										
				22.3	4.5	140	3-day	Jain	Ridge wind power project post-constru																										
																								_						15.2	3.1	128	weekly	Jain	Annual report prepared for PPM Energ Cape May Point, New Jersey, USA.
			2007	10.7	3.9	199	weekly	Jain	Jain, A. P. Kerlinger, R. Curry, and L. Slo Ridge wind power project post-constru Annual report prepared for PPM Energ Cape May Point, New Jersey, USA.																										
			2008	8.2	3.4	209	weekly	Jain	Jain, A. P. Kerlinger, R. Curry, and L. Slo Ridge wind power project post-constru Annual report prepared for PPM Energ Cape May Point, New Jersey, USA.																										
			2012	12.1	NA	96	weekly	Shoenfeld	Tidhar, D., J. Ritzert, M. Sonnenberg, M. Fatality Monitoring Study for the Maple Final Report: July 12 – October 15, 2012 America by Western EcoSystems Techr Waterbury, Vermont.																										
Munnsville	NY	1.5	2008	0.7	2.2	215	weekly	Jain	Stantec Consulting Services Inc. 2009. Munnsville Wind Farm, New York, 2008. Renewables.																										



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Site	State	Turbine Size (MW)	Year	Estimated Bat Mortality per Turbine	Estimated Bird Mortality per Turbine	Survey Period Lenath (Davs)	Search Interval	Estimator	F
Steel Winds	NY	2.5	2012	6.3	4.3	161	weekly	Jain w/o area	Stantec Consulting Services Inc. 2013.
				6.9	8.5			Jain w/ area	Monitoring Report, 2012. Prepared for
				5.8	4.0			Huso w/o area	7
				6.4	7.2			Huso w/ area	
			2013	15.3	15.5	150	3-day	Huso w/ area correction	Stantec Consulting Services Inc. 2014. Monitoring Report, 2013. Prepared for
Wethersfield	NY	1.5	2010	24.5	2.6	184	weekly	Jain	Jain, A., Kerlinger, P., Slobodnik, L., Cur Report for the Noble Wethersfield Wind Fatality Study - 2010. Prepared for Nob
Site 2-10	PA	unknown	2008	16.0	1.0	unknown	unknown	unknown	Taucher, J., T. Librandi-Mumma, and V
			2010	5.0	2.0	229	daily	Shoenfeld	Commission Wind Energy Voluntary Co
Site 2-14	PA	unknown	2008	7.0	7.0	229	daily	Shoenfeld	
			2009	7.0	5.0	229	daily	Shoenfeld	
Site 2-19	PA	unknown	2010	31.0	3.0	229	daily	Shoenfeld	
			2011	8.0	5.0	229	daily	Shoenfeld	
Site 2-2	PA	unknown	2008	19.0	2.0	229	daily	Shoenfeld	
			2009	13.0	4.0	229	daily	Shoenfeld	
Site 2-4	PA	unknown	2009	29.0	10.0	229	daily	Shoenfeld	
			2010	32.0	3.0	229	daily	Shoenfeld	
Site 24-1	PA	unknown	2010	59.0	4.0	229	daily	Shoenfeld	
			2011	30.0	7.0	229	daily	Shoenfeld	
Site 24-3	PA	unknown	2009	12.0	3.0	unknown	unknown	unknown	
			2010	38.0	3.0	229	daily	Shoenfeld	
			2011	19.0	3.0	229	daily	Shoenfeld	
Site 35-1	PA	unknown	2010	22.0	2.0	229	daily	Shoenfeld	
			2011	11.0	3.0	229	daily	Shoenfeld	
Site 5-5	PA	unknown	2009	13.0	1.0	unknown	unknown	unknown	
			2010	11.0	1.0	229	daily	Shoenfeld	
Site 6-1	PA	unknown	2009	28.0	2.0	229	daily	Shoenfeld	
			2010	29.0	2.0	229	daily	Shoenfeld	
Site 6-16	PA	unknown	2011	32.0	5.0	229	daily	Shoenfeld	
Site 6-3	PA	unknown	2007	30.0	2.0	229	daily	Shoenfeld	
			2008	27.0	2.0	229	daily	Shoenfeld	
Laurel Mountain	WV	1.6	2012	23.4	9.0	200	3-day	Shoenfeld	Stantec Consulting Services Inc. 2013. construction Monitoring Data Report f Randolph and Barbour Counties, West Wind, LLC.

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Site	State	Turbine Size (MW)	Year	Estimated Bat Mortality per Turbine	Estimated Bird Mortality per Turbine	Survey Period Length (Days)	Search Interval	Estimator	R	
Mount Storm	WV	2.0	2008	24.2	3.8	92	daily	Erickson et al. 2003	Young, D.P., W.P. Erickson, K. Bay, S. Nc Energy Facility, Phase 1: Post-construct	
				7.8	2.4	2.4 weekly	weekly		NedPower Mount Storm, LLC.	
			2009	21.4	7.6	169	weekly		Young, D. P., K. Bay, S. Nomani, and W Energy Facility, post-construction avian	
				28.6	8.7		daily		Western EcoSystems Te	Western EcoSystems Technology, Inc.,
			2010	22.4	2.8	93	daily		Young, D.P., S. Nomani, W. Tidhar, and Facility Post-construction Avian and Ba NedPower Mount Storm, LLC.	
Mountaineer	WV	1.5	2003	47.5	4.0	222	2x per week	Shoenfeld	Kerns, J., and P. Kerlinger. 2004. A study Mountaineer Wind Energy Center, Tuck for 2003	
Pinnacle	WV	2.4	2012	96.5	9.6	275	weekly	Huso & Dalthorp	Hein, C.D., A. Prichard, T. Mabee, M.R. construction Monitoring at the Pinnack 2012. Prepared for Edison Mission Energy	



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Attachment WPE-6

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Introduction

Since 1999 over 100 seasonal nocturnal migration marine radar studies have been completed as part of pre-construction risk assessments for proposed wind energy projects in the eastern US.

Regulators, developers, stakeholders and biologists assume that study results inform risk:

high passage rate & low target altitude = high risk?





Methods

- Tested whether standardized pre-construction passage rate & other metrics correlated with post-construction fatality estimates using non-parametric correlation coefficients.
- Assessed variation in metrics across studies.
- Analyzed geography and landcover as covariates -ANOVA.



What have we learned from pre-construction radar studies? David Tidhar, Christopher Nations, and David P. Young

Results



& fatality estimates



Discussion

1. Pre-construction passage rates do not correlate with post-construction fatality estimates

2. No correlation between mean flight height or % targets flying within Rotor Swept Area (RSA)

5. Mean altitude and % targets within RSA differed significantly between seasons

3. Little variation in seasonal flight direction (T = 95 % CI bootstrapped)



4. Landcover and geography do not significantly effect passage rate, altitude or % targets within RSA

Results of one-way analysis of variance for separate tests of effects of landcover, geography, & season on passage rate, altitude, and % targets within RSA. Tests significant at α = 0.05.					
Response	Effect	Effect df	Error df	F	p-value
Passage Rate	Landcover	3	88	2.46	0.068
Altitude	Landcover	3	87	0.39	0.758
Percent within RSA	Landcover	3	86	0.06	0.980
Passage Rate	Geography	4	51	1.53	0.207
Altitude	Geography	4	50	0.90	0.471
Percent within RSA	Geography	4	50	0.13	0.972
Passage Rate	Season	1	91	0.02	0.888
Altitude	Season	1	90	5.29	0.024
Percent within RSA	Season	1	89	24.21	<0.001



•The assumption that higher passage rate = higher risk is not supported by existing data. •Variation between sites does not appear to significantly effect target direction, passage rate, altitude, or % targets within RSA. However, further evaluation of landcover warranted. •Additional pre-construction radar studies in heavily studied region (NY, VT and NH) may yield little benefit for project risk assessment. Post-construction radar studies would yield better value and benefits to the wind industry (streamline approach), agencies (concurrent risk & impact data) and wildlife (focused evidence-based mitigation).

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Summary: Testimony of Wallace Erickson electronically filed by Christine M.T. Pirik on behalf of Icebreaker Windpower Inc.