**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.

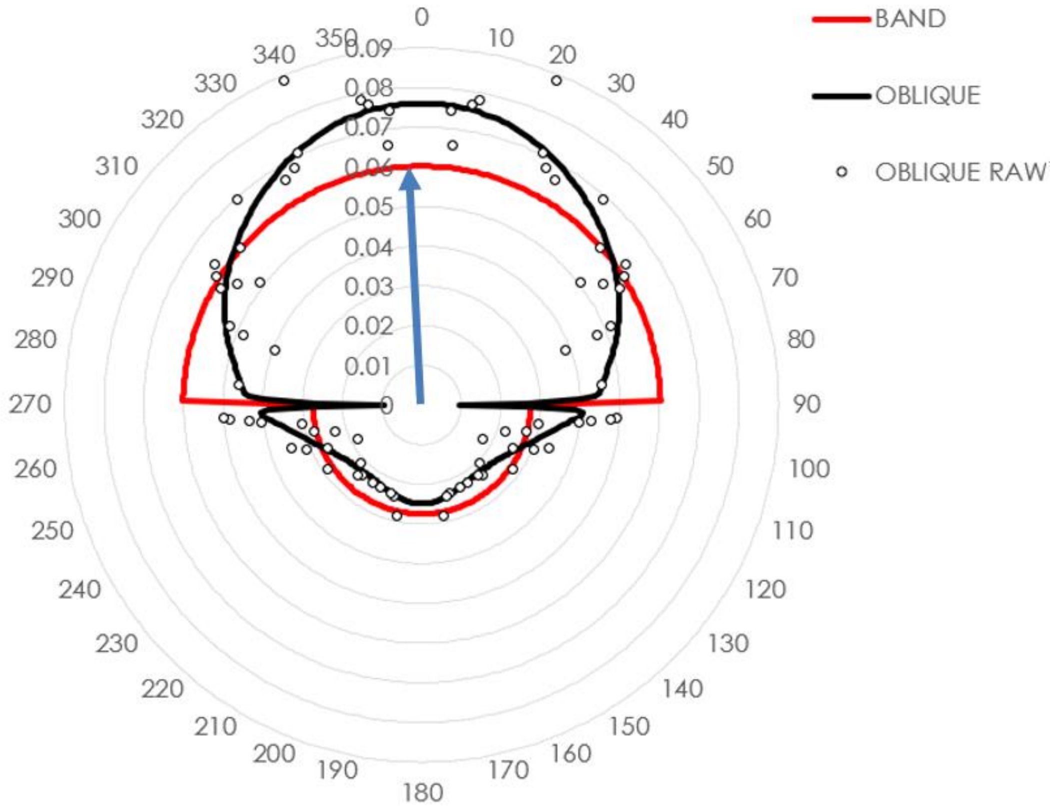


**Figure 3. Estimated probability that a marbled murrelet will be struck by a blade of a large turbine as it flies through the rotor swept area for all approach angles possible in the 360-degree sphere around a turbine. The blue arrow indicates the direction that wind is blowing *towards*. For each of 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.**

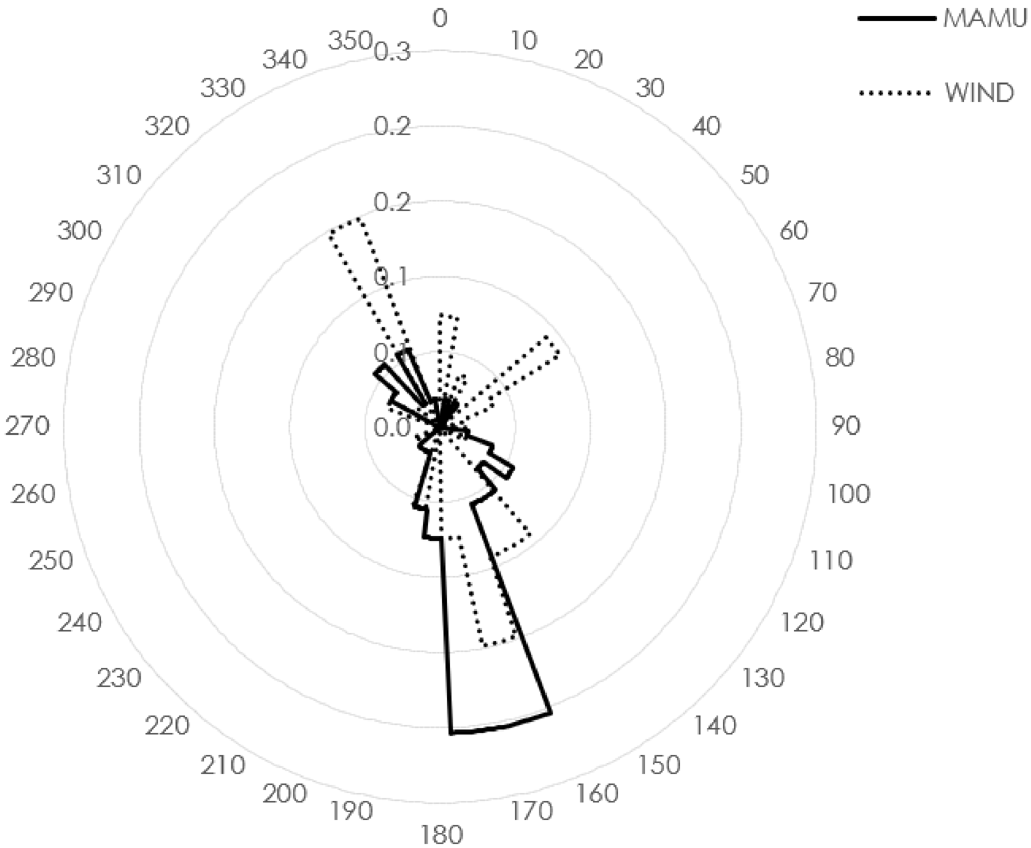


**Figure 4. Circular histogram generated using a 10-degree bin that depicts the proportion of flight directions (MAMU) and wind directions (WIND) determined for the 55 marbled murrelet ridge crossings detected during radar surveys. To facilitate comparison, murrelets and wind both move *towards* the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