FLIGHT HEIGHT DISTRIBUTION AND COLLISION RISK OF THE MARBLED MURRELET *BRACHYRAMPHUS MARMORATUS*: METHODOLOGY AND PRELIMINARY RESULTS

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SUMMARY

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Modified X-band marine radar was used to quantify flight heights, passage rates and flight behavior of Marbled Murrelets *Brachyramphus marmoratus* on the Olympic Peninsula, Washington, and to assess the collision risk associated with future coastal wind developments. Over three mornings, 287 height observations were collected for targets matching murrelet speed, flight height and density on radar. Mean height above ground level was 246 (SE 4.7) m. The lowest murrelet-type target detected was at 62 m, while the highest was recorded at 663 m. Fifty percent of murrelet-type targets were detected between 196 m and 286 m. A maximum-likelihood model of flight heights estimated that 4.6% of murrelets were flying at or below the average wind turbine rotor-swept height of 130.5 m as the birds transited to and from nest sites. From the same model, it was estimated that 0.5% and 0.01% of birds, respectively, were flying at or below the heights of typical communication towers and transmission lines. These data comprise three days of sampling at a single location, and thus may not be representative of height distributions found in other sites or regions. Flight heights likely vary with topography, distance from the ocean, weather, and other factors, and thus the proportion of birds flying below turbine height likely varies both spatially and temporally. Additional data on murrelet flight heights are now being collected to determine how the relative risk of collision changes with topography and weather conditions. This information should help predict the risk of collision with artificial structures, including wind energy developments that may pose a risk to murrelets.

Key words: marine radar, Marbled Murrelet, *Brachyramphus marmoratus*, wind energy development, marine radar, inland flight, collision risk model

INTRODUCTION

Effective management of threatened or endangered species requires baseline data on behaviors that put a species at risk from human activities. The Marbled Murrelet *Brachyramphus marmoratus* was listed as threatened by the US Fish and Wildlife Service in 1992 (US Fish and Wildlife Service 1997). Breeding populations of Marbled Murrelets are found in North America along 10 460 km of coastline, from the Aleutian Islands of Alaska south to central California (McShane *et al*. 2004). Throughout most of its breeding range, the Marbled Murrelet uses old-growth and mature coniferous forest habitat for nesting and the nearshore marine environment for foraging. Its inland nesting range depends primarily on the distribution of suitable habitat within a region, and extends up to 60 km inland in Alaska and British Columbia (Piatt *et al*. 2007), 84 km in Washington (Hamer 1995), 22 km in Oregon, and 16 km in California (McShane *et al*. 2004). Marbled Murrelets nest at elevations up to 1500 m (Burger 2002). Murrelets therefore transit a wide band of variable landscapes to reach nest sites along the Pacific coast.

Onshore and nearshore areas within and adjacent to murrelet foraging and nesting grounds have recently been a focus of planning for wind energy projects (AWEA 2010, NREL 2010, Elliot *et al*. 1986). The potential for wind energy development to negatively affect birds and bats is well documented, with mortality from direct turbine strikes being a primary concern (Kuvlesky *et al*. 2007). In addition to wind turbine development, increasing numbers of communication towers and other tall structures within the range of the murrelet create risks of collision.

Currently, there is a paucity of empirical data (i.e. large datasets of directly measured flight altitudes) to assess murrelet vulnerability. A baseline distribution of murrelet flight altitudes and passage rates is needed during the early planning phases of a project to estimate potential fatalities from collision using risk-of-collision models. By incorporating flight heights, passage rates and other information, collision models will allow a more complete evaluation of risks and impacts to local populations.

Detection of transiting murrelets by visual observation is problematic due to the difficulty of quantifying high-flying birds in low light, fog and low ceiling conditions (Naslund & O'Donnell 1995, Rodway *et al*. 1993, Jodice & Collopy 2000). Visual estimation of flight height is also hampered by short observation duration and the lack of a consistent vertical scale. In addition, observers generally see murrelets only within 100 m, or hear murrelets within 200 m (Ralph *et al*. 1994); thus, few birds are detected. Low-flying birds are detected more readily than high-flying birds, resulting in biased data on flight altitudes. The use of radar technology avoids these limitations and biases.

Several types of radar have been effective tools in ornithological research for more than four decades (Eastwood 1967). A combination of horizontally and vertically oriented radar can be used to quantify murrelet passage rate, speed, flight behavior and flight altitude at distances up to 1.5 km from the radar station (Burger 1997, Cooper & Blaha 2002). Marine radar is the easiest and least expensive to operate, and, with slight modification, can be used to measure flight altitude. Additional benefits include high resolution, commercial availability and reasonable portability of the equipment (Cooper *et al*. 1991, Hamer *et al*. 1995). Some of the first radar studies on the Olympic Peninsula, Washington (WA), Vancouver Island, British Columbia (BC), and in the North Cascade mountain range (WA) found an initial peak of silent murrelets 45–60 min before sunrise, when low light levels precluded detection by standard audio-visual surveys (Burger 1997, Cooper & Blaha 2002).

Without information on flight heights, a quantitative assessment of the risk of collision with various structures (such as wind turbines, communication towers and transmission lines) for the Marbled Murrelet is impossible. The goals of this study were to measure the flight altitudes of murrelets transiting to and from breeding sites in an area suitable for wind development and to model murrelet flight height distribution at one inland site along the Queets River (WA) to improve predictions of collision risk.

STUDY AREA AND METHODS

Using radar to estimate murrelet passage rates throughout the Olympic Peninsula, Cooper *et al*. (2001) found consistently high passage rates near the mouth of the Queets River watershed. This area has also been carefully examined in recent years as a potential site for wind power generation (Elliot *et al*. 1986, NREL 2010). Our surveys took place on 18-20 July 2009 during partly to mostly cloudy (but dry) weather conditions at two sites adjacent to the Queets River near the confluence of the Clearwater River, Jefferson County, near Queets, WA (Fig. 1). Winds at ground level during all three survey periods measured <5 km/h. The first survey was conducted on a gravel bar (located at 47°32'58.12"N, -124°16'45.5"W) on the Queets River. The radar lab was moved approximately 176 m and placed on a bridge (47°32'58.34"N, -124°16'37.06"W) over the Queets River for the remainder of the surveys. The bridge site was used to improve the detection of low-flying birds. Both sites were located near the mouth of the Queets River at elevations of approximately 13 m (gravel bar) and 30 m (bridge). Radar surveys were completed during the morning

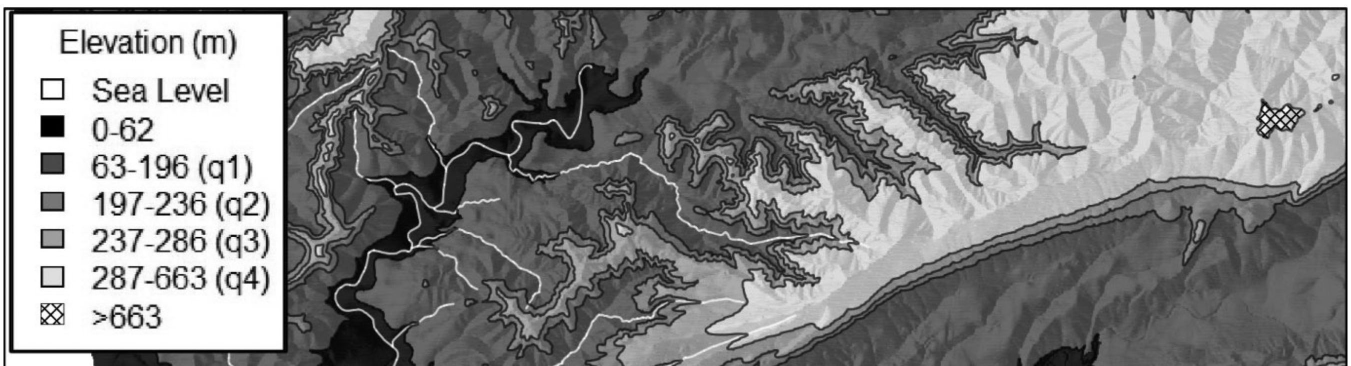

Fig. 1. Radar survey locations (hatched circles) near the confluence of the Queets and Clearwater rivers, Jefferson County, WA, and surrounding topography overlayed with quartiles of measured flight altitudes of Marbled Murrelets.

activity period, beginning approximately 105 min before official sunrise and ending 75 min after sunrise, for a total of 3 h of sampling each day. That period encompassed the known peak of daily murrelet activity (Burger 1997, Evans Mack *et al*. 2003) on the Washington coast. Times of sunrise were obtained from NOAA sunrise/sunset tables for Forks, WA.

Radar tracking was performed using two 12 kW high-frequency marine radar units (Furuno Model FR-1510 Mark 3, Furuno Electric Company, Nishinomiya, Japan) transmitting at 9410 MHz (X-band). To enhance the detection of small targets at a distance, the pulse length on both units was set to 0.07 µs. Both radar units had a vertical span of 25° and a horizontal beam width of 2° and were operated at the 1.5 km scale. Radars were powered by 2000 kW Honda quiet generators positioned within 10 m of the radar lab.

One radar unit, operated in a horizontal plane, was used to map individual flight paths and calculate passage rates. At both sites, forest to the north and south of the river effectively formed a low barrier, possibly limiting the ability of the radar to detect targets that were distant (>1 km) and low to the horizon. To mitigate those effects, the horizontal unit was tilted upward 25°, raising the bottom radar energy lobe approximately 12.5° above the horizon. Target speed was measured as the distance between echoes on the radar screen. Murrelets were discriminated from other radar targets by accepting only targets with (1) speeds >56 km/h, (2) linear flight paths and (3) dense, compact radar signatures (Hamer *et al*. 1995). Information recorded for each murrelet-type target identified by the horizontal-scanning radar included time, radar species identification, outside observer's species identification, flight behavior, flight direction, flight speed and furthest distance detected from the radar unit. Inland flights of murrelets often follow watersheds oriented in an east–west direction as the birds transit back and forth from inland nesting habitat to marine waters. Murrelet targets were classified as flying landward or seaward if they flew within ±60° of the prominent axis of the watershed in a landward or seaward direction, respectively (Cooper *et al*. 2001). We used a Welch two-sample *t*-test to compare heights of landward- and seaward-flying birds.

A second radar unit was set up to rotate on a vertical plane, with its axis perpendicular to both the horizon and the projected flight path of the murrelets as they moved through the Queets River watershed. The bearing and radial distance to each murrelet-type target was used to calculate the height of each bird above the radar elevation. The height of birds above ground level was calculated by subtracting the difference between the ground elevation beneath the point of detection and the elevation of the radar unit from the measured height of the target. Heights were recorded only for targets that had been identified by the horizontal radar as a murrelet-type detection.

To estimate the best-fit parameters for the observed flight height distribution, the empirical data were fitted to several probability density distributions using maximum likelihood parameter estimation (Venables & Ripley 2002). Possible distributions were chosen from those previously reported in the literature as being appropriate for such distributions—normal, log-normal, gamma, log and exponential (Johnson 1957, Intachat & Holloway 2000, Klaassen & Beibach 2000, Shamoun-Barnes *et al*. 2006). Model fit for each of the distributions was assessed using Akaike's Information Criterion (AIC), the model with the lowest AIC score being chosen as the best-fit model (Burnham & Anderson 2002). The resulting model was used to estimate the proportion of birds

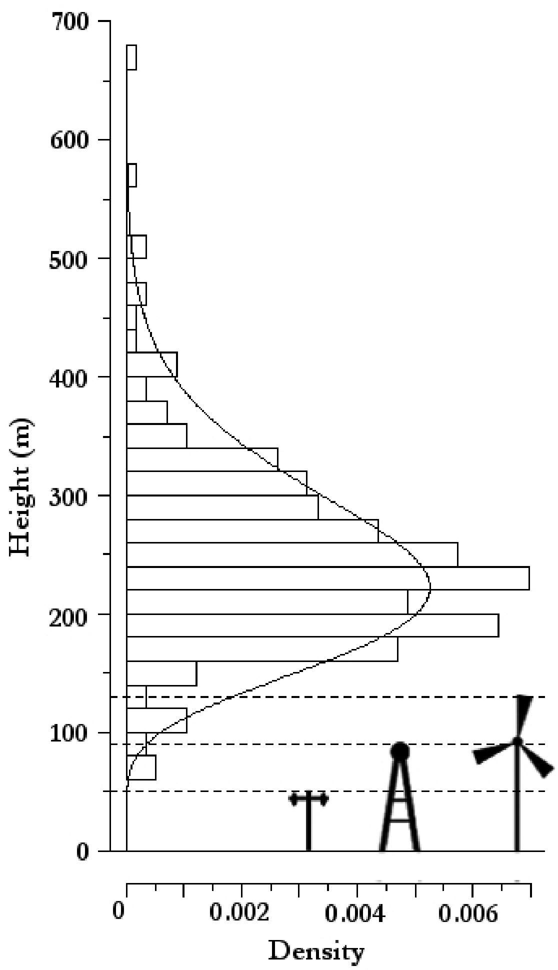

Fig. 2. Murrelet-type target heights in 25 m increments recorded near the confluence of the Queets and Clearwater rivers, Jefferson County, WA, 18–20 July 2009. Bars represent empirical data; curve is a maximum-likelihood fitted gamma probability density function. Approximate transmission line, communication tower and wind turbine heights shown for scale.

TABLE 1
Daily variability in passage rates and heights of murrelet-type targets detected using horizontal scanning radar near the confluence of the Queets and Clearwater Rivers, Jefferson County, WA, 18–20 July 2009

Parameter	18 Jul	19 Jul	20 Jul
Targets observed	144	121	115
Adjusted passage rate[a]	144	150	115
Mean height (SE), m	237 (6.6)	253 (6.8)	255 (11.5)
Estimated % below turbine height	5.0	1.0	8.2
Estimated % below communication tower height	0.5	<0.1	1.8
Estimated % below transmission line height	<0.1	<0.1	0.1

[a] Adjusted for 23 min lost due to technical problem.

at risk for collision with human-made structures (e.g. power lines, communication towers and wind turbines) that evaded radar detection by flying low enough to be masked by ground clutter, trees, structures and other hindrances. We estimated the proportions of birds flying under transmission line (50 m), communication tower (90 m) and wind turbine (130 m) heights as the integrals from ground level to structure height of the best-fit maximum likelihood-estimated probability density function.

To help verify the species identifications made by the radar technicians, audio-visual surveys were also conducted by two observers standing outside the radar lab. Following the Pacific Seabird Group (PSG) Marbled Murrelet Inland Survey Protocol (Evans Mack *et al*. 2003), these surveys started and ended at the same time as the radar surveys. Radar technicians were in radio contact with ground observers to communicate the distance, direction and flight path of murrelet-type targets detected on the radar. Night-vision goggles were used during the dark portions of the survey period. On 18 July, two observers separated and conducted visual and auditory surveys for passing murrelets from a gravel bar approximately 100 m west and east of the radar station. The following morning, one observer moved to a stretch of the Clearwater River approximately 750 m north-northwest of the radar station, while the second observer was located on the Hoh Mainline bridge. On 20 July, both observers returned to the main gravel bar located west of the bridge where visual and audio detection seemed optimal.

RESULTS

Height above ground level

The vertical radar detected 287 (76%) of 380 murrelet-type targets recorded on the horizontal radar. Observers saw no targets on the vertical radar that did not also appear on the horizontal unit, indicating that both units had identical areas of detectability. The mean height of murrelet-type targets above ground level (agl) was 246 (SE 4.7) m (n = 287). The lowest murrelet-type target detected was at 62 m while the highest was at 663 m (Fig. 2). Fifty percent of targets were detected between 196 m and 286 m (Fig. 2). Target heights above ground level did not vary significantly among days sampled (ANOVA, $F = 1.69$, $P = 0.18$; Table 1). Mean flight altitude of landward targets was 241 m (n = 143), while seaward targets flew at an average height of 253 m (n = 144). There was no significant difference in the flight altitude of landward versus seaward birds ($t = -1.278$, $P = 0.203$). Figure 1 illustrates the relationship of the observed heights to the surrounding topography.

The profile of Marbled Murrelet flight heights at the mouth of the Queets River during the time sampled was best described by a gamma probability density function with shape of 9.65 and rate of 0.04. Using those parameters, we estimated that 4.6% of murrelets during the study were flying at or below a wind turbine height of 130.5 m, 0.5% were flying below communication tower heights of 90 m, and 0.01% were below transmission line heights of 50 m (Fig. 2). Flight altitudes and risk estimates varied moderately among days (Table 1).

Counts and passage rates

Both horizontal and vertical radar detected murrelet targets on all three survey mornings. Over the 3-day period, the horizontal radar detected 380 murrelet targets during 517 minutes of sampling, resulting in a mean adjusted daily passage rate of 135 murrelet-type targets per 7.1 km^2 (Table 1). Sixty percent (228) of the murrelet targets were recorded before sunrise. For targets flying landward, the mean time of activity was 60.4 (SE1.8) min before sunrise, while the mean time of activity for seaward targets was 22.7 (SE2.5) min after sunrise (Fig. 3). All but two murrelet targets were classified as flying either landward or seaward.

The mean flight speed of the murrelet-type targets recorded by surveillance radar was 95.3 (SE 1.3) km/h (n = 294), with a minimum of 65.6 km/h and maximum of 108.7 km/h. Mean flight speed for all landward murrelet targets (n = 148) was 88.1 (SE 1.3) km/h while seaward targets (n = 146) averaged 104.5 (SE 2.1) km/h. Flight speeds of murrelet targets flying landward were significantly lower than seaward flight speeds (Mann–Whitney *U*-test, $W = 6798$, $P < 0.01$).

Audio-visual observations

Over the three survey mornings, six murrelets were detected visually and five additional birds were heard calling. With the exception of one visual observation on 18 July, all murrelets were detected before sunrise. The average height of visual detections was 26 (SE 4.2) m. All audio detections—multiple overlapping keer calls, faint to moderately loud—were recorded as coming from westerly directions. Only two visual detections occurred on 20 July, probably because of moderate fog, a low ceiling and impaired visibility.

DISCUSSION

With the rapid growth of the wind energy industry and the ubiquity of sites along the Pacific northwest coast rated as "good" or better for wind generation (Elliott *et al*. 1986, AWEA 2010, NREL 2010), there will be increasing demand to develop wind resources in areas where murrelets fly over land. The potential for such development in coastal areas within the breeding range of this federally listed species increases the need for basic information on the flight behavior of murrelets transiting between nest sites and the ocean. While the spatial distribution of murrelet breeding habitat in the western US is fairly well-known, specific information regarding murrelet flight-heights and flight behavior is needed if wind energy is to be developed at sites where murrelets are at risk of collision with turbines. The potential

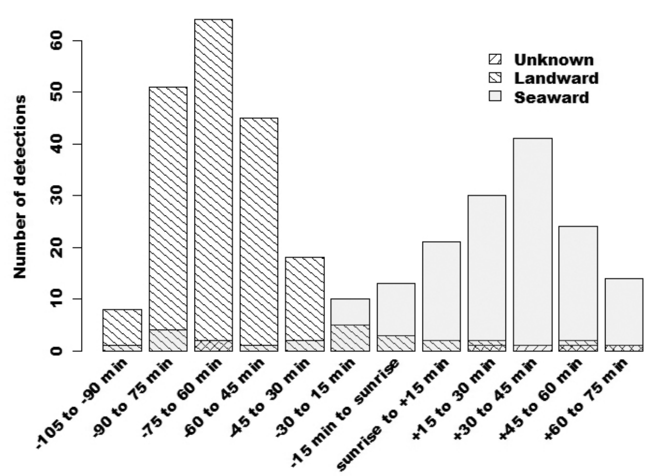

Fig. 3. Time of activity and flight direction in relation to sunrise in 15 min periods for murrelet-type targets detected at the Queets and Clearwater confluence.

for wind energy development to negatively affect birds and bats is well documented, with mortality due to direct strikes on turbines being a primary concern (Kuvlesky *et al*. 2007).

Our data on passage rates, time of activity, flight direction and flight speeds conform closely to those expected in a population of nesting or transiting Marbled Murrelets. The measured passage rate of 135 murrelets per 7.1 km^2 per day was similar to findings of Cooper *et al*. (2001), who reported a mean of 122 landward birds per morning at the same site. Other results collected from ten watersheds on the Olympic Peninsula in 2000 had maximum counts of inbound murrelet targets ranging from 28 to 93 detections per morning and mean counts from 25.3 to 160 murrelets per morning (Raphael *et al*. 2002).

Because murrelets follow a consistent pattern of landward and seaward flights each morning, we compared the time of murrelet targets to values reported in the literature as a way of assessing the likelihood that non-target species (with similar daily flight patterns) infiltrated the data. Previous studies have reported a peak of landward flights 35–60 min before sunrise (Burger 1997), 35–45 min before sunrise (Cooper & Blaha 2002) and 20–75 min before sunrise (Cooper *et al*. 2001). Thus, there is general consensus that the number of flights measured with marine radar peaks 0.5–1 h before sunrise. At the Queets River, the time of landward flights averaged 60 min before sunrise.

Seaward flights are often more variable in time. Reported peaks were 30 min before sunrise to 90 min after sunrise (Burger 1997), coincident with sunrise (Cooper & Blaha 2002) and 20 min before to 65 min after sunrise (Cooper *et al*. 2001). At the Queets River, the time of seaward flights averaged 23 min after sunrise. Reported flight directions (Burger 1997, 2001; Cooper *et al*. 2001, Cooper & Blaha 2002) show distinct patters of landward and seaward flights following river valleys (typically in an east–west direction). Similarly, at the Queets River site all but two murrelet targets flew in an easterly or westerly direction. Without exception, previously reported flight speeds were slower for birds headed inland than for seaward transits (Burger 1997, Cooper *et al*. 2001). We too found slower flight speeds for landward murrelet targets when compared with seaward targets.

There are no published data for comparison with our distribution of flight heights. These data represent three days of sampling at a single location, and thus may not be representative of height distributions found at other sites or regions. Flight heights likely vary with topography, distance from the ocean, weather and other factors, and thus the proportion of birds flying below turbine height likely varies both spatially and temporally. Table 1 illustrates the temporal variability observed over the three days of this study. This study has established an initial flight height estimate for the Marbled Murrelet and demonstrates a feasible method to calculate site-specific murrelet height distributions. Wind projects within the airspace of Murrelet Murrelets along the Pacific coast are primarily in early development stages, and there are few data on the potential mortality risk to murrelets from wind turbines. Murrelet collisions with wind turbines or other fixed structures will likely remain unquantifiable for some time as a result of the low numbers of murrelets transiting through some proposed project sites and the difficulty of finding carcasses in dense, brushy, coastal forest terrain.

At least three hypotheses could explain the high flight altitudes of the birds we studied. Murrelets are preyed upon by raptors, including Sharp-shinned Hawks *Accipiter striatus* (Marks & Naslund 1994), Peregrine Falcons *Falco peregrinus* (Nelson 1997), Northern Goshawks *Accipiter gentilis*, Bald Eagles *Haliaeetus leucocephalus* (Nelson 1997, Burger 2002) and possibly others. High flight may reduce exposure to such predators. Birds nesting at higher elevations in the Olympic Mountains (inland from the study area) also need to gain altitude to clear obstacles such as ridge tops and peaks. In addition, higher flight altitudes may give birds a landscape perspective that assists their navigation to and from nest sites when visibility is not limited by clouds. Previous studies have noted the highest numbers of murrelets at elevations <600 m (Burger 2002) and higher numbers of detections along flight corridors such as river valleys (Rodway & Regehr 2000). Murrelets have also been observed flying over ridges and mountain passes at 600–1000 m elevation (Burger 2001, Rodway *et al*. 1993). Therefore, flight altitudes likely depend in part on surrounding topography and the spatial arrangement (including elevation) of suitable habitat. In this study, more than 75% of the birds were observed flying at a height greater than that of a continuous ridge lying along the coast to the west and northwest of our radar survey stations (Fig. 1).

This is the first published information regarding the heights at which murrelets fly when transiting between foraging areas in the open ocean and inland nesting sites. Still lacking is information on how flight heights vary with topography, distance from ocean, time of breeding season, acreage and density of suitable habitat patches, weather or other important factors. It is also unknown whether murrelets exhibit avoidance behaviors when approaching a wind farm or individual wind turbines. However, with additional site-specific data on passage rates, height profiles and flight routes in proposed wind project areas, it will be possible to elaborate the risk-of-collision model and assess the relative risks to murrelets before construction. Such data would allow comparisons of risk to murrelets between potential wind sites and may assist in selecting sites of lower risk to this species. The collection of post-construction radar data at the same sites could provide information on murrelets' avoidance of wind parks or individual wind turbines. If birds are found to avoid wind parks or individual wind turbines, that would imply lower risk of collisions and potential mortality than indicated by our preliminary risk-of-collision model, which assumes little or no avoidance behavior.

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