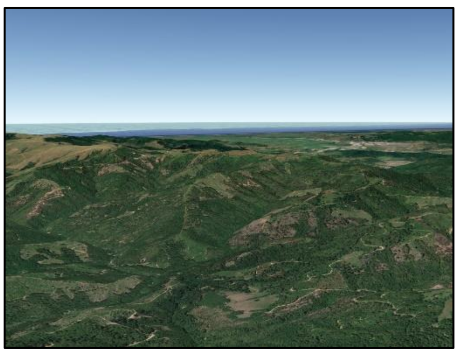
APPENDIX O

Biological Resources: *Marbled Murrelet Collision Risk Assessment Associated with the Humboldt Wind Project Proposed for Humboldt County, California*



Marbled Murrelet Collision Risk Assessment Associated with the Humboldt Wind Project Proposed for Humboldt County, California

Project #3980

Prepared for:

Humboldt Wind, LLC
11455 El Camino Real, Suite
160 San Diego, CA 92130

Prepared by:

H. T. Harvey & Associates

Richard Golightly, Ph.D., Senior Associate Ecologist
Stephanie Schneider, M.S., Wildlife Ecologist
Scott B. Terrill, Ph.D., Principal

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Executive Summary

Marbled murrelets (*Brachyramphus marmoratus*) are a federally threatened and state endangered seabird that fly between the ocean and inland sites used for nesting. In southern Humboldt County, development of a wind energy facility has been proposed by Humboldt Wind, LLC., which would require construction of a line of turbines (string) along the top of Bear River Ridge and Monument Ridge. There is potential for murrelets to encounter the wind turbines associated with this Project if they cross the turbine string as they transit to and from nesting habitat. Marbled murrelet activity at the site of this Project was assessed by using radar data from surveys during the 2018 murrelet breeding season (April through September; Evans Mack et al. 2003). We used this radar data to develop a Collision Risk Model (CRM) to estimate the magnitude of effects to marbled murrelets and assess potential risk.

For this CRM to produce reliable estimates of collision, it was essential to understand murrelet activity across the length of the turbine string. Radar-based observations of murrelet flights were used to calculate passage rates (birds/day/km) for the breeding period. For purposes of estimating annual collision risk in this analysis of data from one breeding season, we also generated informed estimates of murrelet activity during the non-breeding season using a series of assumptions based in the scientific literature.

Murrelet flights inland were non-random and varied predictably in time and space. Inland flights have been reported to be more frequent during the breeding season (Naslund 1993, Sanzenbacher et al. 2014). Passage rates (birds/day/km) were calculated for each month to represent the temporal scale of variability of inland activity. The turbine string was divided into 11 zones based on topography and passage rates were determined for each zone.

The CRM used passage rates, murrelet size, flight speed, and turbine characteristics to calculate the probability that a murrelet crossing the turbine string would pass through a rotor swept area of a turbine and, upon passage, could collide with a rotor blade. To the maximum extent possible, input data was based on empirically derived values to ensure that estimates reported here were as realistic as possible. Because turbine types and number have not yet been determined, we assumed a worst-case (maximum size/maximum number) turbine scenario for input variables including maximum rotational speed and percent of time operational. In this worst-case scenario, 0.3477 birds are estimated to collide with turbines associated with the proposed facility and, if extrapolated over the 30-year life of the Project, there would be potential for a total collision of 10.43 murrelets (1 every 3 years). The actual number of murrelet collisions is likely to be lower because wind regimes may be such that turbines experience winds insufficient for rotation to occur and, if winds adequate for rotation to occur, they may not necessarily cause blades to move at full-speed.

Like other CRMs, the model presented here was sensitive to change in avoidance probability (the probability that a bird can detect and avoid a turbine). The CRM was also sensitive to changes in both operational factors specific to the turbines (e.g.: blade speed) and passage rates of murrelets. Passage rate varied across the turbine

string, and the zone-specific passage rate ranged from an annual average of 0.003 to 0.767 birds/day/km across the 11 zones ($\bar{x}$ = 0.2912 birds/day/km for the entire length of the turbine string). Consequently, because some zones have minimal collision risk while others have a relatively elevated risk, the CRM provides a useful tool to inform decisions regarding turbine layout and operation such that the potential for collision is minimized.

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Richard T. Golightly, Ph.D.
Stephanie R. Schneider, M.S.
Scott. B. Terrill, Ph.D.

Section 1.0 Introduction

The marbled murrelet (*Brachyramphus marmoratus*, hereafter "murrelet") is a small seabird found along the Pacific Coast of western North America, ranging from central California to northern Alaska (Carter and Erickson 1992, Piatt and Naslund 1995). This species was listed as Federally Threatened in 1992 (Federal Register 57 FR 45328) and listed as State Endangered in California in 1992 (USFWS 1997). Like other members of the family Alcidae, murrelets are long-lived, with the oldest individual being at least 21 years old (R. Golightly, personal observation), require 2 to 3 years to reach sexual maturity (Peery and Henry 2010), and do not nest every year (Peery et al. 2004, Hébert and Golightly 2006). They lay a single egg on the branch of an old tree as far inland as 88 km from the ocean (Raphael et al. 2016). Paired birds are thought to persist through time, and pairs often reuse the same nest or nest stand for repeated years (Golightly and Schneider 2011, Plissner et al. 2015). This low fecundity, which is typical of alcids, results in slow population growth with the population's capacity for growth being most sensitive to adult survival (Sæther and Bakke 2000, Peery and Henry 2010).

Humboldt Wind, LLC has proposed to build a wind energy facility in southern Humboldt County, CA (hereafter "Project"). The Project is within the range of the murrelet and there is potential for murrelets to fly through the area where the turbines will operate. The Project has projected a maximum capacity of 155 megawatts that may be generated by up to 60 turbines, depending on turbine type which has yet to be determined. The turbines will be installed on Bear River Ridge and Monument Ridge, two prominent ridges that are both bordered by the Eel River to the north and Bear River to the South. Old-growth forest available to murrelets for nesting in southern Humboldt County occurs up-river and southeast from the Project. Murrelets primarily use the Eel River valley and, to a lesser extent, the Bear River valley, as corridors for transiting between foraging grounds at sea to inland nesting habitat. These ridges parallel the valley floor and are 750 to 915 m above the valley, but there is still potential that some murrelets will cross these ridges during daily transit during the breeding season and, on occasion, outside of the breeding season. To assess interaction between the Project and flying murrelets requires quantitative assessment of movements by murrelets associated with the ridges where the turbines will be placed.

In contrast to most seabirds which nest on offshore rocks and islands, murrelets typically nest in large branches of old-growth and late-successional coniferous trees. Murrelet nests are infrequently found due to the difficulty of accessing the canopy of old-growth forests and because of the cryptic behaviors exhibited by murrelets in and around their nest (Nelson and Hamer 1995, Golightly and Schneider 2009). Murrelets do not build nest structures, but instead they lay and incubate their egg on a large, flat tree branch with natural depressions or moss, lichen, and tree litter. In northern California, redwoods (*Sequoia sempervirens*) are the most common conifer available for nesting although they also nest in Douglas Fir (*Pseudotsuga menziesii*; Golightly et al. 2009).

Murrelets spend much of their life at sea and must transit between foraging areas at sea and inland nesting habitat throughout the year, but most inland flights occur during the breeding season as murrelets incubate their egg and, upon hatching, feed young (Naslund 1993, Hébert and Golightly 2006, Sanzenbacher et al. 2014).

Generally, in Oregon and northern California, egg laying begins between mid-April and June depending on ocean conditions. Chicks hatch between late May and July. Incubation lasts for 28 to 30 days with each parent taking a 24-hour shift sitting on the egg and alternating with its mate until the chick hatches. During incubation, each nesting murrelet makes a single transit between land and sea each morning around sunrise (45 minutes prior to and 75 minutes following sunrise; Evans Mack et al. 2003). The chick is fed by the parents for another approximately 28 days until it fledges and flies to the ocean. After their chick hatches, adult murrelets continue to make this early morning transit each day to deliver a fish to their chick and they often embark on an additional flight to feed chicks in the evening around sunset (with the average flight occurring 23 minutes before sunset; Hébert and Golightly 2006). Outside of the breeding period, murrelets will periodically travel inland at dawn (Naslund 1993, Sanzenbacher et al. 2014) for unknown reasons that may include maintaining pair bonds, examining future nesting areas, or engaging in other social activities probably associated with breeding (Carter and Sealy 1986, Carter and Erickson 1992, Naslund 1993). Throughout the year, murrelets restrict transits between the ocean and inland nesting habitat to times of limited lighting—sunrise and sunset—to minimize discovery of eggs and chick by predators and minimize risk of predation to the flying adult by birds of prey (Nelson 1989, Hébert and Golightly 2006). At sunrise breeding birds may be accompanied by additional non-breeders that may be seeking nesting opportunities or socializing (Naslund 1993, Peery et al. 2004, Hébert and Golightly 2006).

To reach an inland nest, murrelets must be good flyers. However, they must also successfully capture small fish and invertebrates underwater and to do so requires that they are adept at swimming. Their body form is a compromise that allows them to fly efficiently through both the air and water; specifically, murrelets have wings that are small relative to their mass (217 g; Hébert and Golightly 2006). When transiting between foraging and nesting habitats murrelets can attain cruising speeds that average 81 km per hour and have been documented flying as fast as 154 km per hour (Nelson 1997, Elliott et al. 2004).

Murrelet flights over Bear River Ridge and Monument Ridge are thought to be rare relative to flights in the river valleys and nesting habitats. Radar is the most effective way to ensure that rare events are adequately detected for purposes of objectively assessing movements across a space; a single radar station can acquire data on bird movements as far as 1.5 km in all directions (Stantec 2018) which is unlike audio-visual surveys that have a very limited detection range (100-200 m). Also unlike audio-visual surveys, radar can accurately measure flight speed, altitude, and direction which are all important for development of CRMs. Therefore, the Project commissioned Stantec Consulting Services, Inc., to establish radar sampling stations on Bear River and Monument Ridges where turbines will be installed and begin surveys for murrelets (Stantec 2018). Radar sampling occurred each month (April to September) of the 2018 breeding season (Stantec 2018). Sampling occurred in the evening during each of these months to detect potential flights associated with feeding chicks. Telemetry studies (Hébert and Golightly 2006) report that few flights occur outside of the low light periods associated with sunrise and sunset; however, to validate this observation along the ridges Stantec has also conducted some limited mid-day sampling. Radar-based observations of murrelets flying over and in the vicinity of these two ridges were used to determine ridge crossing locations, flight direction, flight heights, and flight speeds. This technique has been used elsewhere to obtain two breeding seasons of murrelet flights upon which to base a risk assessment (Nations and Ericson 2009, Sanzenbacher and Cooper 2010, Sanzenbacher et al. 2015). However, the intensity of radar sampling for the risk assessment associated with this Project has been greater than previous radar sampling in the range of the murrelet (Stantec 2018; see also Cooper and Sanzenbacher 2006, Hamer Environmental 2009, Sanzenbacher and Cooper 2010, Sanzenbacher et al. 2015); this larger dataset created by more frequent sampling has allowed for stratification spatially across the ridge and by month of the breeding season.

In the case of murrelets, the turbines will not directly damage or degrade murrelet nesting habitat; however, the turbines do represent a hazard in that they pose a collision risk for murrelets that cross Bear River Ridge or Monument Ridge. The earliest physics-based model to estimate collision risk for birds that encounter wind turbine was developed by Tucker (1996). Today, collision risk models (CRM) are frequently developed to predict likely collisions between sensitive species and proposed wind energy developments. Multiple approaches for modeling collision risk have been developed (Masden and Cook 2016) and used to assess risk posed by both onshore and offshore wind facilities to a variety of situations including migrating flocks of shorebirds (Gordon and Nations 2016), eagles (USFWS 2013), seabirds (e.g.: Cooper and Day 2004), sea ducks (Desholm et al. 2006), terns (Everhart and Stienen 2007) and murrelets (Nations and Ericson 2009, Sanzenbacher and Cooper 2010, Sanzenbacher et al. 2015). CRMs generally have two goals: (1)) estimation of the number of birds that fly through the rotor swept area, and (2) estimation of collision probability for birds that fly through a rotor swept area (Masden and Cook 2016). CRMs require the input of a considerable amount of data including site-specific information about population densities, feeding and flight behaviors, size and speed of the bird, bird flight paths, wind conditions, characteristics of individual wind turbines, and wind turbine layout (Tucker 1996, Holmstrom et al. 2011, Band 2012, Christie and Urquhart 2015). It is essential to ensure that input parameters are, to the greatest extent possible, based on empirically-derived data and that reliance on assumptions not supported by data are limited for the CRM to produce estimates that approach reality (Holmstrom et al 2011, Band 2012, Masden and Cook 2015).

To assess the risk that installation of turbines on Bear River and Monument Ridges may pose to murrelets transiting to and from nesting habitat, we developed a CRM following the approach detailed by Band (2012). The Band model was conceived of in 1995 (Masden 2015) and developed in conjunction with the Scottish Natural Heritage (SNH 2000), an organization created by the Scottish Government in 1991 and tasked with the responsibility to secure the conservation and enhancement of Scotland's natural heritage (Scotland 1991). Since inception, the Band Model has undergone several revisions and refinements (SNH 2000, Band et al. 2007, Band 2012) following critical review (Chamberlin et al. 2005) and international input from the Strategic Ornithological Support Service (Brittan) and the Joint Nature Conservation Committee (United Kingdom; Band 2012, JNCC 2014). The Band Model guidance has been applied extensively in Europe to assess collision risks at various onshore and offshore wind energy projects that are currently operational (Furness 2013, Cook et al. 2014) thus allowing for validation.

For preliminary estimation purposes, calculations for the CRM we used the largest turbine being considered at each of the 60 potential sites currently identified as suitable for turbine installation. Because installing a turbine of this size at all 60 sites would produce more energy than planned (by as much as 162.6%), it is likely that the actual number or size of turbines will be less. Thus, risk to murrelets has been overestimated and represents the upper bounds of what might be expected. This CRM will also have the potential to inform decisions of optimal siting of turbines in a way that reduces collision risk for murrelets.

1.1 Objectives

The first objective of this CRM was to provide an estimate of the potential number of collisions between turbines and murrelets that could be expected over the expected life of the Project. A secondary objective was to partition estimates of risk across the ridge into topographically distinct zones such that areas of high use by murrelets may be identified and inform decisions regarding turbine placement such that collision risk is reduced.

Section 2.0 Methods

2.1 Overview

2.1.1 Project description

The layout of turbines proposed for the Project follow the two ridge tops in a roughly sequential pattern that form a continuous line of turbines (hereafter, "turbine string") along the ridge line. The Project may use up to 60 turbines, depending on size and generating capacity selected.

2.1.2 Collision risk approach

Overall collision risk to marbled murrelets was assessed using a deterministic model (Figure 1). First, we used the number of murrelets observed crossing the ridge for the extent of the turbine string (including buffer areas that extended beyond the edge of first and last turbines). Radar surveys (Stantec 2018) were used to estimate the number of birds that will likely encounter a rotor swept area. Because data provided by Stantec (2018) indicated that murrelets cross these ridges in a spatially predictable and non-random fashion such that they differentially used low-points and passes relative to other topographical features, the turbine string was sub-divided into zones based on topography (depending on if a section of ridge lacked a low-point or saddle, included a prominent low-point or saddle, or descended towards the Eel or Bear River valley). The potential for interaction between murrelets and turbines was determined by modifying zone-specific passage rates by the proportion of airspace occupied by turbine rotors in each zone. This partitioning of risk by zone provides a tool to optimize placement of turbines such that areas of high-use might be avoided and thereby minimize risk to murrelets. Second, we estimated collision probabilities for a bird that flew through a rotor swept area using the kinematic model specified in Band (2012) which uses bird speed, size, and various turbine characteristics to quantify the probability of a turbine blade occupying the same space as a bird during the time that it takes the bird to transit through the rotor swept area. Final numbers were then adjusted for the probability that murrelets would detect and avoid the turbines (Appendix A). Calculations of possible collisions were summed by month to reflect the changes in flight frequency or ridge use associated with murrelet activity throughout the changing chronology of the nesting season.

Murrelet flight activity was measured approximately 1-3 times each month from April to September 2018 using ornithological radar (Stantec 2018), which is the standard for assessing collision risk to murrelets (Hamer Environmental 2009, Nations and Erickson 2009, Sanzenbacher and Cooper 2010, Sanzenbacher et al. 2015). Using topography and other considerations such as radar coverage, the turbine string was subdivided into zones (Figure 2) and murrelet activity detected using radar was assigned to each zone. Murrelet activity from each month was used to calculate a passage rate of murrelets (birds/day/km) through each zone of the turbine area. Based on those passage rates, passage through the rotor swept area was calculated. Potential murrelet collisions were calculated for a turbine in the zone using the Band (2012) Model and modified by an avoidance probability of 0.95 in April and 0.98 for the remainder of the year.

To facilitate production of this estimate of the collision risk posed to murrelets by turbines associated with the Project, we used a series of assumptions to forecast murrelet passage rates across these ridges during the non-breeding period. Except for the Radar Ridge radar study (Hamer Environmental 2009) and CRM (Nations and Erickson 2009), other murrelet-specific CRMs similarly relied on a series of assumptions to infer the inland activity of murrelets during the non-breeding season. Lastly, important variables in the model were varied to assess sensitivity of the outcome to the perturbation of various input values. To the maximum extent possible, the model used empirical data to inform the risk assessment rather than relying on assumptions about passage rates on behaviors.

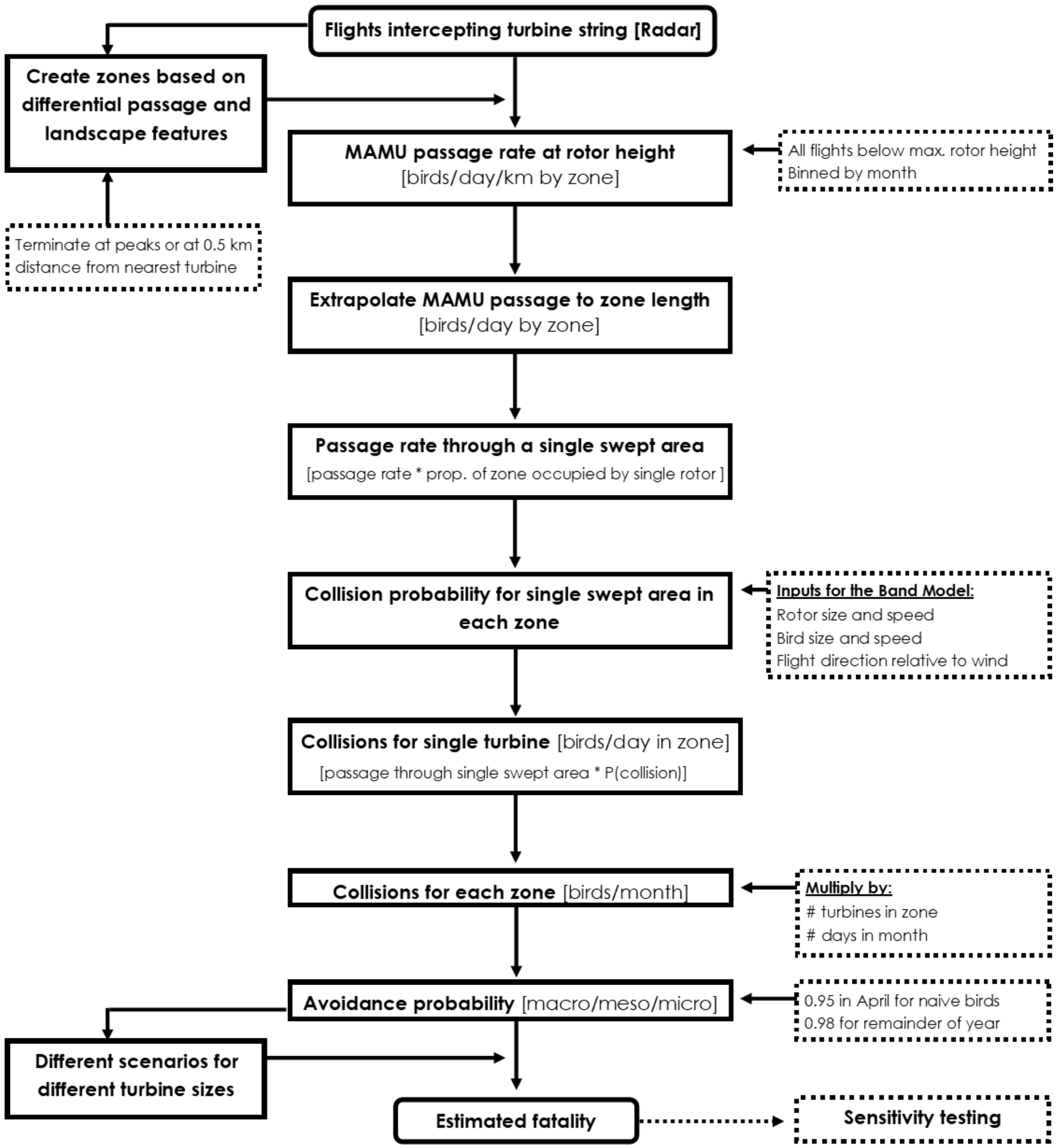

Figure 1. A flow diagram indicating structure of the Collision Risk Model for the turbines proposed for the Humboldt Wind Energy Project.

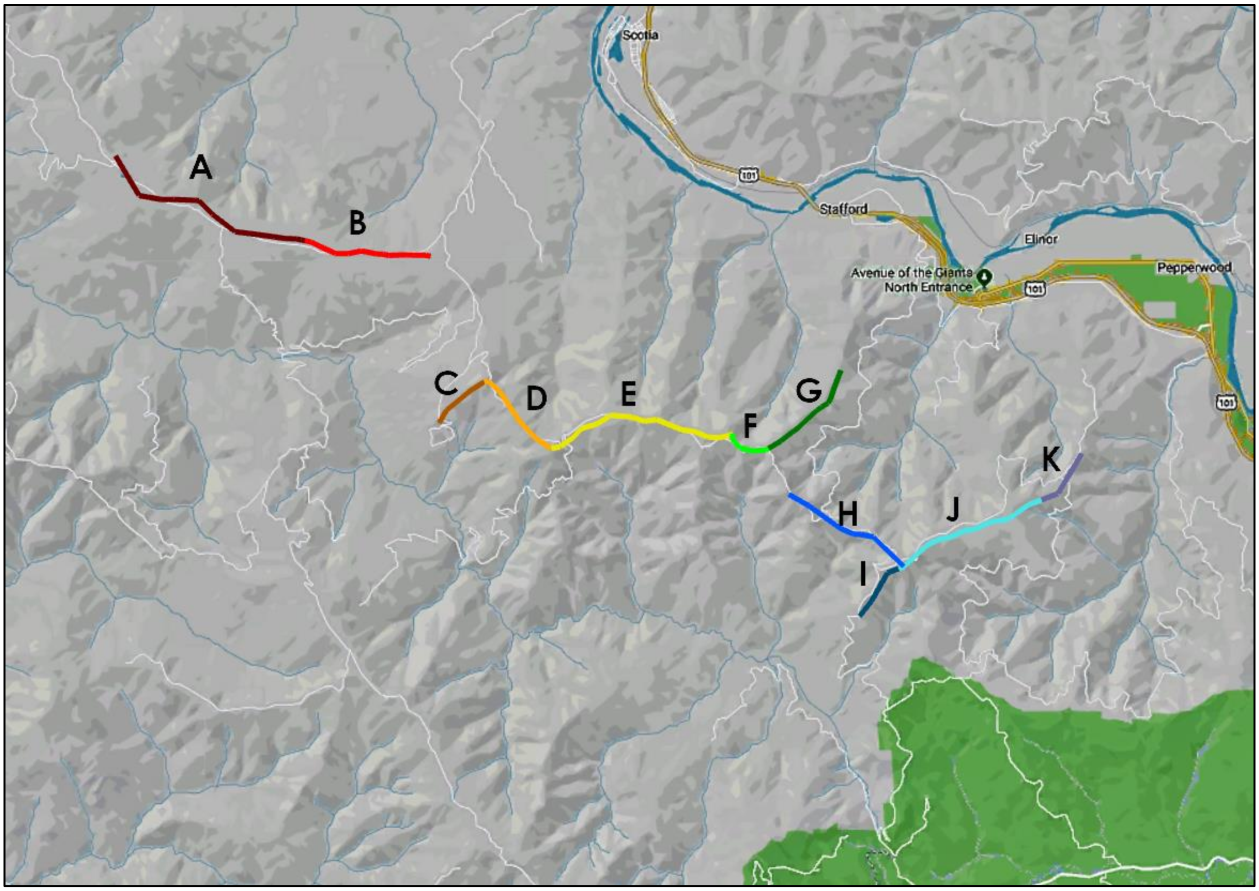

Figure 2. Map of topographically delineated zones used to assess collision risk for marbled murrelets flying through the proposed Humboldt Wind Energy Project as they transit between the ocean and inland nesting habitats.

2.2 Collision risk assessment

2.2.1 Radar data

Stantec (2018) provided detailed descriptions of murrelet flights intersecting or passing over Bear River Ridge and Monument Ridge in the Project area. Seven radar stations were positioned along these ridges; position was dictated by topography to facilitate radar vision out to 1.5 km distance. Each horizontal radar was accompanied by a "vertical radar" to estimate altitude of murrelet-like targets when possible.

Radars were operated during the murrelet breeding period (April to September) in the mornings, from 90 minutes prior to and 75 minutes following sunrise, and in the evenings, from 60 minutes prior to and 60 minutes following sunset. This comprehensive sampling schedule ensured that the daily activity period of murrelets transiting between the ocean and inland nesting habitat were captured in their entirety. On an additional 5 occasions, radar surveys occurred mid-day to assess flights occurring outside the usual activity period. Targets were recorded and subsequently identified in the lab. All flights that occurred during the observation period were included in their analysis of murrelet flight activity in the vicinity of the proposed Project. For this analysis, operators had high confidence in their ability to identify murrelets from other targets and both landward and seaward flights were recorded during each sampling period. Others (Cooper et al. 2001) have reported problems with contamination after sunrise (non-murrelet targets that could be confused with murrelets); consequently, other studies have used only the targets before sunrise and adjusted the before sunrise passage to account for after sunrise flights. Because of the confidence in target identification in this project, flights after sunrise were directly counted and reported. In any case where there was ambiguity in the identity of a murrelet-like target, it was treated as a murrelet. Consequently, any error in this approach would likely be an overestimate of the true passage rate.

The radar operators reported cases where they could determine targets that consisted of more than one bird. In a few other radar surveys, operators have been unable to reliably ascertain flock size in a target and used a modifier to the target count to account for targets containing more than one bird (e.g.: Sanzenbacher et al. 2015). Here we converted the target count to bird count by treating each bird present in a multi-bird target as a distinct murrelet flight (i.e., a two-bird target was counted twice).

Targets were tracked for periods adequate to provide flight speed over ground and flight direction. When the target direction indicated a potential to cross the ridge, that flight path was projected forward and assigned a location where it intersected the proposed turbine string. Where a flight path suggested that the target could pass through more than one point in the turbine string and be exposed to more than one turbine, the flight path was projected forward resulting in two intersections of the turbine string.

Each target was accompanied by flight speed, wind speed, date and time of day. Morning and evening surveys at a station were combined (although each is separately reported) to calculate a daily passage rate at a station. Mid-day surveys did not report any murrelet flights during the period (consistent with the telemetry study by Hébert and Golightly 2006) and thus did not contribute to the assessment of passage through the turbine string. Targets at a distance or flying in directions that could not involve the ridge, or that were flying parallel to the ridge were not included as crossing the ridge and not included in the calculated passage rate. Finally, any target at an altitude of 230 m above ground was described as occurring above the turbines and did not have potential for collision (8.6 % of ridge crossings) and was not included in the calculated passage rates.

2.2.2 Sampling area

The radar defined the area sampled. Because the sampling area covered approximately 72.2% of the length of the turbine string proposed by the Project, we extrapolated murrelet activity to the areas of the turbine string that were not explicitly covered by the radar. This included areas between radar stations and areas where the radar vision was obscured due to vegetation, clutter, or topography (known as "blind spots"). The spatial extent of this assessment also extended a minimum of 400 m beyond the last turbine on either end of a string.

The turbine string was subdivided into zones based on discontinuous segments of turbines and topography. Segments lacking radar-coverage were added to a neighboring zone based on topography. Then, murrelet activity was assigned to each zone. Where blind spots occurred, or radar coverage was inadequate, the rate of murrelet activity was assigned based on the neighboring zone that was measured by radar. If there was no difference in murrelet activity between neighboring zones, all segments were merged. Each zone had a horizontal length (calculated in Google Earth) and a vertical height (based on the maximum height of a turbine rotor).

2.2.3 Passage rates

Overall passage rate of murrelets (birds/day/km) was calculated for each zone using combined landward and seaward flying murrelets in morning and evening sampling periods. When the zone contained areas not covered by radar, a passage rate was calculated for the portion of the zone for which there were data. That rate was then applied as an attribute of the entire zone. Passage rates were also stratified by morning period, evening period, and month.

2.2.3.1 Breeding season

Most inland flights occur during the breeding season (Naslund 1993). Murrelets detected during radar surveys crossing the proposed turbine string from April through September represent the breeding season passage rates.

2.2.3.2 Non-breeding season

Murrelet activity expected during the non-breeding period was estimated to assess the potential passage of murrelets through the turbine string for the period of October through March. To estimate inland flight activity during the non-breeding period (October-March), we used the year-round radar flight estimates from Epsa Lagoon (on the coast, 10 km north of Orick, CA; Sanzenbacher et al. 2014). Epsa Lagoon was used as a comparison because of the robust sample size associated with this site. We calculated a ratio that was representative of each non-breeding month when compared to the average of May and July passage rates calculated by Sanzenbacher et al. (2014). That ratio was then used to generate non-breeding passage rates for Bear River and Monument Ridges by multiplying the ratio from Epsa Lagoon by the May-July passage rate calculated for each zone on Bear River Ridge and Monument Ridge. Finally, because murrelets are flightless during the fall molt, we assigned the molt to the month of November and assumed that murrelets could not fly inland during this time. Although this assignment of the molt to November lacks site-specific data, it is only important to the CRM that it be assigned to a single fall month.

Once passage rates were calculated using the ratio estimate, numbers were subjected to the same calculations as the empirical data from the breeding season.

2.2.4 Collision probability

Collision probability is defined as the chance that a bird will be struck by a rotor blade following entry into a rotor swept area. Many birds that pass through the swept area do not contact the turbine blades. The numbers of birds predicted to pass through the rotor swept area (different passage rates for each zone) were subject to analysis in the model by Band (2012) for determination of collision probability. The Band Model does not include the effect of turbulence and turbulence is not thought to be a factor that substantially alters collision probability (Appendix B).

The Band Model treats bird passages through a rotor swept area as if flight paths are all perpendicular to a rotor. Band recognized that the approach angle of birds through the rotor swept area would vary but the positive and negative influences on collision probability would cancel. To ensure this was the case for murrelets, we calculated collision probability for each bird based on flight speed and angle off the wind using a refinement to the Band model developed for such purposes (Appendix C). In the case of murrelet flights, Band appears to be correct in assuming that the tradeoff between differing angles of approach would cancel.

2.2.5 Avoidance probability

Avoidance probability is the likelihood that an individual bird will detect the turbines and adjust their flight to avoid the turbines. Avoidance is theoretically partitioned into macro-avoidance (entirely avoiding the area with turbines all together), meso-avoidance, and micro-avoidance. Unfortunately, in practice, it is difficult to measure these separately and reporting of avoidance includes all three measures represented by a single value.

There are no murrelet-specific studies of avoidance. However, Sanzenbacher and Cooper (2015) discuss cases of murrelet avoidance of structures where no collision occurred (100% avoidance). Murrelets fly in and out of the canopy of large trees at high speeds and are presumed to recognize and avoid obstacles, even in low-light. The amount of time a murrelet will spend in a turbine area is short. In other seabirds the avoidance probability used in CRM's is often 0.99 (applied where empirical evidence supports this or greater values) or, more conservatively 0.98 in the absence of empirical studies (Appendix A). Birds that are territorial and spend a significant amount of their day in the vicinity of wind turbines (e.g.; kestrels) and continue to hunt prey near wind turbines exhibit a relatively lower avoidance of turbines as individuals may become distracted when they shift their focus from avoiding structures to defending their territory or capturing prey as they continue to navigate across the landscape (Whitfield and Madders 2006, Cook et al. 2014). For murrelets, we used 0.98 as a conservative avoidance probability in all months except April when a value of 0.95 was used. In April, naïve young murrelets may accompany adults on their first flights inland since hatching. It is possible that these young murrelets exhibit lower micro-avoidance; however, data do not exist to corroborate this logic. Regardless, to be very conservative, we used a lower avoidance probability in April (0.95) to consider the possibility of naïve individuals interacting with the turbines when first visiting nesting areas.

2.2.6 Analysis scenario

The type, number, and placement of turbines as well as their operational time and rotational speed directly relate to the likelihood that upon passing through this rotor swept area, murrelets will collide with a blade. Due to the need for flexibility in turbine type, number, and placement we ran the CRM under the assumption of a "worst case" turbine scenario in terms of the potential impact to murrelets. Specifically, we assumed that: (1) the largest turbines being considered for use by the Project would be installed; (2) this turbine would be installed at each of the 60 presently identified locations; (3) turbines would operate 100% of the time; and (4) blades would rotate at their maximum speed. If all 60 of these large turbines were installed, energy production potential would exceed the maximum project capacity. If the number of large turbines were reduced to match the planned capacity there would be less rotor swept area, and fewer collisions; how many fewer collisions would depend on which turbine sites were not included. Thus, this report overestimates collision risk due to these assumptions alone.

This turbine, identified here as "large", had an overall height of 179.5 m, a blade radius of 74.5 m, a blade width at the widest point of 4.2 m, and a max speed of 17 rotations per minute. Blade pitch was not available in turbine specifications, so we assumed a blade pitch of 15 degrees, which is the default value for the Band Model in absence of more specific data.

2.3 Sensitivity analysis

Parameters input into the model were varied to assess how that variation affected the outcome of the collision risk assessment. Each parameter was changed, and a new outcome determined. Passage rate, blade speed, and proportion of time that the turbines were operational were each changed by 10%. Avoidance rate was changed by 1%.

Section 3.0 Results

3.1 Overview

Stantec (2018) surveyed for a total of 209 hours in the morning and 132 hours in the evening between April and September 2018. In their radar report, Stantec (2018) identified 35 possible murrelet targets approaching or crossing the ridges between April and September 2018. After adding buffers on the ends of turbine strings (having the effect of increasing the area of intercept) and eliminating 3 targets that were flying at least 230 m above the ridge which is well above any potential turbine, the CRM considered 55 murrelets to have crossed Bear River and Monument ridges where turbines will be installed. Of these 55 crossings, 72.7% occurred in the morning and 27.3% occurred in the evening; 67.3% were heading inland, 16.4% were heading seaward, and the direction for 16.4% could not be characterized. Of these crossings, 25% (n=14) were reported to be 2-bird flocks.

These 55 crossings were used to calculate passage rates of murrelets (birds/day/km) crossing the Project Area for each month of the breeding season. Altitude of targets potentially flying below the rotor was uncertain, and all flying murrelets below maximum rotor height were considered in the calculations of passage rate for the area.

3.2 Collision risk assessment

The turbine string and the associated buffers were divided into 11 zones (Figure 2). Each zone varied in length and number of turbines. Passage rates varied by zone by month with the greatest passage rate in June (Table 1). Annual passage rate across all zones was 0.2192 murrelets/day/km. The breeding season accounted for most of the murrelet activity in a year.

Collision probability averaged 0.0433 for the large turbine (Table 2). The estimated number of collisions across the entire turbine string in a single year was 0.3477 collisions per year (Table 2). The greatest number of collisions occurred in May and the breeding season (April-September) accounted for 98% of collisions.

Overall, the number of collisions over the 30-year life of the project assuming the worst-case scenario used when assessing the collision risk was 10.43 murrelets (Table 3).

Table 1. Monthly and annual passage rates (birds/km/day) of marbled murrelets through the proposed Humboldt Wind Energy Project by zone (A-K; Figure 1) and across the entire wind energy facility.

Zone		Passage rate (birds/day/km)												
Name	Length (km)	Apr	May	Jun	Jul	Aug	Sep	Oct [a]	Nov [b]	Dec [a]	Jan [a]	Feb [a]	Mar [a]	Average
A	3.893	-	1.039	0.000	0.000	0.000	0.173	0.002	0.000	0.008	0.005	0.005	0.016	0.106
B	2.239	-	0.000	0.000	0.922	2.765	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.316
C	1.071	0.000	0.408	6.127	1.838	0.000	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.697
D	1.678	0.000	0.199	0.000	0.000	0.000	0.298	0.002	0.000	0.008	0.005	0.005	0.016	0.044
E	3.389	0.000	0.049	0.000	0.487	0.000	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.049
F	0.799	0.000	0.000	0.000	1.395	0.000	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.121
G	1.904	0.926	0.000	7.407	0.926	0.000	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.767
H	2.389	0.105	0.105	0.209	0.105	0.000	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.047
I	1.093	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.003
J	2.795	0.000	2.216	0.000	0.000	0.000	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.191
K	1.109	0.451	0.902	1.803	2.254	0.902	0.000	0.002	0.000	0.008	0.005	0.005	0.016	0.533
ALL	**22.359**	**0.112**	**0.556**	**1.036**	**0.506**	**0.322**	**0.053**	**0.002**	**0.000**	**0.008**	**0.005**	**0.005**	**0.016**	**0.219**

[a] Estimated from proportional flight activity levels provided in Sanzenbacher et al. 2014; To be replaced with empirical data in subsequent reports.
[b] Month during molt with minimal flight activity by murrelets. When available, empirical data will indicate the exact timing of molt.

Table 2. Monthly and annual collision risk estimates for marbled murrelets by zone (A-K; Figure 1) and across the entire proposed Humboldt Wind Energy Project. The Collision Risk Model assumed a layout of 60 large turbines (turbine height = 180 m, blade radius = 75 m, blade width = 4.2 m, and rotation speed = 17 rotations per minute)

Zone			Collision estimates (birds/period)												
Name	Length (km)	Turbines (#)	Apr	May	Jun	Jul	Aug	Sep	Oct [a]	Nov [b]	Dec [a]	Jan [a]	Feb [a]	Mar [a]	Year
A	3.893	13	-	0.0352	0.0000	0.0000	0.0000	0.0057	0.000078	0	0.000285	0.000156	0.000141	0.000542	0.0421
B	2.239	10	-	0.0000	0.0000	0.0240	0.0721	0.0000	0.000060	0	0.000219	0.000120	0.000108	0.000417	0.0970
C	1.071	1	0.0000	0.0011	0.0155	0.0048	0.0000	0.0000	0.000006	0	0.000022	0.000012	0.000011	0.000042	0.0214
D	1.678	4	0.0000	0.0021	0.0000	0.0000	0.0000	0.0030	0.000024	0	0.000088	0.000048	0.000043	0.000167	0.0054
E	3.389	10	0.0000	0.0013	0.0000	0.0127	0.0000	0.0000	0.000060	0	0.000219	0.000120	0.000108	0.000417	0.0149
F	0.799	1	0.0000	0.0000	0.0000	0.0036	0.0000	0.0000	0.000006	0	0.000022	0.000012	0.000011	0.000042	0.0037
G	1.904	3	0.0175	0.0000	0.0561	0.0072	0.0000	0.0000	0.000018	0	0.000066	0.000036	0.000032	0.000125	0.0811
H	2.389	6	0.0040	0.0016	0.0032	0.0016	0.0000	0.0000	0.000036	0	0.000131	0.000072	0.000065	0.000250	0.0110
I	1.093	2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000012	0	0.000044	0.000024	0.000022	0.000083	0.0002
J	2.795	9	0.0000	0.0520	0.0000	0.0000	0.0000	0.0000	0.000054	0	0.000197	0.000108	0.000097	0.000375	0.0528
K	1.109	1	0.0028	0.0024	0.0045	0.0059	0.0024	0.0000	0.000006	0	0.000022	0.000012	0.000011	0.000042	0.0181
ALL	**22.359**	**60**	**0.0243**	**0.0956**	**0.0792**	**0.0599**	**0.0744**	**0.0087**	**0.000360**	**0**	**0.001314**	**0.000719**	**0.000650**	**0.002502**	**0.3477**

[a] Estimated from proportional flight activity levels provided in Sanzenbacher et al. 2014; To be replaced with empirical data in future reports.
[b] Month during molt with minimal flight activity by murrelets. To be replaced with empirical data in future reports.

Table 3. Summary of values for each parameter associated with the Humboldt Wind Collision Risk Model inputs (A, B, D, G-J, N-W, AA, AB, AF, AH, AJ), intermediate calculations (C, E, F, K, L, M, X, Y, Z, AC, AD, AE,), and outputs (AI, AK, AL, AM).

Parameter		Value
EXPOSURE AREA		
A	Turbine string length (km)	22.4
B	Turbine string height (m)	179.5
C	Exposure area (km^2) = A*B	4.01
D	Rotor radius (m)	74.5
E	Rotor swept area (m^2) = pi*(D^2)	17433
F	Proportion of area occupied by a rotor [weighted by zone for entire area]	0.0036
EXPOSURE TIME		
G	Proportion of time turbines rotate in morning [a]	1
H	Proportion of time turbines rotate in evening [b]	1
MURRELET PASSAGE THROUGH EXPOSURE ZONE		
I	Morning crossings (birds/km/morning) [weighted by zone for entire area]	0.169
J	Evening crossings (birds/km/evening) [weighted by zone for entire area]	0.050
K	Morning crossings adjusted for operational time (birds/morning/km) = G*I	0.169
L	Evening crossings adjusted for operational time (birds/evening/km) = H*J	0.050
M	Daily crossings adjusted for operational time (birds/day/km) = K+L	0.219
MURRELET CHARACTERISTICS		
N	Length (cm)	25
O	Bird width (cm)	41
P	Flapping or gliding flight	Flapping
Q	Bird-powered flight speed (m/s)	22.7
R	Proportion of flights with wind (downwind)	0.545
S	Proportion of flights against wind (upwind)	0.455
ROTOR CHARACTERISTICS		
T	Blades (#)	3
U	Blade pitch (deg) [c]	15
V	Blade speed (rotations per minute) [d]	17
W	Maximum blade width (m)	4.2
COLLISION PROBABILITY UPON PASSAGE THROUGH ROTOR [BAND MODEL]		
X	Collision probability if flying with wind [D,N,O,P,Q,R,S,T,U,V,W]	0.0248
Y	Collision probability if flying against wind [D,N,O,P,Q,R,S,T,U,V,-W]	0.0655
Z	Average collision probability = (R*X)+(S*Y)	0.0433
PROBABILITY OF AVOIDING TURBINES [MACRO/MESO/MICRO]		
AA	Avoidance probability in April	0.95
AB	Avoidance probability in May - March	0.98
PROBABILITY OF FATALITY		
AC	Average exposure rate (birds/day) = M*A	4.901
AD	Passage through rotor swept area (birds/rotor/day) = AC*F	0.01757
AE	Collisions following passage through swept area (birds/rotor/day) = AD*Z	0.00076
AF	Probability of fatality following collision with rotor	1
AG	Fatalities per rotor (birds/rotor/day) = AE*AF	0.00076
AH	Rotor swept areas (#)	60
AI	Daily fatality without avoidance (birds/day) = AG*AH	0.0456
AJ	Exposure duration (days)	365
AK	Annual fatality without avoidance (birds/year) = AI*AJ	16.66
AL	Annual fatality with avoidance (birds/year) = AK*(1-AA in Apr & 1-AB in May-Mar)	0.3477
AM	30-year fatality estimate	10.43

a Morning = -1.5 to +1.25 hr relative to sunrise; assumed rotor operates 100% of time which overestimates collision
b Evening = -1 to +1 hr relative to sunset; assumed rotor operates 100% of time which overestimates collision
c Average pitch for a generic turbine

3.3 Sensitivity analysis

This model, like other CRMs, was sensitive to avoidance probability for the calculations of collision (Table 4). If the avoidance probability used was 0.99 instead of the 0.98, the collisions would decrease by 4.86 birds for a total of 5.57 murrelets over 30 years. However, if the calculations used 0.97 for the avoidance probability then the collisions over a 30-year period would rise to 15.29 murrelets.

A 10% change in passage rate also changed the 30-year collision estimate; a 10% increase would bring the estimate up to 11.47 murrelets and a 10% decrease would drop the estimate down to 9.39 murrelets.

The model assumed that turbines would operate at 100% output (maximum blade speed) and 100% of the operational period that birds were transiting. However, actual blade speed and proportion of time in operation will depend on wind regime and turbine model (for cut-in and cut-out wind thresholds) and winds will likely be less than this optimal operation scenario; this will result in a lower model output (reduced collision probability resulting in a lower fatality estimate). For perspective on realistic operation conditions, we evaluated sensitivity to variation in blade speed and operation changes resulting from less than optimal wind conditions. If, for example, the winds caused turbines to operate at 75% of maximum blade speed, the 30-year collision estimate would be reduced by 2.58 murrelets to 7.85 murrelets.

Table 4. Sensitivity analysis of the Collision Risk Model for 60 large turbines installed as part of the Humboldt Wind Energy Project. Changes in input parameter characterized changes in collision estimates expressed as a percent of the unmodified collision estimate as well as the number of birds at 1-year and 30-year intervals.

Parameter	Unmodified parameter	Change in input		Change in output		
		%	Absolute	%	1-year	30-year
Avoidance probability	0.98 [a]	1	0.01	46.56	0.162	4.86
Passage rate (birds/day/km)	0.219	10	0.022	10.00	0.035	1.04
Blade speed (rotations per minute)	17	10	1.7	9.84	0.034	1.03
Proportion of time turbines rotate in AM	1 [b]	10	0.1	7.71	0.027	0.80
Proportion of time turbines rotate in PM	1 [c]	10	0.1	2.29	0.008	0.24

[a] All months except April, April avoidance was held constant at 0.95

[b] AM activity period was 165 min (90 min before and 75 min after sunrise)

[c] PM activity period was 120 min (60 min before and 60 min after sunset)

Section 4.0 Discussion

It is important to note that the data from this first breeding season exceeds the quantity of effort for other CRMs for murrelets. For example, the breeding season effort during the morning reported by Stantec (2018) is 14-times greater than the annual radar survey effort in the morning used for the CRM at Bear River Ridge (Sanzenbacher and Cooper 2010), and when evening survey effort was included the effort in this Project was 22-times greater. When the Humboldt Wind Energy Project's radar sampling effort was compared to the Skookumchuck Wind Project (Sanzenbacher et al. 2015), the annual effort was 2.8-times greater and when evening flights reported by Stantec (2018) were included, it was 4.5-times greater. Finally, the effort reported by Stantec (2018) in the morning during the breeding season was 5.5-times greater than the average effort for the Radar Ridge Wind Resource Area (Hamer Environmental 2009), and 9-times greater when evening surveys were included. This significantly greater effort was needed to stratify the sample spatiality so that the CRM can provide flexibility to develop appropriate siting and accommodate turbine operation.

This CRM for Humboldt Wind also differs from other CRMs for marbled murrelets in the following ways:

1. The robust radar sampling allowed division of the proposed turbine string into zones.
2. Turbine operation was assumed to be 100% of time with a wind that facilitated maximum blade speed. This assumption is unrealistic and is used for modelling purposes only. A reduction in operating time and blade speed, which varies as a function of wind regime that may actually occur at the Project, will likely result in lower collision risk (see Table 4).
3. There have been few CRMs developed explicitly for murrelets and they have primarily used the collision calculations of Tucker (1996) or a modification of those calculations. The Band Model has been widely used in Europe and uses a similar logic to Tucker; they both assume that birds approach turbines in a perpendicular fashion. One distinction is that the Band Model accounts for, and Tucker does not, birds flying against the wind (which will experience a higher risk of collision than birds flying with the wind due to the difference in the speed as they transit through the rotor swept area). The Band Model did not require assumptions about proportions of birds in different approaches and the consequential effect from averaging. Here the Band Model appeared to approximate the correct collisions despite oblique angles of entry (Appendix C).
4. Radar data was adequate to measure direction of approach, empirically identify multiple-bird targets, and calculate actual bird speed.
5. Evening sampling with the radar allowed empirically measured passage rates for evening flights rather than multipliers or assumptions.

Each radar sampling session occurred over a longer sampling time than other murrelet CRMs (except Hamer Environmental 2009), in terms of daily activity periods. The longer sampling time ensured inclusion of flights earlier or later than the periods used in established protocols. Morning sampling began 15 minutes earlier that typical. On five occasions there was sampling mid-day to assess the potential for murrelet movements at unexpected times of day.

4.1 Passage rates

Passage rates in 2006 and 2007 reported by Sanzenbacher and Cooper (2010) along Bear River Ridge northwest of the Humboldt Wind Project's location were 0.4575 birds/morning/km. We report a lower overall passage rate of 0.169 birds/day/km. Radar stations 1-3 of the Sanzenbacher and Cooper (2010) study were closer to the ocean (between 9 and 13 km inland versus 19 and 33 km inland) and were lower in elevation($\bar{x}$ = 592 m versus 759 m). Therefore passage rates observed by Sanzenbacher and Cooper (2010), although nearby, do not necessarily characterize murrelet use of ridges associated with the Humboldt Wind Project (Stantec 2018).

Passage rates varied monthly in a manner consistent with the telemetry study conducted 110 km north of the Project area in Redwood National and State Parks (Hébert and Golightly 2006); thus, sampling effort in the radar project (Stantec 2018) was adequate to produce a similar resolution in the data. As expected, passage rates across the project area were also much greater during the morning activity period relative to the evening; evening passage rates here were 28% of the overall passage rate. Interestingly, Hébert and Golightly (2006) also reported that 28% of flights occurred during the evening activity period. In Washington, at the proposed Skookumchuck Wind Energy Project, Sanzenbacher et al. (2015) reported a morning exposure rate that was calculated differently in Sanzenbacher and Cooper (2010) or for the zones in this Project and these parameters are not comparable without additional manipulation.

Generally, for marbled murrelet CRMs, only two years of information is used to assess variation in passage rate. At Bear River Wind Park (Sanzenbacher and Cooper 2010), the passage rate in two years of study varied by a factor of 1.56 between years. At Skookumchuck (Sanzenbacher et al. 2015), two years of study differed by a factor of 1.37 (the average adjusted passage rate was 0.610 birds/day/km). At Radar Ridge (Hamer Environmental 2009), there were 3 years of study and the range from high to low differed by a factor of 2.1 (average passage rate was 0.638 birds/day/km).

Passage over the site was non-random. Topography that facilitates reduced energy costs of transportation by birds can cause those birds to concentrate as they use passes to fly over ridges. There appears to be such concentrations associated with the topography in the 2018 passages. A statistical analysis will await a better sample of transiting birds next year.

4.2 Fatality rates

Based on the radar data collected during the breeding season and an informed estimate of inland activity during the non-breeding season, the fatality estimated for this Project was 10.43 birds over the 30-year life of the Project (or 1 bird every 3 years). This estimate is conservative and likely over-estimates risk to murrelets because it includes turbines that will not be included in the final Project, the model assumed maximum rotation rate and 100% operation time, and radar sampling was very inclusive. Further, total targets may have included some contamination with birds that were not murrelets but were still included in the estimate of murrelet passage rate. Other scenarios such as smaller turbines, fewer turbines, selective placement of turbines will have the effect of reducing this estimate.

4.3 Conclusions

The CRM produced a likely conservative (over-estimate) fatality estimate of 10.43 murrelets over the 30-year life of the Project. When operating time and final layout are also considered, the actual estimate for this year may be potentially much less. When the passage rate data was stratified by month, it approximated other measures or indexes of murrelet activity using other methodologies (e.g. telemetry or audio-visual surveys); this observation is consistent with the model having good resolution of differences in passage rate. This good resolution was due in part to the intense effort of the radar sampling for murrelets and will have the potential to inform decisions of optimal turbine siting from the perspective of murrelets.

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Appendix A. Avian avoidance of wind turbines

Avoidance probability is the likelihood that a bird approaching an operating wind turbine will perceive the turbine and take evasive action. This includes avoiding the entire area occupied by turbines (macro-avoidance), flying at a distance from the turbine (meso-avoidance), and maneuvering to avoid collision with the rotor swept area in striking distance of turbine structures (micro-avoidance). These three scales of avoidance are often lumped in CRMs due to the difficulty of separately quantifying each of these distinct forms of avoidance. Their accurate estimation is important but requires knowledge of bird behavior at several scales that is generally unknown, though radar techniques may inform estimated of macro avoidance.

Data to inform the appropriate value to be used for these probabilities was lacking for nearly all early windfarms. Values were often estimated to be very conservative to ensure conservation of the species which the CRM addressed. Since the early CRM's, there have been many analyses to inform the choice of a value for avoidance probability based on different species, empirical studies, monitoring projects, and theoretical calculations (see Furness 2013, Cook et al. 2014). In 2005, the Scottish Natural Heritage recommended a general conservative default value of 0.95 but, based on additional evidence from terrestrial wind facilities, this was revised upwards to 0.98 in 2010 (SHN 2010) as a conservative measure applicable most situations and species, including many seabirds. In a subsequent analysis, Cook et al. (2014) reviewed avoidance at 35 windfarms and concluded that many birds (including some sensitive seabirds) were more likely to have avoidance factors approaching 0.99. For seabirds, Furnace (2013) in a review of avoidance rates recommended a precautionary 99.5% avoidance for all seabirds. Maclean et al (2009) recommended a default avoidance of 99% but noted that 99.5% was more appropriate for seabirds. The lowest empirically measured avoidance probability that we have found in the literature for any bird was 0.95 for the kestrels (Whitfield and Madders 2006).

Gulls and kittiwakes have mean micro avoidance of 99.95% (minimum 99.25%); gulls also show moderate macro avoidance (Furnace 2013). Post-construction monitoring has shown that terns had a micro-avoidance probability of 0f 99.945% and moderate macro avoidance (Furnace 2013). In another post-construction monitoring project offshore, gannets were reported to have very high macro avoidance consistent with the precautionary estimate of 99.85 (Whitfield and Urquhart 2013) while Rothery et al. (2009) estimated a macro avoidance of 100%. Macro-avoidance by Common Eider have reported as 99.98% (Petersen et al. 2006).

In addition to the data from other seabirds, there is little empirically derived and murrelet-specific data to inform the avoidance probability in this CRM. This is partially because few wind turbines have been installed in a space frequented by murrelets. Further, murrelets themselves are very difficult to study (they fly fast and usually in low light conditions). However, murrelets are known to nest in old-growth forest canopies and exhibit considerable ability to maneuver around complicated objects in their airspace, even during low-light conditions when accessing their nest. Although they fly over human modified habitat while transiting from the ocean to nesting habitat further inland, there are no data to suggest they collide with structures like buildings, signs, or other man-made structures.

Other CRM's for murrelets (Nations and Ericson 2009, Sanzenbacher and Cooper 2010, Sanzenbacher et al. 2015) have used a range of values for avoidance that with time have become more similar with the general recommendations for seabirds in general. In the CRM for the proposed Skookumchuck Wind Energy Project, Sanzenbacher et al. (2015) discussed avoidance factors and noted several related situations with other seabird species or anecdotes about murrelet flight that suggest that murrelets were likely to avoid human structures. Further, Sanzenbacher et al. (2015) concluded that the avoidance rate for murrelets is likely much greater than 0.95 (one of the three avoidance rates they modeled). In the Bear River Wind Project (Sanzenbacher and Cooper 2010), a range of avoidance rates were used but they noted that murrelets may be as adept at avoiding collisions as has been empirically measured for other seabirds. There is at least one report of an interaction between murrelets and powerlines; Sanzenbacher et al. (2015) described a study by Cooper using radar to investigate powerlines and concluded an avoidance rate of 1.0.

In this CRM we followed the guidance of SNH (2010) and used an overall avoidance of 0.98. We believe this rate balances the need to be cautionary, but realistic. In our attempt to be cautious, in the month of April, we lowered the rate to 0.95 with the presumption that inbound birds could include naïve first-year birds that may be naïve to turbines or other structures. Although conservative, this is only speculative logic and neither the naïve nature of first-year birds nor the estimated decreased avoidance probability for naïve individuals is supported by empirical evidence. Furthermore, based on empirically derived avoidance rates of auks, other seabirds, and many birds in general that come from recent studies of currently installed wind energy facilities, it is likely that the actual avoidance of turbines by murrelets throughout the year will be greater than 0.98. Thus, the avoidance rates used to estimate murrelet collision risk for this Project should be considered conservative and may, along with the previously described project infrastructure and management assumptions, further contribute to a CRM overestimate of collision.

Appendix B. Limited evidence of avian fatalities caused by rotor turbulence at wind energy facilities

For small birds, there is little evidence that encountering rotor turbulence results in a fatal, non-collision outcome. The original source for this issue in the literature appears to be Winkelman (1992) as summarized in Winkelman (1994); they provided an anecdotal description of flight behavior in a monitoring report (however, assessment of down-stream turbulence had not been part of the monitoring design). Winkelman (1992) reported that 3 songbirds were fatally impacted by turbulence during nocturnal migration. However, visual observations of bird flight behavior were made using a night scope coupled with a video recording device and the turbulence generated by the turbines was never quantified. Winkelman (1992) described the impact of these 3 songbirds: "during and after passage, strongly fluttering, just after passing the mast the bird suddenly flutters down with no wing beats anymore" (Appendix 16b, Winkelman 1992). For these 3 individuals, the presence of external or internal injury was not confirmed by necropsy as none of the bodies were physically recovered. Larger birds (gulls, ducks) were also observed passing through the rotors (n=4), but none were fatally impacted by rotor turbulence.

Other subsequent monitoring efforts have failed to identify turbulence as a cause of mortality (see Desholm 2006, Krijgsveld et al. 2009, May et al. 2017). There are several reasons why this might be the case. For one, formal studies intended to directly link down-stream turbulence to avian fatality have not occurred. Winkelman (1992) monitored an old-style wind farm where turbines had a rotor radius of 15 m and maximum rotation speed of 48 rpm. In contrast, typical modern turbines have a rotor radius near 75 m and maximum rotation speed of 20 rotations per minute. Turbulence associated with the larger turbines used today may exert different influences on small birds transiting through the rotor (Krijgsveld et al. 2009). Another potential reason that avian mortality due to turbulence has not been subsequently observed is that conclusions made by Winkelman (1992) could be mistaken; although direct collision was not seen using the thermal imaging technology, it is possible that these birds did in fact come into direct contact with a turbine blade which resulted in a fatal outcome. Finally, concern may result from confusion with the impacts of rotor-generated turbulence on bats, specifically the affliction known as "barotrauma" (Rydell et al. 2017); this phenomenon is distinct from the potential impact suggested by Winkelman (1992) on birds. Barotrauma is unknown in birds (Baerwald et al. 2009) because the respiratory system of birds, specifically their rigid lungs with unidirectional ventilation and cross-current blood-gas relationship, is anatomically distinct from that of bats (West et al. 2009).

Widely applied collision risk models (CRM) for birds, including Band (2012) and Tucker (1996), do not include a specific modifier for turbulence wake behind the rotor of a wind turbine. For marbled murrelets, inclusion of a turbulence factor in a CRM would likely result in overestimate of fatality. Relative to songbirds, murrelets are 2 to 40 times heavier, have different wing loading characteristics, and fly relatively fast as they transit between the ocean and inland nesting habitat (Elliot et al. 2004). To the best of our knowledge, there is only one CRM that has included a factor for turbulence effects in the wake of a rotor: the marbled murrelet CRM from the

Bear River Wind Project (Sanzenbacher and Cooper 2010). This factor was included at the request of the regulatory agencies reviewing this project, and the authors of the CRM specifically noted an absence of murrelet specific data. Other murrelet-specific CRM's have not included downstream turbulence; Nations and Ericson (2009; known as Radar Ridge project) did not include down-stream effects and noted that any negative bias would probably be negligible. In a CRM for Red Knots, Gordon and Nations (2016) could not find any quantitative basis for including turbulence as a factor and suggested that the effects of turbulence were unlikely to be significant enough to include in their CRM. They also indicated that in their extensive review of the literature at the time that they did not find other CRMs that had incorporated this factor.

Appendix C. Comparison of collision risk estimated for oblique approach angles relative to a simplified method for marbled murrelets

Accurate estimation of avian collision risk can be a critical step in the planning and operation of wind energy facilities. To estimate avian collision risk, a kinematic calculation of the probability that a bird flying through a rotor swept area will be struck by a blade is required. Exact calculation of this probability is very complicated and, all Collision Risk Models (CRMs) make assumptions so that these calculations can be simplified enough to facilitate derivation of formulas and implementation of calculations. However, over-simplification can result in inaccurate estimates of the true collision risk if they no longer account for principal features of avian-turbine interactions.

One potentially important feature that has been generally overlooked by the most widely used CRMs is oblique approach angles; an assumption that avian flight paths are perpendicular to the turbine orientation is built into the calculations derived by both Tucker (1996) and Band (SNH 2000, Band 2012). This simplification was justified by Band (2012) based on the logic that, as the angle of approach increasingly deviates from 90-degrees, the area occupied by a rotor from the perspective of a bird becomes increasingly smaller until the area occupied by the rotor at 0 and 180 degrees is very small. For example, using turbine dimensions specified in Table 3 of this report, the area occupied by the rotor would be reduced by 99.6%. Probabilistically, it is very unlikely that a bird would enter a rotor swept area at this extreme angle because the total front of interaction is very small; however, the chance of being struck would also become quite great. Band (2012) assumed that these two opposing issues would cancel each other out. Unlike Tucker (1996), Band (2012) recognized that the collision risk would be greater for birds flying against a wind as they pass through a rotor swept area and his model does account for this by calculating collision risk separately for flights that are with and against the wind.

Refinements to calculations made by Tucker (1996) and Band (2012) that enable determination of collision probabilities for birds that approach turbines at oblique angles have been proposed by Holmstrom et al (2011) and Christie and Urquhart (2015), respectively. Following presentation of the equations needed to assess collision probability at perpendicular angles, both studies present case studies to demonstrate the potential importance of incorporating these refinements. Based on their case studies, both studies concluded that the angle of approach should be considered when estimating avian-turbine collision risk.

Based on recommendations to consider the effect of oblique approach angles in the assessment of collision risk, we compared the collision probability estimated using the Band Model (2012) with collision probabilities estimated by the refinement on the Band Model (2012) developed by Christie and Urquhart (2015).

Using the Excel spreadsheet provided as supplementary material by Christie and Urquhart (2015), we generated a collision probability for each of the 55 observed murrelet ridge crossings. To do this we first determined the angle that each flight would enter a rotor swept area based on the flight direction and wind directions recorded for each crossing (Stantec 2018). We then input crossing-specific bird speed (speed over ground) and wind speed recorded for each crossing.

All estimates were based on passage through the large turbine modeled previously (See Table 3 for specifications). The Band Model (2012) estimated that a murrelet 25 cm in length with a wingspan of 41 cm, and average speed of 22.7 m/s over ground would have a 6.5% chance of colliding with a blade when flying against the wind and a 2.5% chance of colliding with a blade when flying with the wind (Figure 3); when considering the proportion of the 55 crossings that were upwind versus downwind, the average probability of collision estimated by the Band Model for this scenario was 4.37%. The probability of collision derived using the Christie and Urquhart Model (2015) for each of the 55 crossings ranged from 1.8% to 8.8% and averaged 4.56% (Figure 3). Based on the differences in average collision probability derived from these two approaches, the Christie and Urquhart (2015) method would cause fatality estimates to rise by 0.0186 birds per year (0.56 birds over 30 years). Based on the similar outcomes from these two approaches, we conclude that Band's (2012) assumption that the tradeoff between the area occupied by the rotor swept area and risk of collision for the various angles of approach would cancel.

For the 55 murrelet crossings used to assess collision risk, the assumptions of the Band Model closely approximated the approach recommended for use by Christie and Urquhart (2015). Murrelets detected crossing the ridges associated with the Project were typically confronted with winds that were paralleling their flight path such that they would encounter turbines in a perpendicular orientation (Figure 4). This similar orientation between the wind direction and bird direction facilitates a reliable approximation of collision risk by the Band Model (2012) to in this situation.

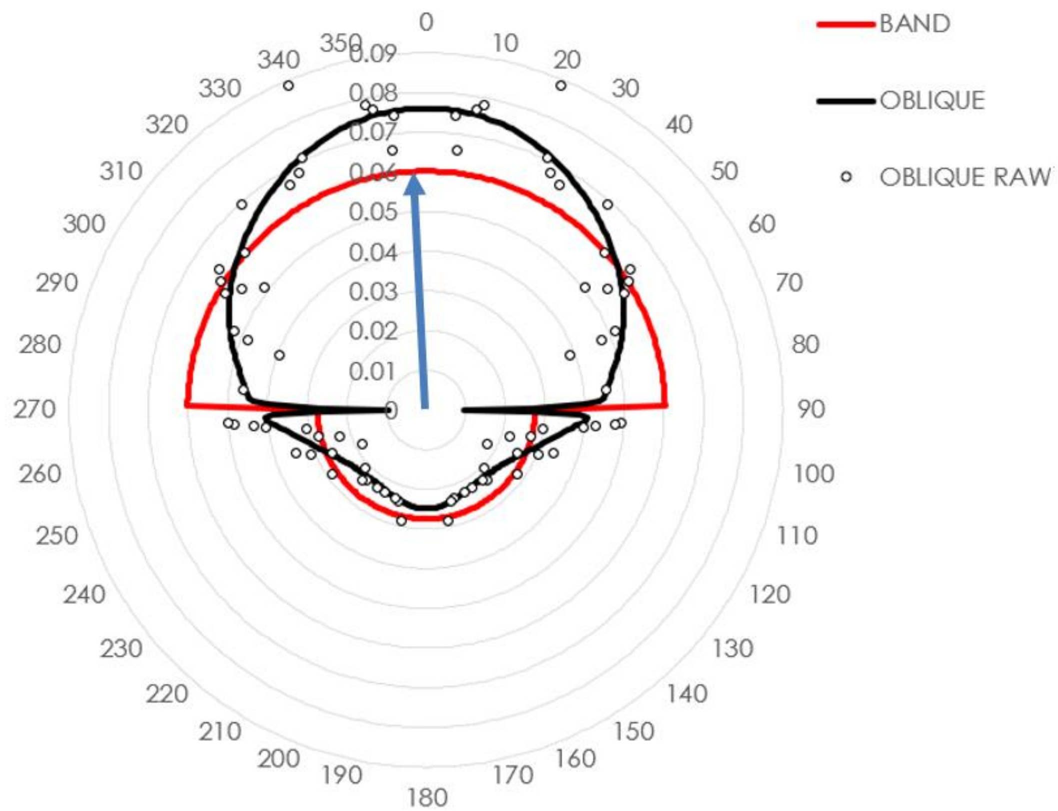

Figure 3. Estimated probability that a marbled murrelet will be struck by a blade of a large turbine as it flies through the rotor swept area for all approach angles possible in the 360-degree sphere around a turbine. The blue arrow indicates the direction that wind is blowing *towards*. For each of the three scenarios, risk was lowest when birds transited with the wind (90 to 270 degrees) and greatest when birds transited against the wind (0-90 degrees and 270-360 degrees). The red line (BAND) depicts collision probabilities generated by the Band Model (2012). The open circles (OBLIQUE RAW) represents the exact collision probability generated by the Oblique Model (Christie and Urquhart 2015) for each of the 55 marbled murrelet ridge crossings. To facilitate direct comparison of collision risk profiles for the Band and Oblique Model, the black line (OBLIQUE) was generated using empirically-derived averages for flight speed and wind speed for the 55 ridge crossings.

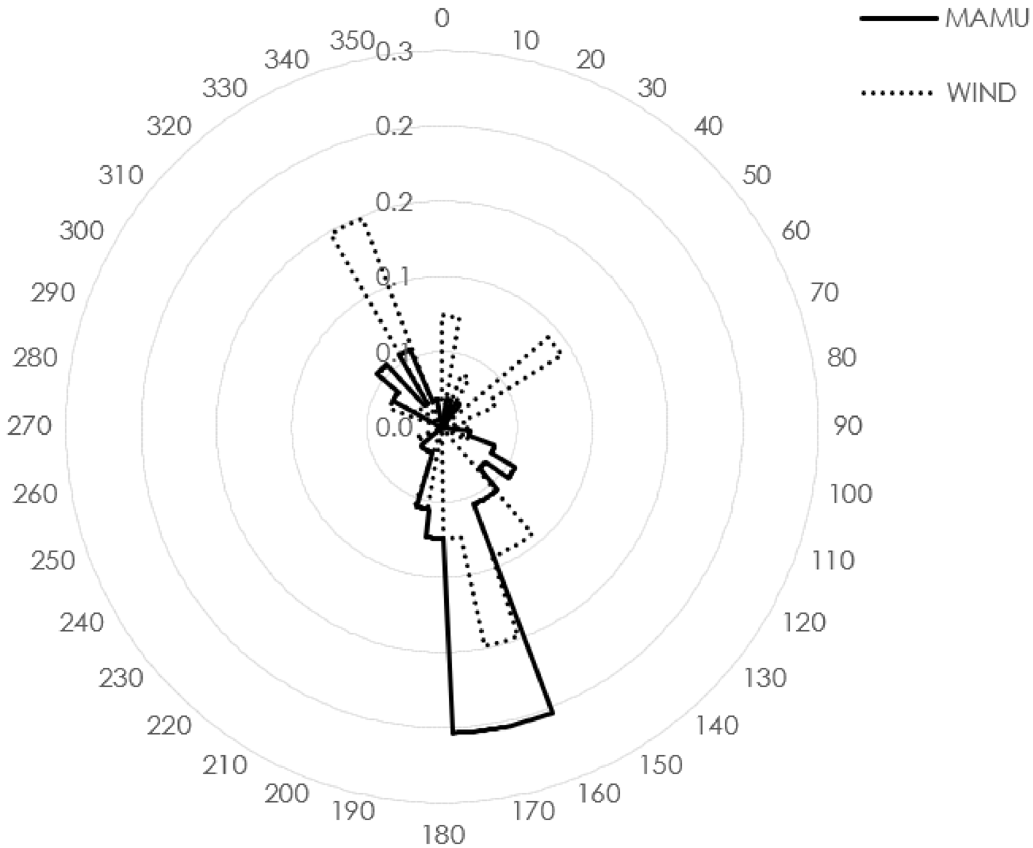

Figure 4. Circular histogram generated using a 10-degree bin that depicts the proportion of flight directions (MAMU) and wind directions (WIND) determined for the 55 marbled murrelet ridge crossings detected during radar surveys. To facilitate comparison, murrelets and wind both move *towards* the indicated direction.