A Quantitative Methodology for Determination of Migratory Bird Mortality Risk at Windfarms

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Abstract.

Assessment of migratory bird mortality risk at windfarm sites to date has relied mostly on traditional biological techniques - visual surveys and literature reviews – resulting in at best qualitative estimation of risk. The subjectivity and indeterminacy inherent in this approach subsequently leaves the conclusions open to vigorous debate between the project stakeholders. Radar is increasingly being used to conduct bird surveys at wind farm sites based on its ability to extend the distance the biologist can "see" as well as its capability to detect and track birds at night. Radar techniques to date however have primarily relied on conventional radar ornithological methods where a trained biologist monitors a radar screen visually deciding which "blip" on the radar screen is a bird and manually recording the number of birds and other data. This technique, while more reliable than visual surveys alone, is still highly subjective and results can vary greatly by operator and technique.

Since the 1980's, the U.S. Air Force has led development of specialized avian radar systems to detect and track birds to reduce aircraft-bird collisions (strikes) and has developed complex programs and mathematical models to predict and manage strike risk. A variant of these models has been applied to the communication tower and wind energy industries that uses data from modern avian radar and meteorological systems to collect detailed data activity and more accurately model bird movements in project areas and to quantitatively predict bird mortality risk from collisions with the structures. The objectivity in the data and model provides the wind energy industry with a new tool to more accurately predict and assess potential risk, evaluate project impacts, and address core developer and stakeholder issues.

Additionally, the current generation of advanced avian radar systems now on the market can be integrated with windfarm control systems to continuously monitor bird activity around the windfarm applying the model in real-time to provide active risk mitigation through a variety of response measures that can include selective idling of turbines during periods of high mortality risk conditions. Recent studies have indicated that the economic impact to the wind energy project from this technological approach is minimal as the high risk periods typically occur during times of low wind and/or non-peak demand resulting in a manageable mitigation cost.

Bird Survey Methods.

Assessment of migratory bird mortality risk at windfarm sites to date has relied mostly on traditional biological techniques - visual surveys and literature reviews – resulting in at best a highly subjective, qualitative estimation of risk. Visual survey techniques include point counts, where the biologist periodically "count" birds within a view 360 degrees around a reference point (figure 1) and other methods that similarly rely on the skill and visual acuity of the field biologist to see, count and project the number of birds in a project area.

Figure 1: Traditional point count bird survey

Radar Ornithology.

Radar ornithology is being increasingly being used for bird surveys at wind farm sites based on the ability of radar to extend the distance the biologist can "see". Radar ornithology offers several advantages to the study of bird movements as it can sample large volumes of airspace continuously and consistently and can track birds of all sizes, well beyond the capabilities of an observer with a spotting scope (Eastwood, 1967; Blokpoel, 1976).

Even during conditions of good visibility, small, high-flying or distant birds that often are missed by visual observers can be detected by radar (Korschgen et al., 1984). Radar also allows study of nighttime, dusk, and dawn bird movements when visual observations are unreliable or not possible and radar operates well in fog when typical visual techniques are ineffective (Gauthreaux, 1994). Radar provides highly reliable information on the movements of birds within a range of a few kilometers (Williams et al., 1972; McCrary et al., 1981; Cooper et al., 1991) with small marine radars (10 kilowatt [kW] power) able to reliably detect individual small birds (swallows) out to 1.2 km (0.75 mi.) and single larger birds out to 2.4 km (1.5 mi) (Gauthreaux, 1994).

Virtually any radar can detect and track birds with birds appearing as small “blips” in the radar display (figure 2). Radar bird surveys typically have a trained biologist monitor the radar screen visually deciding which blip on the radar screen is a bird and manually recording the number of birds and other data such as estimated bird size, speed, direction and altitude.

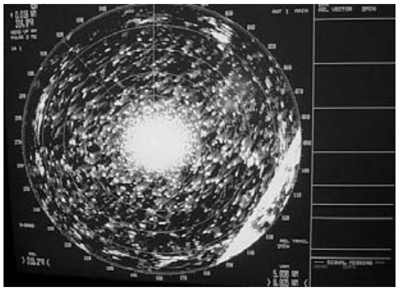

Figure 2: Unprocessed “raw” marine radar display during migration

The most commonly used radar for bird surveys is the “fan beam T-bar marine radar” (figure 3) which ranges from low cost, low power units widely that are typically used on recreational boats to more expensive, industrial grade systems that are used on commercial, oceangoing ships. Some efforts have been directed to improve the manual interpretation process by recording the radar display and post analysis of image or video, but the method is still highly reliant on manual interpretation of the base radar imagery. While more reliable than visual survey, “manual” radar ornithology is highly labor intensive and very costly for long term survey or operational monitoring.

Manual Radar Ornithology Data Error.

Manual radar ornithology is subject to a high level of error in data reliability due to a number of factors that include, but are not limited to operator proficiency, inter-and intra-operator variability, fatigue, count limitations, equipment capabilities, and, methodology. Observer fatigue in air traffic control radar operation is well studied and is directly analogous to radar ornithology (*Fatigue in Air Traffic* Controllers, Transport Canada, TP 13457, July 2000). Likewise, count error introduced by a high number of bird targets is obvious (figure 2) as during peak activity periods there can be simply too many targets for the operator to accurately assess and count. Low activity periods however also can be demanding as watching a radar display during periods of low activity involves intense concentration while waiting for “something to happen”.

Measurement accuracy is also a leading error cause that includes count errors (over- or under-counting or mis-identification of a bird target), target detectability, and equipment sensitivity. Marine radar data is normally rendered to a data display as a Plan Position Indicator (PPI) display (see figure 2). The raster image of a PPI display can be visualized as a piece of graph paper: the larger the piece of graph paper and the smaller the grid squares, the finer the detail that can be rendered in scale. The lower cost, recreational marine radars that are used for many bird surveys have small screens and with few colors or shades (of grayscale) with far lower resolution than the higher cost, larger high resolution displays in more expensive industrial marine radars. Recreational marine radar systems are additionally rarely capable of rendering radar target intensities at more than 16 levels and, even when they can, only 2-3 levels of variability can be perceived by the human eye. Video or screen image recording of the display further compresses the detail resulting in

Figure 3: T-bar type marine radar in horizontal surveillance scanning position

more lost data and introduced artifacts.

Manual radar ornithology typically uses the “echo trail” function to show the target “track”. During migration with a significant number of bird targets moving at one time, the screen can quickly become saturated with bird targets and trails complicating target counting (figure 2). It is not unusual for the ornithologist to simply stop counting targets during high activity conditions resulting in significant undercounts and data gaps.

Many manual radar ornithology surveys also use only a single radar to survey both the vertical (y-z) and horizontal planes (x-y) with samples for each collected for short periods of time (typically 15 minutes) by “flipping” the radar from the horizontal survey mode (figure 4) onto its side into the vertical mode (figure 5) where the radar antenna spins in a windmill manner scanning from horizon-to-horizon (figure 6, Harmata et al. 1999). The resultant data gaps from the horizontal and vertical must be extrapolated introducing data gap bias into the data.

Figure 4: Marine radar in the horizontal scanning position

Figure 5: Marine radar in the vertical scanning position

Many radar bird surveys also use data from the radar in the horizontal scanning position to project bird counts and “passage rates” with altitude estimated based on calculation, not actual measured height of the target above the ground. In the horizontal mode the amount of the radar display lost to ground clutter (terrain, vegetation) is generally high (see figure 2). When the ground clutter level gets too high and saturates the radar receiver, or is so high that the addition of a small target such as a bird does not significantly change the signal, the target is cannot be “seen” by the observer on radar screen and is not counted (is “lost” in the clutter). In contrast, scanning in the vertical mode, mostly looks at clear air and only scans the ground clutter near the horizontal plane and up to the height of the terrain, so that the majority of the bird targets are clear of clutter. Imaging small targets against clear air results in a greater contrast than when imaging targets against a background of clutter, and accordingly, vertical scanning has a significant advantage over horizontal radar for detecting and counting the actual number of targets passing through a survey area.

The physics of insect contamination in radar data is also widely not completely or mis-understood. In manual radar ornithology, targets moving under 4 meters/seconds (m/s) in the data are frequently simply discarded as insects and not included in the bird target count based on misinterpretation of conclusions from studies with military tracking radars (Larkin 1991, *Flight speeds observed with radar, a correction: slow “birds” are insects*). Although pencil (tight) beam marine radar can detect insects, those that use the T-bar antenna start at a performance disadvantage. Under the right conditions, insects are readily detectable and observable when the marine radar is set to the shortest range setting (0.25 nm). But as the range setting is increased, the numbers of small targets visible is reduced significantly with this same “scaling effect” occurring with larger targets such as birds and bats with the result that valid bird targets are often rejected as insects in manual ornithology.

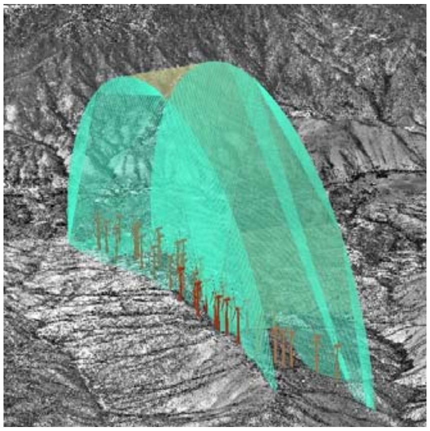

Figure 6: Vertical scanning coverage for wind farm survey

Automated Avian Radar Systems.

Since the 1980's, the U.S. Air Force has led development of specialized, highly automated avian radar systems to detect and track birds to reduce aircraft-bird collisions (strikes) and has developed complex programs and mathematical models to predict and manage strike risk. These advanced avian radar systems (figure 7) have recently become available on the commercial market and are seeing increasing use for environmental survey and scientific research. The systems generally include high-end, high-resolution industrial radars scanning simultaneously in both the vertical and horizontal planes and sophisticated, real-time radar data processing computer algorithms that automate clutter suppression and bird target identification, tracking and counting reducing or eliminating many of the deficiencies inherent in manual radar ornithology. The more advanced systems additionally can operate unattended 24-7, cost-effectively collecting detailed datasets on bird activity at project sites that can be used to assess bird activity and model mortality risk.

The current generation avian radar systems can also be integrated with windfarm control systems to continuously monitor bird activity around the windfarm applying the risk models in real-time to provide active risk mitigation through a variety of response measures that can include selective idling of turbines during periods of high mortality risk conditions. Recent long term studies have indicated that the economic impact to the wind energy project from this technological approach is minimal as the high risk periods typically occur during times of low wind and/or non-peak demand.

Quantitative Bird Mortality Risk Analysis for Wind Farms

A variant of the military birdstrike models has been developed for the communication tower and wind energy industries that uses data from these modern avian radar and meteorological systems to more accurately model bird movements in project areas and quantitatively predict migratory bird mortality risk. The objectivity in this model provides the industry with a new tool to more accurately predict and assess potential risk, evaluate project impacts, and address core developer and stakeholder issues.

Bird avoidance of obstacles such as tall structures, radio towers, communication towers, and wind turbines during day and night periods (including dawn and dusk) is near 100% as evidenced by the fact that significant bird kills are generally not observed daily near buildings, forests, towers, wind farms, and other similar structures. Mortality risk appears however to increase during nocturnal movements under conditions of low visibility (generally defined as visibility of less than 1/3 mile) such as heavy fog and haze (Kruse 1996, Kemper 1996, Larkin 2000, WT Docket No. 03-187 2004). Accordingly, migratory bird collision mortality risk analysis for wind farms is typically focused on periods when risk conditions of low visibility (e.g. fog) occur at night. The level of avoidance of birds to obstacles under conditions of low visibility at night is not well understood however and some avoidance is likely to exist even under these conditions.

Figure 7: Advanced avian radar system developed by DeTect, Inc. of Panama City, Florida, model MERLIN XS2530e

The commonly applied methodology for normalizes the bird passage rates across a 1 kilometer (km) front at the height affected by the turbine rotor – the Rotor Swept Zone (The RSZ is defined as the turbine blade reach area from the lowest sweep point of the turbine blade to its highest sweep point) - over the period of one hour. Automated radar technology scans the full 1 km surface area at a sample rate of approximately 24 observations per minute with sampling in both the vertical and horizontal simultaneously and continuously. Subsequently, survey data, including passage rates of birds across areas of concern, can be analyzed at higher resolution time frames to provide maximum insight into the dynamics of bird activity at the site as well as mortality risk.

Evaluation of a risk considers:

(1) the specific risk,

(2) probability of occurrence, and

(3) resultant consequences.

Risk assessment is the relationship of exposure to the risk versus the consequence(s) of the risk. The specific risk to birds presented by a proposed windfarm is collision (strike) of birds with the wind turbine components (tower, hub, blades) resulting in serious injury or mortality. The majority of studies of wind farm bird collisions have recorded relatively low levels of mortality (Drewitt, et al., 2006). As discussed previously, migratory birds generally have good visual powers to "see and avoid collisions" with static or moving objects, however bird visual acuity is compromised during conditions of low visibility conditions at night. Low visibility conditions occur during fog, sea mist and low cloud conditions, or occasionally from other obscurants such as smoke, and are exacerbated at night.

This probability analysis model is based on the model originally developed and used by the USAF for calculating aircraft-bird strike risk (Meyer, George E, 1975; Tucker, V.A. 1996). This model calculates the risk of a bird collision with turbine components based on the frontal zone presented by the target relative to the bird targets passing through the zone and provides a quantitative basis for estimation of risk.

In this model, the radar scanned zone is the total area in which the radar collects data (Figure 8; yellow shaded area). Data for the 1 km front is the area within the radar scanned zone 0.5 km to either side of the radar (Figure 8; green shaded area). The rotor swept zone (RSZ) is the 1 km wide area within the 1 km front area from the bottom most sweep of the turbine blade to the topmost extent of the rotor blade sweep (Figure 8; red shaded area). The Rotor Swept Area (RSA) is the circular area "swept" by the blades of a turbine during operation.

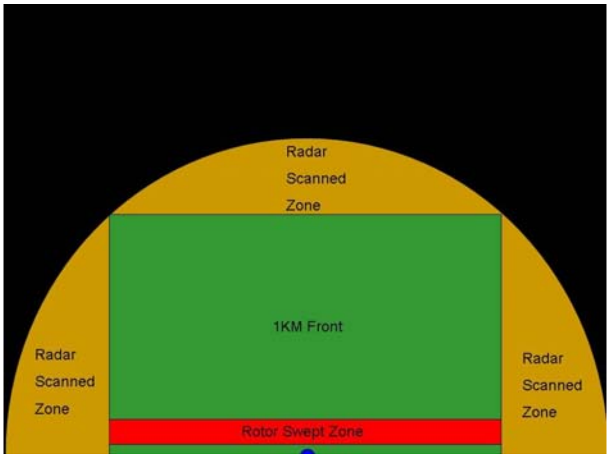

Figure 8: Illustration of the radar scanned zone, the 1 km front, and the rotor swept zone

The moving parts of the wind turbine (the blades) present the most strike risk to birds, but birds can collide with any part of the wind turbine structure, including the support tower (figure 9) and the central hub of the nacelle (hub).

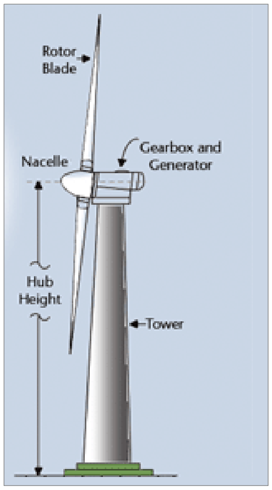

Figure 9: Components of a typical wind turbine.

The RSA and RSZ can be calculated for each specific project from the turbine manufacturer data. For a single turbine installation, the Rotor Swept Area occupies only a very small portion of the 1 km front, and the blades only occupy a small percentage of the swept area at any given time. The Frontal Area presented by the turbine includes the frontal area of the tower, the generator, gearbox, blades and nacelle, and are included in the calculated value for the Frontal Area used for risk analysis (expressed as an area in square meters; Figure 10).

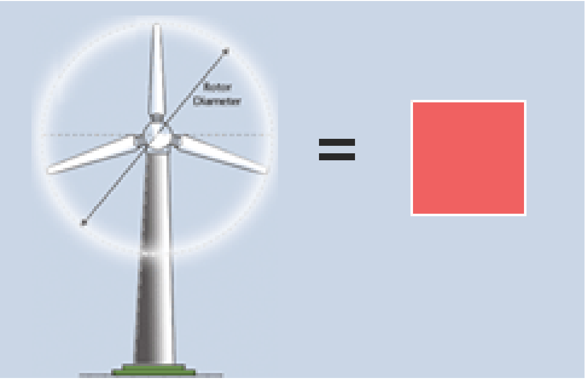

Figure 10: The frontal area of a wind turbine can be expressed as an equivalent frontal area in square meters.

Using the frontal area, the number of discrete pathways within the RSZ can be determined with a Discrete Pathway being equal in area to the frontal area of the wind turbine. The total number of Discrete Pathways (Figure 11) in the RSZ for a single wind turbine is calculated as:

Rotor Swept Zone / Frontal Area of the turbine structure

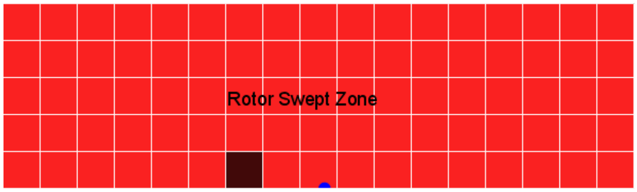

Figure 11: Array of discrete pathways in the rotor swept zone with one of all the Discrete Pathways blocked by a wind turbine

The calculated number of Discrete Pathways for a project results in a 1 in "x" chance (with "x" being the Number of Discrete Pathways) that a target passing through the Rotor Swept Zone will have to change its flight path to avoid a component of the turbine structure. Accordingly, if the Passage Rate of targets (number of bird targets/hour/1 km front) as measured by the radar does not exceed the number of discrete pathways, then statistically no single target crosses the probability "Risk Threshold" of having to see and avoid any turbine component. This model assumes a worst case scenario of zero avoidance of obstacles by birds during low visibility at night conditions, so that the actual risk is most likely lower than the risk projected.

Conclusion

The advantage of this model is that the data is highly quantitative and objective, providing a means to develop standardized data for the wind energy industry to more reliably compare projected results with the actual mortality at the operating wind farm. Data developed by the model can also be used with advanced avian radar system technology as a risk mitigation system where the radar integrated with windfarm control systems to continuously monitor bird activity around the windfarm applying the model in real-time to provide active risk mitigation responses that can include selective idling of turbines during periods of high mortality risk conditions. Recent studies have indicated that the economic impact to the wind energy project from this technological approach is minimal as the high risk periods typically occur during times of low wind and/or non-peak demand resulting in a manageable mitigation cost.

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