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Research Paper, part of a Special Feature on Quantifying Human-related Mortality of Birds in Canada

Canadian Estimate of Bird Mortality Due to Collisions and Direct Habitat Loss Associated with Wind Turbine Developments

Estimation de la mortalité aviaire canadienne attribuable aux collisions et aux pertes directes d'habitat associées à l'éolien

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ABSTRACT. We estimated impacts on birds from the development and operation of wind turbines in Canada considering both mortality due to collisions and loss of nesting habitat. We estimated collision mortality using data from carcass searches for 43 wind farms, incorporating correction factors for scavenger removal, searcher efficiency, and carcasses that fell beyond the area searched. On average, 8.2 ± 1.4 birds (95% C.I.) were killed per turbine per year at these sites, although the numbers at individual wind farms varied from 0 - 26.9 birds per turbine per year. Based on 2955 installed turbines (the number installed in Canada by December 2011), an estimated 23,300 birds (95% C.I. 20,000 - 28,300) would be killed from collisions with turbines each year. We estimated direct habitat loss based on data from 32 wind farms in Canada. On average, total habitat loss per turbine was 1.23 ha, which corresponds to an estimated total habitat loss due to wind farms nationwide of 3635 ha. Based on published estimates of nest density, this could represent habitat for ~5700 nests of all species. Assuming nearby habitats are saturated, and 2 adults displaced per nest site, effects of direct habitat loss are less than that of direct mortality. Installed wind capacity is growing rapidly, and is predicted to increase more than 10-fold over the next 10-15 years, which could lead to direct mortality of approximately 233,000 birds / year, and displacement of 57,000 pairs. Despite concerns about the impacts of biased correction factors on the accuracy of mortality estimates, these values are likely much lower than those from collisions with some other anthropogenic sources such as windows, vehicles, or towers, or habitat loss due to many other forms of development. Species composition data suggest that < 0.2% of the population of any species is currently affected by mortality or displacement from wind turbine development. Therefore, population level impacts are unlikely, provided that highly sensitive or rare habitats, as well as concentration areas for species at risk, are avoided.

RÉSUMÉ. Nous avons évalué les impacts de la construction et de l'opération de parcs éoliens sur les oiseaux au Canada en considérant la mortalité attribuable tant aux collisions qu'à la perte d'habitat de nidification. Nous avons estimé la mortalité par collision à partir de données provenant de la recherche de carcasses dans 43 parcs éoliens, et avons inclus des facteurs de correction tenant compte de l'efficacité des observateurs, de la persistance des carcasses et du fait qu'elles pouvaient se trouver à l'extérieur de l'aire couverte par les recherches. En moyenne, 8,2 ± 1,4 oiseaux (IC à 95 %) ont été tués par éolienne par année dans ces parcs, quoique ce nombre a varié de 0 à 26,9 oiseaux par éolienne par année lorsque les parcs ont été pris individuellement. Fondé sur 2 955 éoliennes construites (bilan en décembre 2011 au Canada), nous estimons que 23 300 oiseaux (IC à 95 % = 20 000 à 28 300) seraient tués à la suite de collisions avec les éoliennes chaque année. Nous avons ensuite estimé la perte directe d'habitat à partir de données de 32 parcs éoliens au Canada. En moyenne, la perte d'habitat par turbine s'élevait à 1,23 ha, ce qui équivaut à 3 635 ha d'habitat perdu au profit d'éoliennes dans l'ensemble du Canada. Selon des estimations de densité de nids publiées, une quantité d'habitat de cet ordre pourrait contenir 5 700 nids, toutes espèces confondues. En présumant que les milieux voisins sont saturés et que deux adultes sont déplacés par site de nidification, les effets de la perte d'habitat directe sont moins importants que ceux qui sont attribuables à la mortalité directe. Or, la puissance éolienne installée augmente rapidement et on prévoit qu'elle se multipliera par plus de dix d'ici 10 à 15 ans, ce qui pourrait se traduire par la mortalité directe d'environ 233 000 oiseaux/année et le déplacement de 57 000 couples. Malgré les préoccupations quant aux impacts des biais des facteurs de correction sur la précision des estimations de la mortalité, ces valeurs sont vraisemblablement moins élevées que celles calculées pour les collisions avec d'autres sources anthropiques comme les fenêtres, les véhicules ou les tours, ou encore celles associées à la perte d'habitat attribuable à de nombreuses autres formes de développement. Les données sur la composition spécifique indiquent que < 0,2 % des populations, peu importe l'espèce, est en réalité touchée par la mortalité ou le déplacement

[1]Canadian Wildlife Service

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occasionné par le développement éolien. Ainsi, les répercussions sur le plan des populations sont peu probables, pourvu que les milieux très sensibles ou rares, de même que les aires de concentration d'espèces en péril soient évités.

Key Words: *bird populations; Canada; collision mortality; correction factors; habitat loss; wind turbine*

INTRODUCTION

Although wind power is widely viewed as a clean alternative to fossil fuel-based energy generation, there has been some concern regarding the impact of wind farms on birds (Kern and Kerlinger 2003, Langston and Pullan 2003, Kingsley and Whittam 2005, Drewitt and Langston 2006, Barclay et al. 2007, Smallwood 2013). Birds can be killed through collisions with turbines and other ancillary structures such as meteorological (met) towers or power lines, and through nest mortality if vegetation clearing, required for project development, occurs during the nesting season (Band et al. 2007, Smallwood and Thelander 2008). Construction associated with wind turbines can also lead to loss of nesting habitat, thus reducing the carrying capacity or productivity of a site in the longer term.

Most turbine collision studies have reported low levels of overall bird mortality (Drewitt and Langston 2006, 2008), especially when compared to mortality from other man-made structures such as communication towers (Kerlinger et al. 2011, Longcore et al. 2012). Results from mortality studies at various sites in the United States and Europe generally suggest that annual bird collisions range from 0 to over 30 collisions per turbine, although data collection protocols, experimental design, and analysis methods varied substantially among wind farms, making many studies difficult to compare (Kuvlesky et al. 2007, Sterner et al. 2007, Stewart et al. 2007, Ferrer et al. 2012). Erickson et al. (2001) estimated 33,000 birds killed per year based on 15,000 turbines in the United States for an average of 2.1 birds/turbine/year. Manville (2009) suggested that this may be a considerable underestimate, and provided a number of 440,000 birds per year with 23,000 turbines installed, but did not provide a rationale for the revised number. Smallwood (2013) estimated 11.1 birds/megawatt/year (or 22.2 birds per turbine for a typical modern 2 MW turbine), which would represent about 573,000 birds killed each year across an installed capacity in 2012 of 51,630 megawatts. One report from Spain (Atienza et al. 2011) suggested mortality rates could be as high as 300 - 1000 birds/turbine/year, but little justification was provided for this estimate.

Passerines typically comprise 80% of all fatalities, most of which involve nocturnal migrants (Mabee et al. 2006, Kuvlesky et al. 2007), but some of the greatest concern has related to raptors. The behavior of some diurnal migrating birds, such as raptors, makes them vulnerable to collisions with wind turbines, particularly if they are hunting (Higgins et al. 2007, Garvin et al. 2011, Martínez-Abraín et al. 2012). Raptor mortality rates were particularly high at some early, large-scale wind energy facilities in California, e.g., Altamont (Orloff and Flannery 1992). Although some reports suggest that newer wind facilities are generally associated with lower bird fatality rates (Erickson et al. 2001, 2005), others propose that the more modern turbine designs, with taller towers and larger blade lengths with higher tip speeds, pose higher collision risks (Morrison 2006). For nocturnal migrants, there is little evidence that particular species of birds are more vulnerable than others, and mortality is thought to be proportional to the relative abundance of each species (Drewitt and Langston 2006). Current levels of mortality are not thought to impact most individual bird populations (Kuvlesky et al. 2007, Arnold and Zink 2011). Nevertheless, these collisions contribute to the cumulative mortality of birds (Gauthreaux and Besler 2003) and potentially could influence the long-term viability of some populations. Particular concern has been expressed that even low levels of mortality for species with low population densities and slow reproductive rates, such as raptors, could have population level impacts (Manville 2009).

Nest mortality and the displacement of breeding pairs through loss of habitat may also occur when habitat is removed for the construction of turbine pads, access roads, and power lines (Pearce-Higgins et al. 2012). Such impacts are similar to those from many other types of development, but nevertheless represent a potential impact of a wind farm. Newer facilities are constructed with larger, more efficient turbines that result in fewer turbine pads and roads per unit of energy. In Canada, most wind farms have been built in agricultural areas or other disturbed areas, but some have been built in areas that were formerly relatively undeveloped, e.g., contiguous forest.

Wind energy development in Canada has grown dramatically in recent years and has been subject to considerable effort for environmental assessment, relative to many other forms of development, but a comprehensive analysis of data from Canadian sites has not yet been undertaken (Smallwood [2013] used data from only two Canadian sites). Installed capacity of commercial wind power in Canada increased by 750% between 2005 and 2011; as of December 2011, there were over 135 wind farms with 2955 wind turbines in the country, and this number is expected to increase tenfold over the next 10 - 15 years (CANWEA 2011). The high effort required for environmental assessments has been due partly to uncertainty about the impacts of a relatively new and changing technology, as well as concerns about wildlife impacts observed at some of the early facilities such as those in California. As a result, many facilities have undergone lengthy baseline studies for multiple seasons and years to determine wildlife use of the site

(Stantec, *unpublished report*; Jacques Whitford Ltd., *unpublished report*). The results of these studies have, at some sites, influenced the location of turbine locations within a wind facility (Golder Associates Ltd., *unpublished report*) and, occasionally, influenced the decision whether or not to proceed with development of a wind facility (e.g., National Wind Watch 2011). Once constructed, many sites have carried out extensive postconstruction studies to monitor direct mortality caused by wind turbines to birds and other wildlife.

We analyze available data on bird mortality from postconstruction monitoring reports in Canada to derive national and provincial estimates of total bird mortality from collisions with wind turbines, and compare them with published estimates from other countries and estimates of bird mortality from other forms of development. We also estimate the loss of breeding habitat, and potential rates of nest mortality as a result of construction activities. Although we acknowledge that other wildlife, particularly bats, may also be impacted by wind power projects, we limited our current analyses to impacts on birds.

METHODS

Collision mortality data

We obtained all available postconstruction monitoring reports for sites across Canada that had been submitted to Natural Resources Canada as part of the postconstruction monitoring requirements of an environmental assessment. We also obtained data from postconstruction monitoring reports published on wind developers' or their consultants' websites, as well as some confidential data directly from developers or their consultants on the condition that they could be used for this analysis, but could not be publically released. These reports provide the results of carcass searches conducted at the base of turbines at operating wind farms; however, few include mortality data from meteorological towers or above ground power lines so those were excluded from our study. We obtained data for wind farms in eight provinces, but were unable to obtain relevant data for wind farms in the Yukon, Manitoba, or Newfoundland and Labrador. There are currently no wind farms operating in the Northwest Territories or Nunavut.

Most data in postconstruction monitoring reports were collected by environmental consultants contracted by the wind energy developer. Data collection methodologies used to estimate mortality were not standardized and therefore varied somewhat between wind energy developments and consultants, especially prior to 2007 when federal environmental assessment guidelines for birds were published (Environment Canada 2007*a*,*b*). The lack of standardization in data collection protocols means that the raw carcass counts may not be comparable among studies because the proportion of carcasses retrieved may vary among study. Nevertheless, by taking into account appropriate correction factors specific to the methodology in each study, it is possible to estimate mortality rates, and make direct comparisons among studies.

We estimated collision mortality based on data collected from searching for carcasses around a fixed distance, usually 50 m, from the base of turbines, and corrected for incomplete detection. Carcass searches are only expected to find some of the birds killed by turbines. Some carcasses may be removed by scavengers, others may land outside the search area, while others may be overlooked by the searcher. Each of these factors may vary among studies depending upon the terrain, the area searched, and the individual searching in the field. We applied a standardized approach to correcting the raw data using Equation 1, which is similar to that used for postconstruction monitoring studies in some provinces (e.g., OMNR 2011):

$$C = c / (Se * Sc * Ps * Pr * Py) \quad (1)$$

where, C = corrected number of bird mortalities, c = number of carcasses found, Se = proportion of carcasses expected to be found by searchers (searcher efficiency), Sc = proportion of carcasses not removed by scavengers over the search period (scavenger removal), Ps = proportion of area searched within a 50 m radius of turbines (assuming a uniform distribution of carcasses within the 50 m radius), Pr = proportion of carcasses expected to fall within the search radius, and Py = proportion of carcasses expected during the times of year that surveys took place. Our analyses assumed that all carcasses found were killed as a result of collisions with turbines.

All but three of the studies we analyzed estimated both searcher efficiency and scavenging rates specific to their study design and study area. There was substantial variation in the estimated values for searcher efficiency (range 0.30 to 0.85) and scavenger removal rates (range 0.10 to 0.91) highlighting the importance of using site-specific values whenever possible. Differences in searcher efficiency are expected because of variation in the habitat being searched, which varied from gravel pads to agricultural fields to regenerating vegetation, as well as differences in observers and their experience. Scavenger rates are also expected to vary among sites, depending both on the habitat, which affects the ease with which scavengers can find carcasses, as well as the scavenger community in any given area, which potentially includes birds, mammals, and invertebrates such as ants and burying beetles (Labrosse 2008).

We acknowledge the possibility that some estimates of detection probabilities and scavenger removal rates may be biased in various ways. In some studies, multiple observers with different levels of experience may have carried out the carcass searchers, but only a single value of searcher efficiency was provided, and it was not clear whether this was an appropriately weighted average across observers. Some reports indicated that carcasses used for searcher efficiency and or scavenger trials were not always placed in the same habitat types where carcass searches were conducted; if they were concentrated in habitats that were easier or harder to search, this could have created a bias. The type of carcasses used in the searcher efficiency and scavenger removal trials also varied among projects: most studies used migratory birds that had previously been found around turbines, but a few used young chickens and quail of varying ages. Labrosse (2008) demonstrated that detection probability associated with carcasses increases with the contrast and color against the background. If domesticated birds are used for searcher efficiency trials, this could lead to biased estimates if they are more conspicuous than typical wild birds. Furthermore, searcher efficiency trials should be done “blind” so that the searcher is unaware when they are being tested to avoid changes in search patterns on testing days, but if the searcher finds a domestic bird he/she will immediately be aware of the trial. Scavenger removal trials may also have been biased if they were only carried out during part of the season, if domestic birds instead of wild birds were used, if they were not placed in all of the habitats being searched, or if some of the carcasses had already been dead for a while; freshly dead birds are likely to be scavenged much faster than birds that have been dead for several days and are partly dehydrated (Van Pelt and Piatt 1995). For the purpose of this study, we have accepted the values provided in the individual studies, but recognize that, in some cases, this may lead to bias, an issue which we consider in the discussion.

Most studies did not estimate the proportion of birds expected to fall beyond the typical 50 m search radius (Pr), so we used standardized estimates based on a limited number of studies that monitored a larger search area. The distribution of carcasses in relation to distance from the turbines is unlikely to vary much among sites, because it is affected mainly by the height of the turbines (Hull and Muir 2010), which is very similar for most Canadian turbines, and is not affected by habitat, searcher efficiency, or scavengers. Hull and Muir (2010) used a Monte-Carlo approach based on ballistics to model the proportion of carcasses that would be thrown various distances from a turbine, assuming that birds acquire a forward momentum based on the speed of the blade and are equally likely to be hit anywhere along the length of the blade. For turbines with an 80 m high nacelle and 45 m long blades, similar to most Canadian turbines, they suggested that 99% of small birds (10 g) would land within 71 m of the turbine base. This distance increases to nearly 90 m for midsized birds (680 g), and 115 m for large birds (4500 g). Because most birds killed at Canadian turbines were small to midsized, we assumed that a radius of 85 m would include nearly all individuals, and used empirical data from postconstruction monitoring reports that had searched areas up to 85 m around turbines in open habitats. All of these studies used equal-width transects to provide uniform coverage through the search area. In three studies, a 120 x 120 m square grid was searched around each turbine, while one used a 160 x 160 m square grid. All of these studies provided complete coverage out to 60 m, but to estimate the number of carcasses that fell between 60 - 85 m from the turbine, we extrapolated the number of carcasses found per square meter in the corners of the square search grid to a circle with a radius of 85 m. Averaged across these four studies, we estimated that only 48.2% of carcasses fell within a 50 m radius. This estimate is very close to an estimate based on our own unpublished study in spring 2013 that searched the entire 85 m radius around turbines in an agricultural area and found 58 carcasses of which only 46.5% were within a 50 m radius. We applied a correction factor of 48% (a weighted average of these studies) to the estimated mortality for all wind farms that only searched up to a 50 m radius.

Most sites were only surveyed for part of the year, generally in seasons when the highest risk of mortality was anticipated, usually the spring and autumn migration periods. In one case, only three months, i.e., one season, of postconstruction monitoring data were collected. Most of the reports provided the total number of carcasses and estimated total mortality per site only for seasons that were surveyed. To extrapolate estimates to an annual total (Py), we used data from four wind farms in Alberta and one in Ontario that were surveyed for up to two years throughout the annual cycle, and for which mortalities were reported for each month. Using these data, we estimated the monthly distribution of mortality throughout the year. We then estimated annual mortality for other sites by dividing the corrected number of bird mortalities per turbine by the proportion of mortalities expected during the actual dates that surveys took place, e.g., in Alberta, on average, 95% of mortalities occurred between April and November; in Ontario, 98.5% of mortalities occurred during this time period. For sites in Ontario and east, we used the Ontario estimate, whereas for sites in Manitoba and west we used the Alberta estimate of proportion of mortalities expected during the actual dates that the surveys took place. We acknowledge that there are limitations to extrapolating results from one season to other seasons based on only five studies, because seasonal patterns of mortality rates may vary among locations. However, because most studies concentrated their efforts during seasons with the highest expected mortality, and because relatively few birds are found during the summer and winter months, any error associated with extrapolation to these seasons is unlikely to have much impact on our estimates.

We applied the appropriate correction factors (Equation 1) to all 43 wind farms using the data provided in reports on searcher efficiency, scavenger rates, and area searched. Where multiple years of data were collected at a site, we used the average of all years for the analysis. In some studies, there were insufficient data to apply correction factors and estimate mortality for each season, i.e., spring and fall, so we used average factors. At one wind farm in Alberta, searcher efficiency was not reported and, at two wind farms, scavenger impacts were not reported. In these cases, we applied the average values for wind farms in Alberta (Se = 0.65 and Sc = 0.61). We did not include data from any reports in our analysis where both searcher efficiency and scavenger impact data were absent, or where surveys occurred for less than three months throughout the year.

To determine if there was any significant variation in estimated mortality among provinces, we conducted a one-way Analysis of Variance (ANOVA) using estimated average mortality for each of the 43 wind farms as the sampling unit and province as the predictor variable. We estimated avian mortality for each province based on estimated average mortality per turbine in that province for studies for which we had data, multiplied by the total number of turbines in the province. For provinces without any collision data, we used the estimated averaged mortality per turbine across Canada. We estimated total collision mortality for wind farms across Canada as the sum of the provincial estimates.

We did not analyze whether specific turbine model types or characteristics posed a higher risk to birds relative to other types because there was relatively little variation in the total height of wind turbines (hub height plus rotor radius) in the sample for which we had data. Of the wind farms analyzed in this study, 81% started their postconstruction monitoring studies after 2007, and based on a review of turbine specifications, we found that the total height (tower and blades) of nearly all of the turbines erected since 2007 was between 117 m and 136 m with a nameplate capacity of 1.5 MW to 3.0 MW.

Species-specific population impacts

We estimated the population relevance of mortality as the number of individuals of each species lost from collisions per year with wind turbines relative to the total estimated population size of that species. Of the 43 reports reviewed, 37 reported species composition of the fatalities. Because relatively few individuals of any one species were detected at each site, we pooled species-composition data across all sites to estimate the percentage of mortalities that were represented by each species. The annual mortality estimate of each species at a national scale was calculated using Equation 2:

Mortality Species X = Mortality/turbine * # Turbines * % carcasses Species X (2)

We used the Partners in Flight (PIF) landbird population database (http://rmbo.org/pif_db/laped/), Status of Birds in Canada (http://www.ec.gc.ca/soc-sbc/index-eng.aspx?sL=e&sY=2010), and the USFWS Waterfowl Population Status 2012 report (http://www.fws.gov/migratorybirds/NewReportsPublications/PopulationStatus/Waterfowl/StatusReport2012_final.pdf) to obtain estimates of the total population size of each of the 10 most abundant species in carcass searches as well as any species listed as Endangered or Threatened under the Species At Risk Act (Government of Canada 2002). Population impact for each species was then calculated as the total estimated mortality for that species divided by its estimated population size.

Loss of nesting habitat

We used information from 32 environmental assessments and postconstruction reports for wind energy developments in Canada to estimate total habitat loss from power lines, roads, substations, laydown areas, and turbine pads at each site. There is some evidence that habitat loss increases in an approximately linear fashion with wind farm size, e.g., number of turbines (Stantec, *unpublished report*). As such, we summed habitat loss from each component and presented the value as habitat loss (ha) per turbine. Average habitat loss per turbine per wind farm was calculated and extrapolated to predict habitat loss per turbine at the remaining 103 wind farms.

We used ecological land classification, habitat mapping or remote-sensing imagery provided in the environmental assessments to classify habitats for the 32 wind farms as agriculture, grasslands, deciduous forest, coniferous forest, or mixed forest. Habitat data provided in many environmental assessments were insufficient to provide finer-scale classifications. The remaining 103 wind farms for which environmental assessments could not be obtained were located based on their geographical coordinates, and assigned to one of these broad habitat classifications based on SPOT satellite imagery for the location. Nest densities in these habitats were estimated based on previous Canadian studies of incidental take due to forestry operations (Hobson et al. 2013), mowing, and other mechanical operations in agricultural landscapes (Tews et al. 2013). We used the MODIS land cover classification layer to calculate the total area of each broad habitat type and province and the Hobson et al. (2013) and Tews et al. (2013) nest densities to estimate total number of nests. The percent of nesting habitat lost for a given habitat type in a province was calculated by dividing the predicted habitat lost from wind energy developments by the total area for that habitat type across the province.

RESULTS

Collision mortality estimates

Estimates of collision mortality among the 43 wind farms varied between 0 and 26.9 birds per turbine per year. On average, estimated mortality (± 95% C.I.) was 8.2 ± 1.4 birds per turbine per year. There was no significant variation in estimated mortality per turbine among provinces in Canada ($F_{7,35} = 1.52$, $p = 0.191$). Based on 2955 installed turbines (the number installed by December 2011), the estimated annual

Table 1. Estimated bird mortality per turbine from collisions at wind farms with available carcass search data, and estimated total mortality per province based on the number of installed turbines.

Province/Territory	No. of Wind Farms	No. of Turbines	No. of Wind Farms Analyzed	Estimated Mortality/ Turbine	Predicted Estimated Mortality
Yukon (YK)	2	2	0	8.2†	16
British Columbia (BC)	3	83	2	8.4	697
Alberta (AB)	26	588	7	4.5	2646
Saskatchewan (SK)	5	132	3	10.1	1333
Manitoba (MB)	3	123	0	8.2†	1009
Ontario (ON)	38	965	19	10.8	10,422
Quebec (QC)	15	672	2	5.2	3494
New Brunswick (NB)	4	113	2	2.4	271
Nova Scotia (NS)	26	161	6	11.2	1803
Prince Edward Island (PE)	9	90	2	15.2	1368
Newfoundland (NF)	4	26	0	8.2†	213
Total	135	2955	43		23,273

†Where no data were available for a particular province, the weighted national estimate was used.

mortality across Canada was 23,300 birds (95% C.I. 20,000 - 28,300). Nearly half of all collisions occurred in the province of Ontario where the highest numbers of turbines are installed (Table 1).

Species-specific population impacts

Overall, the 37 reports that recorded species composition during postconstruction mortality surveys identified 1297 bird carcasses of 140 species. The most frequently recovered species were Horned Lark (*Eremophila alpestris*), Golden-crowned Kinglet (*Regulus satrapa*), Red-eyed Vireo (*Vireo olivaceus*), European Starling (*Sturnus vulgaris*), and Tree Swallow (*Tachycineta bicolor*; Table 2). For the most commonly recovered carcasses, and also for species at risk, collision mortality was estimated to have an annual impact of less than 0.8% of any population at a national level (Table 2).

Loss of nesting habitat and nest mortality estimates

On average, total habitat loss per turbine at 32 wind farms in Canada was 1.23 ± 0.72 ha. Based on this average, the predicted total habitat loss for wind farms nationwide was 3635 ha (Table 3). Using the nest density estimates provided in Hobson et al. (2013) and Tews et al. (2013), the total number of potentially affected nests in each habitat for all represented provinces was 5715. We had few data on the timing of construction activities to estimate the number of nests that might have been disturbed or destroyed during construction. The amount of nesting habitat disturbed or destroyed was estimated to vary from 0.002% of coniferous forest in the Yukon Territory to almost 8% of mixed forest in Prince Edward Island (Table 3).

DISCUSSION

Collision mortality estimates

Our estimates for average annual mortality per turbine at wind farms in Canada of 8.2 birds is higher than most estimates derived from reports from individual studies in Canada. This is due mainly to incorporation of two additional correction factors: the proportion of birds likely to fall outside a 50 m search radius, and the proportion of birds killed at other times of year. Nevertheless, our estimates are lower than some recent estimates for bird mortality in the United States. Manville (2009) suggested that annual bird mortality from wind power projects in the United States was 440,000 birds, which equals about 19 birds per turbine based on an estimated 23,000 turbines at the time. However, he did not provide any details on how this estimate was derived. Smallwood (2013) undertook a detailed assessment of correction factors based on data from 60 different reports, and estimated an average mortality of 11 birds per MW per year, implying 22 birds per turbine for a 2 MW turbine. Extrapolated to an installed capacity of 51,630 MW in the United States, this implies 573,000 bird fatalities per year. Most of the difference in Smallwood's estimates, compared to ours, appears to be due to differences in the correction factors rather than a difference in the number of carcasses found in the data he analyzed. For example, he used larger corrections for birds falling outside a 50 m radius; by assuming a logistic distribution of carcasses, he concluded that carcasses could fall up to 156 m away from an 80 m turbine, though this is farther than Hull and Muir (2010) suggested is likely. Furthermore, his analysis assumes that mortality is proportional to the rated capacity of the turbines, but particularly for newer turbines this seems unlikely; for example, there is only a 19% increase in the blade swept area between a 1.5 and 3.0 MW turbine (http://site.ge-energy.com/prod_serv/products/wind_turbines/en/15mw/specs.htm; http://www.vestas.com/en/wind-power-plants/procurement/turbine-overview/v90-3.0-mw.aspx#/vestas-univers). A report from Spain estimated that annual mortality was between 300 - 1000 birds per turbine (Atienza et al. 2011), but examination of the underlying data suggests similar number of carcasses were found in Spain as in Canada. Their very high mortality

Table 2. Reported mortality and estimated annual collision mortality and percent of Canadian population impacted for the 10 species most frequently reported as casualties, as well as two species at risk.

Species	No. of Carcasses	Proportion of Total	Total Predicted Mortality[†]	Canadian Population Estimate[‡]	% of Population
Horned Lark (*Eremophila alpestris*)	135	0.10	2327	30,000,000	0.008
Golden-crowned Kinglet (*Regulus satrapa*)	92	0.07	1629	23,000,000	0.007
Red-eyed Vireo (*Vireo olivaceus*)	80	0.06	1396	96,000,000	0.001
European Starling (*Sturnus vulgaris*)	66	0.05	1164	30,000,000	0.004
Tree Swallow (*Tachycineta bicolor*)	53	0.04	931	12,000,000	0.008
Red-tailed Hawk (*Buteo jamaicensis*)	40	0.03	698	582,000	0.120
Ring-billed Gull (*Larus delawarensis*)	27	0.02	465	1,000,000	0.047
Mourning Dove (*Zenaida macroura*)	26	0.02	465	5,300,000	0.009
Mallard (*Anas platyrhynchos*)	20	0.02	465	7,200,000	0.006
Purple Martin (*Progne subis*)	20	0.02	465	523,000	0.089
Canada Warbler (*Cardellina canadensis*; THR)[§]	4	0.003	70	1,350,000	0.005
Chimney Swift (*Chaetura pelagica*; THR)[§]	4	0.003	70	145,000	0.048

[†] Extrapolation based on 2955 turbines across Canada, and assuming that species composition of sampled sites is representative of all sites, ignoring variation in habitat and species distributions.
[‡] Based on estimates from various sources (see Methods).
[§] Threatened on Schedule 1 of Species At Risk Act.

estimates were based on assumptions that searcher efficiency was extremely low, scavenger rates were very high, and large numbers of carcasses fell outside the search areas. However, no evidence was presented to support those assumptions, and it is quite possible that mortality rates were not actually any higher than those in Canada.

We estimated total mortality across all sites in Canada at about 23,300 birds per year based on 2955 turbines. Installed wind capacity is growing rapidly in Canada, and is predicted to increase more than tenfold over the next 10 - 15 years, which could lead to direct mortality of approximately 233,000 birds per year. Based on Smallwood's (2013) analysis, current mortality in the United States is estimated at 573,000 birds per year which, with a projected sixfold increase over the same time period could lead to direct mortality of over 3 million birds per year. Even at these levels, estimated mortality associated with wind turbines would still be lower than those from some other anthropogenic sources. Erickson et al. (2005) estimated 500 million birds killed annually due to collisions with residential buildings, 130 million for collision with power lines, 80 million for collisions with vehicles, and 100 million due to domestic and feral cats. To some degree, these differences in impacts are due to the much larger numbers of other structures in the landscape. For example, in the United States, there were an estimated 100 million residential buildings and average mortality is estimated to be five birds per building (see Klem 1990). However, mortality per structure is also higher for many other structures than wind turbines. For example, in Canada, the average annual mortality rate from communication towers is estimated to be 28 birds per tower (Longcore et al. 2012) compared to 8.2 birds per wind turbine. Several studies have suggested that many migratory birds exhibit avoidance behavior when approaching modern wind turbines (e.g., Erickson et al. 2002, Zdawczyk 2012), which may partly explain relatively low mortality compared to other structures.

We found substantial variation among sites in the estimated mortality per turbine, ranging from 0 to 27 birds per year, but little variation among provinces, although for several provinces we only had data from a few sites. Some natural variation in mortality estimates is expected because of site-specific characteristics that may concentrate migratory birds in some areas and not in others. For example, landscape features such as promontories and large bodies of water are more likely to concentrate migratory birds along the shoreline (e.g., Diehl et al. 2003), as are largely forested landscapes

Table 3. Estimated habitat loss, number of nests lost, or breeding pairs displaced, and percent of nesting habitat lost for each habitat by province.

Province	Habitat	No. of wind farms	No. of Turbines	Predicted habitat loss (ha)	Nests/ha	Estimated No. of nests lost/pairs displaced	Area of habitat (ha)	% of nesting habitat lost
Yukon	Coniferous Forest	2	2	2.5	4	10	123,200	0.002
British Columbia	Mixed Forest	3	83	102.1	5	510	132,000	0.077
Alberta	Agriculture	21	532	654.4	0.2	131	88,700	0.737
Alberta	Grassland	5	56	68.9	0.8	55	75,300	0.092
Saskatchewan	Agriculture	5	132	162.4	0.2	32	122,800	0.132
Manitoba	Agriculture	3	123	151.3	0.2	30	30,600	0.494
Ontario	Agriculture	32	875	1076.3	0.2	215	32,300	3.33
Ontario	Deciduous Forest	2	86	105.8	7.8	825	110,000	0.096
Ontario	Urban	4	4	4.9	0.2	1	2700	0.183
Quebec	Agriculture	10	506	622.4	0.2	124	20,800	2.99
Quebec	Mixed Forest	5	166	204.2	6.2	1266	247,900	0.082
New Brunswick	Coniferous Forest	1	33	40.6	7.2	292	4600	0.891
New Brunswick	Mixed Forest	3	80	98.4	6	590	25,400	0.386
Nova Scotia	Mixed Forest	25	127	156.2	6.2	969	16,500	0.945
Nova Scotia	Deciduous Forest	1	34	41.8	5.7	238	25,400	0.165
Prince Edward Island	Agriculture	4	62	76.3	0.2	15	2300	3.36
Prince Edward Island	Mixed Forest	5	28	34.4	6.2	214	430	7.96
Newfoundland	Mixed Forest	4	26	32.0	6.2	198	59,000	0.054
	TOTAL	135	2955	3635		5715		

relative to predominately agricultural landscapes (Buchanan 2008). Based on data from the postconstruction monitoring reports, we were unable to identify factors other than correction factors that may explain variation in mortality among sites.

The accuracy of collision mortality estimates depends both on the quality of the carcass search data, and the accuracy of correction factors used to account for incomplete carcass detections. If search effort is only sufficient to detect a few (or no) carcasses, estimates will be unreliable regardless of correction factors. Potential biases in correction factors could lead to either over or under estimates of mortality. Several factors could lead to overestimates of searcher efficiency, including use of inappropriate carcasses that may be more conspicuous or larger than species that would be expected to be found during carcass searches (Labrosse 2008), concentrating carcasses in more exposed habitats within the search area, and failing to ensure that searcher efficiency trials occur without the knowledge of the observer. Scavenger rates may be biased if carcasses used in the trials are not fresh (Smallwood 2013), are not representative of the species being detected, or if too many carcasses are used at one time for trials, i.e., scavenger swamping (Smallwood et al. 2010). All of these could result in underestimates of mortality. On the other hand, many studies estimate scavenger removal over the total search interval, e.g., three days. This may lead to an overestimate because, on average, one would expect carcasses to be exposed to potential scavengers for only half the search period, e.g., for a typical three-day search interval, birds would be equally likely to be killed one, two, or three days before the search, leading to an average exposure of 1.5 days. Our correction factors may also be biased low if some birds fall beyond 85 m (Jain et al. 2007, 2009, Smallwood 2013), although ballistic modeling suggests very few birds are expected beyond that distance (Hull and Muir 2010). On the other hand, we assumed that all birds found during carcass searches died as a result of colliding with the turbines. If some of these birds died from other sources of mortality unrelated to wind turbines (e.g., see Nicholson et al. 2005), this would lead to an overestimate of the impacts of turbines.

The net effect of these various potential biases, both positive and negative, is difficult to predict, because some may cancel each other, but overall we believe that our estimates are probably reasonable. Furthermore, we note that, despite some potential biases, the wind industry has some of the most reliable data for estimating incidental mortality to birds of any industrial sector in Canada. Even if we have underestimated some of the correction factors, and the actual mortality is double what has been reported, it is still low compared to other industrial sectors.

Species-specific population impacts

The short-term population effects of wind power in Canada on most species appear to be relatively negligible. Generally, the birds recorded in carcass searches were abundant species with large populations. For example, Horned Lark, Golden-crowned Kinglet, Red-eyed Vireo, European Starling, and Tree Swallow were the most commonly impacted species. For the five most common bird species, the effect of collisions with wind turbines is unlikely to affect their conservation because the estimated mortality represents less than 0.01% of their Canadian populations.

Nevertheless, mortality effects could be potentially important for individual species over the long-term, e.g., 10 - 20 years, especially if wind farms are poorly sited. For example, at a wind farm on Smola Island, Norway, prior to construction, approximately 13 White-tailed Eagle (*Haliaeetus albicilla*) pairs occupied territories within 500 m of the proposed site, whereas in 2009 only five pairs occupied territories (Nygard et al. 2010). Between 2005 and 2009, 36 White-tailed Eagles were killed on the Smola Island suggesting that these collisions were directly impacting the local population of eagles. Some concerns have been expressed that wind turbines in North America could have negative impacts on long-lived species with low reproductive rates such as Golden Eagles (*Aquila chrysaetos*; see Hunt et al. 1998) though population level quantitative data to support this concern have not been published. Mortality for species at risk is a particular concern because any incremental mortality could potentially slow recovery. However, even for Chimney Swifts (*Chaetura pelagica*), a species that is threatened nationally, wind turbine related mortality only affects 0.03% of the population. Nevertheless, as the number of turbines increases, and given that many Canadian birds also migrate through the United States where they are exposed to many more turbines, population effects may eventually become an issue for some species if they are particularly vulnerable to turbines.

Loss of nesting habitat and nest mortality estimates

The other potential source of wind farm-related bird mortality is the destruction of nests during construction. Nest mortality might occur if vegetation containing nests is cleared or destroyed during the bird breeding season. If all construction was conducted during the breeding season, based on nest density estimates, approximately 5700 nests would have been destroyed. However, limited available evidence from postconstruction monitoring reports suggests that most construction activities occur outside of the breeding bird season. For example, in Ontario, we estimated that only 20% of projects conduct clearing activities during the breeding season. In the prairies, up to 50% of projects may carry out some vegetation clearing during the breeding season, with the potential to induce nest mortality. The number of nests disturbed or destroyed from construction activities can be minimized if construction activities are conducted outside of the breeding season.

In addition to collision and nest mortality, birds may also be impacted by the loss of nesting habitat as a result of construction activities that remove vegetation for the turbine pads and infrastructure, i.e., electrical lines, substation, access roads. According to our estimates, approximately 1.23 ha of vegetation is removed per turbine, resulting in a loss of approximately 3600 ha; an area equivalent to 500 km of a typical four-lane highway, including shoulders and ditches. Assuming nearby habitats are saturated, and two adults displaced per nest site, effects of direct habitat loss on reducing bird populations, through lost productivity, the effects of which are equivalent to nest mortality, are lower than that of direct mortality. At the provincial level, effects of direct habitat loss from wind turbines may be more pronounced in less common habitat types, e.g., mixed forest in Prince Edward Island. However, our overall estimates of nesting habitat loss are still much smaller than habitat loss due to many other forms of development such as forestry, agriculture, and mining (see Calvert et al. 2013).

In addition to the direct loss of habitat, birds may avoid foraging, nesting, and roosting habitats near wind farms during construction activities and operation, thus effectively decreasing habitat quality beyond the immediate footprint of the turbine (Band et al. 2007, Higgins et al. 2007). The importance of this indirect effect has rarely been measured, but varies among species depending on their life history, behavior, and habitat requirements (Desholm 2009). For example, some species of birds breeding near wind farms habituate to the presence and operation of the turbines over time, e.g., Pink-footed Goose (*Anser brachyrhynchus*; Madsen and Boertmann 2008), while others tend to avoid these areas because turbines obstruct flight paths and feeding areas (Pearce-Higgins et al. 2009). Some grassland breeding birds, for example, avoid nesting within 100 - 200 m of turbines, although at the Ponnequin Wind Energy Facility in Colorado, grassland songbirds, e.g., Horned Larks and Western Meadowlarks (*Sturnella neglecta*), forage directly beneath turbines (cited in Kerlinger and Dowdell 2003). At the Simpson Ridge Wind Farm in Wyoming, female survival, nest success, and brood survival were not statistically different in areas with and without turbines, although the authors caution that long-term data from multiple locations are needed to validate their results (Johnson et al. 2012). Insufficient data were available in postconstruction monitoring reports used in this study to assess the effect of avoidance of foraging, nesting, or roosting habitats on birds in Canada.

Conservation implications

The accuracy of collision mortality estimates depends strongly on the reliability of correction factors used to account for incomplete carcass detections. Environment Canada’s wind energy guidelines (Environment Canada 2007*a*,*b*) provides guidance on the assessment of potential impacts of wind energy projects on migratory birds in Canada and the type of correction factors that need to be considered during postconstruction monitoring studies. However, specific data collection protocols were not included in these guidelines to accommodate the diversity of landscape and habitat types that exist across Canada. Given concerns about the uncertainty and biases associated with correction factors, national standards should be established to ensure that correction factors are robust and defensible and that the estimated impacts of wind energy developments on migratory birds are accurate. Further directed research on the expected carcass distribution in relation to distance from turbines would reduce uncertainty associated with this correction factor.

Overall, based on the assumptions and limitation outlined in this study, the combined effects of collisions, nest mortality, and lost habitat on birds associated with Canadian wind farms appear to be relatively small compared to other sources of mortality. Although total mortality is anticipated to increase substantially as the number of turbines increases, even a tenfold increase would represent mortality orders of magnitude smaller than from many other sources of collision mortality in Canada (Calvert et al. 2013). Habitat loss is also relatively small compared to many other forms of development, including road development. Population level impacts are unlikely on most species of birds, provided that highly sensitive or rare habitats, as well as concentration areas for species at risk, are avoided.

Although, at a national level, mortality associated with wind energy developments in Canada is unlikely to affect most bird populations based on the approach used in our study, this may not be true for other wildlife such as bats. For example, at some wind farms in Canada, the estimated mortality rate is > 45 bats per turbine annually. It is uncertain whether this level of mortality could have population level impacts because no reliable estimates are currently available of population sizes for most species. Those bat species experiencing significant population declines because of White-nose Syndrome (*Geomyces destructans*) may be especially vulnerable.

In some situations where a species population may be threatened by wind turbine developments or where the rate of mortality may be above provincial thresholds, mitigation may be required. For example, in the province of Ontario, mitigation may be required when mortality estimates exceed 14 birds/turbine/year or raptor mortality exceeds 0.2 birds/turbine/year (OMNR 2011). Mitigation measures to reduce bird mortality may include the feathering of wind turbine blades when the risk to birds is particularly high, e.g., at night during peak migration. In extreme circumstances, operational mitigation techniques may include the periodic shutdown of select turbines during the highest risk periods. At some wind turbine developments in the United States, modified marine radars have been installed to detect approaching bird activity, assess mortality risk conditions, and, when necessary, automatically activate the shutdown of all turbines. However, there are no published reports on the effectiveness of this emerging technology to mitigate bird mortality at wind turbine developments, and the overall relatively low levels of avian mortality caused by wind turbines suggests this should not normally be necessary.

Responses to this article can be read online at:
http://www.ace-eco.org/issues/responses.php/609

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