

**FACTORS INFLUENCING AVIAN MOVEMENT  
PATTERNS AROUND PROPOSED RIDGELINE WIND FARM SITES  
IN BRITISH COLUMBIA, CANADA**

By

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## **ABSTRACT**

Due to the concerns over global warming, the demand for “green” renewable energy is escalating. Wind farms in Canada are being approved for construction at an exponential rate. Because large scale wind energy is relatively new technology, concerns have surfaced over the impact of wind turbines on aerial fauna, such as birds and bats. Proper monitoring protocols designed to understand the animals’ behaviour around these structures are thus vital to identify potential risks.

I monitored bird migration at three mountain ridges near Chetwynd, British Columbia. By using a combination of radar to track nocturnal migrants and stand watches to track diurnal migrants, I investigated how birds use landscape features during migration and how these movement patterns are influenced by regional weather systems.

I found evidence that raptor movement patterns were influenced by topography, as diurnally-migrating raptors tend to move in concentration parallel to the windward edge of the ridgelines. Conversely, nocturnal movement patterns appeared less influenced by local topography than diurnal migrants.

After collecting weather data and examining their effect on avian passage rates, I found that a combination of barometric pressure, cloud cover and wind speed was generally best able to explain and predict passage rates (wind speed being a strong variable).

By understanding the spatial and temporal patterns of migration, wind farm proponents can develop mitigation strategies to minimize collision risk.

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## CHAPTER 1: GENERAL INTRODUCTION

### 1.1- Wind Energy and Concerns with Aerial Wildlife

The demand for “green” renewable energy is on the rise, due in part to concerns over the link between global climate change and emissions from fossil fuel based energy production. For the last ten years, wind energy’s popularity has been growing exponentially in Canada (CanWEA 2006). This is in part because wind energy is viewed as a safe, reliable, economical and renewable energy source (Kuvlesky *et al.* 2007). Estimates suggests that wind energy has the potential to provide more than 20% of Canada’s total energy production (CanWEA 2006). In support of this goal, 10 000 MW of energy should be sourced from wind power by 2010 in Canada, rising to 14 000MW of wind energy by 2015 (CanWEA 2006). However, wind energy is not without controversy, primarily around the potential conflict between turbine farms and migratory wildlife. After many raptor fatalities were discovered at a wind farm at Altamont Pass, California, in the 1980’s, serious concerns surfaced from environmental groups, stakeholders and government agencies about the possible impacts of wind turbines on aerial wildlife (Kunz *et al.* 2007). Internationally, the progress of many wind farm sites has been held back due to the abundance of fatal bird and bat collisions with the turbines (GAO 2005).

Wind farms - defined as a large number of wind turbines concentrated in a single area - can have a variety of potentially-negative impacts on birds and bats. The most commonly examined problem has been fatalities associated with the turbines, but indirect

impacts – such as habitat alteration, or avoidance of areas by wildlife – are also becoming a prominent concern (Kingsley and Whittam 2001; GAO 2005).

There are several studies that review and evaluate how wind turbine mortalities compare to other tall structures such as communication towers, meteorological towers and electrical transmission lines (Thomas 1999, Erickson *et al.* 2001, BirdLife International 2003, Tingley 2003, Kingsley and Whittam 2005, Drewitt and Langston 2006). Current estimates of wind turbine collision-related bird mortality are 2.3 birds killed per turbine per year (NWCC 2004). Those estimates fluctuate from as low as 0.63 birds to as high as 10 birds killed/turbine/year (NWCC 2004). As many as 33 000 birds are killed each year by wind turbines in the USA, 26 000 of which are killed in California where most avian fatality concerns originated (Erickson *et al.* 2001). This number may seem substantial, but pales in comparison to the millions of birds who die each year from collisions with windows, transmission lines, vehicles, communication towers and even due to domestic cats (Erickson *et al.* 2001).

## **1.2- Implications of Increased Wind Development**

Although birds are impacted more by other structures than wind turbines, the concern is still present, especially given that the numbers are low at present due to the relative scarcity of wind farms across North America in comparison to Europe. Further, the methodologies used to evaluate avian and bat mortalities at wind farms are often criticized for underestimating collisions (Kingsley and Whittam 2005). Using today's current estimates of the growth of wind energy across North America, by 2025, wind turbines could kill 1-5 million birds per year (Kingsley and Whittam 2005). The impact on aerial wildlife becomes an even greater concern when wind farms are proposed in

areas containing threatened or endangered bird populations, as the loss of just a few breeding adults or critical habitat could impact vulnerable populations of species-at-risk, or large, long-lived species with generally low annual productivity and maturity.

A study conducted by Hoover and Morrison (2005) concluded that particular topographical attributes such as slope aspect, elevation and inclination combined with wind speed were responsible for high raptor mortality rates at Altamont Pass Wind Resource Area in California. Therefore, topographical features in California may play a key role in bird mortalities at wind farms. High mountains and ridges in British Columbia are similar to those found in California and a proper understanding of how topography influences avian behavior around wind farms, particularly patterns of raptor migration, may allow mitigation of potentially adverse effects of wind farms.

Songbirds constitute the majority of flying vertebrates in most terrestrial ecosystems and most of the avian fatalities found under turbines in the United States (Kunz *et al.* 2007). Erickson *et al.* showed that 78% of those songbird carcasses were protected by the Migratory Bird Treaty Act, and half of these were nocturnal migrants. This raises obvious concerns for nocturnally-active migrant birds and creates challenging impact assessments, as nocturnal studies are often logically problematical.

In order to properly implement mitigation strategies: 1) potentially affected avian wildlife need to be identified, 2) the influence of landscape on migratory patterns must be understood; and 3) techniques for monitoring aerial wildlife need to be enhanced.

### **1.3- Monitoring Avian Collision Potential**

Predicting the impacts that wind turbines might have on birds and bats, and using data on fatalities reported from existing facilities, presents many challenges. Answering some

of the most basic avian behavioral questions requires observing and monitoring nocturnally active aerial wildlife behavior (using appropriate protocols) around potential and existing wind farm facilities (Kunz *et al.* 2007). Nocturnal migration by birds and bats provide scientists and consulting biologists with a logistic challenge in detecting and tracking wildlife. There is no single universal method or protocol used to study the temporal and spatial variation in nocturnal migrants, especially around wind farm facilities (Kunz *et al.* 2007). Rather, there exists a panoply of methods that one can use to answer specific questions on movement patterns, each with its strengths, weaknesses and biases. These include visual means of detection using infrared or thermal cameras, or detection via radars or other tracking devices. Researchers must pick the best methodology and technology available to answer their specific questions. They must also address the limitations and biases that come with this choice (Kunz *et al.* 2007).

Collecting meaningful observations of nocturnal wildlife requires not only selecting the appropriate protocol and technology, but also requires the researcher to include temporal and spatial components in their study in order to answer relevant questions. Below, I outline currently-used tracking methods and assess benefits and limitations of each.

## **1.4- Visual Methods**

### ***1.4.1- Moon Watching***

Early researchers used the full moon and clear skies in order to observe migrating wildlife at night (Lowery 1951). By using a telescope (20-30X) pointed directly at the moon, it was possible to observe and count the silhouettes of birds and bats passing in front of the illuminated disc of the moon. This technique was obviously limited to clear

nights brightly lit by a full moon, as well as suffering from a limited area of monitoring (Kunz *et al.* 2007).

#### **1.4.2- Ceilometry**

Gauthreaux (1969) developed a means of overcoming some of the limitations imposed by moon watching. He developed a portable light source (ex: 100W light), coined a ceilometer, for nights when the moon was not visible. This replaced the light provided by the moon to illuminate a section of the sky, which could then be studied using binoculars, spotting scopes or telescopes. With a 20X telescope, he could observe many birds migrating as high as 605m Above Ground Level (AGL) (Gauthreaux 1969). More recently, some have used artificial light sources as high as 300 000 candle power to illuminate the sky in order to study thrush-size passerines below 500m AGL (Williams *et al.* 2001).

Although ceilometers can provide information about relative passage rates, they are insufficient at providing a detailed understanding of movement patterns, as only a small proportion of the night sky is sampled (Kunz *et al.* 2007). The relatively small distance covered by the artificial light source can provide biased estimates of bird and bat flight altitudes because of the incapacity of monitoring aerial wildlife at higher altitudes (Kunz *et al.* 2007). Williams *et al.* (2001) also observed that small birds and insects were attracted to the scattered light around the main beam, and could thus yield biased estimates of passage rates.

#### **1.4.3- Night-Vision Imaging**

In recent years, night-vision goggles, scopes, powerful 3 million candle power spotlights (fitted with infrared filters) and reflective infrared cameras have become more

popular due to technological advancements. Night-vision goggles offer scientists a greater ability to follow and identify bats, insects and birds. Using both fixed and mobile spotlights also offered increased ability to correctly identify animals by visual means. Using infrared filters instead of visible light sources further diminishes the attraction of birds, bats and insects to the light source, solving detection biases created by using ceilometers (Kunz *et al.* 2007). These improvements have made it possible to correctly discriminate small bird, such as passerines, from bats, as high as 150m AGL (Kunz *et al.* 2007). In a recent study by Mabee *et al.* (2006), the authors were able to illuminate flying targets in the night sky at a wind facility in New York state (USA) using third-generation night-vision goggles and stationary 23 million candle power spotlight fitted with infrared filters and a smaller mobile spotlight. The authors successfully recorded flight information such as flight direction, altitude and behavior (zig-zag, straight line, circling, hovering, etc...) and could distinguish between birds and bats if the targets were below 150m AGL (Mabee *et al.* 2006). However, species identification was rarely possible. A positive attribute of using night-vision imaging is that the data can be recorded and subsequently analyzed in detail in a laboratory to determine how birds and bats responded to moving obstacles, such as wind turbines whose blade sweep zone (danger of collision zone) was below 150m (Mabee *et al.* 2006).

This improved method still provides many limitations. While observing aerial wildlife has improved, detection rates of the same species are variable due to cloud cover, moisture and the effect of distance on detection (Kunz *et al.* 2007). Night-vision goggles have also improved but the photo-multiplier cells produce visual noise making it often

difficult to distinguish between small birds and bats even within the 150m AGL zone (Kunz *et al.* 2007).

#### **1.4.4- Thermal Infrared Imaging**

Unlike night-vision imaging or ceilometers, thermal infrared imaging does not use an artificial light source. Thermal infrared imaging cameras are designed to detect natural heat emitted from objects (Desholm *et al.* 2006, Kunz *et al.* 2007). Any living creature creates metabolic heat from the chemical reactions inside the body. Against a colored heatless background, thermal infrared imaging enables wildlife detection, especially of endothermic animals (Kunz *et al.* 2007). New cameras can capture images at 30 to 100 frames per second and store the information on portable hard drives (Kunz *et al.* 2007). Recent studies have coupled thermal imaging cameras (TIC) with automated detection software and tracking algorithms to assess the behavior of birds and bats around wind farms (Desholm *et al.* 2006, Betke *et al.* 2008). This coupled system referred to as Thermal Animal Detection System (TADS), is designed to automatically detect targets near wind turbines and can be controlled remotely, also making it easier to monitor offshore turbines (Desholm and Kahlert 2005, Desholm *et al.* 2006).

Some scientists have taken this system one step further and coupled it to a fixed-beam vertical pointing radar with a parabolic antenna in order to derive additional bird, bat and even insect movement data around wind turbines (Kunz *et al.* 2007). This approach has produced quantitative migration data at different altitudinal levels and made it easier to distinguish birds from bats and insects (Kunz *et al.* 2007). This system has fewer limitations compared to radars and acoustic monitoring (weather limitations) but is expensive (a suitable camera alone costs \$60,000-\$200,000), often making it an

unaffordable monitoring alternative (Kunz *et al.* 2007). TADS also have limited field of view, with a functional range of a few hundred meters (Desholm *et al.* 2006). Depending on how the cameras are mounted, TADS can effectively monitor one or a very small cluster of turbines (Desholm *et al.* 2006). Despite its capabilities, the cost and limited field of view can make it better for addressing some questions but not others (ex: “what hit a turbine?”, but not “how do bats and birds use topography during migration?”).

#### **1.4.5- Diurnal Stand Watch Observations**

Diurnal stand watch observation is a technique commonly used in the environmental consulting business for tracking diurnally-migrating raptors. This is simple and effective as long as the observer can accurately spot and identify migrating species. The technique relies on observers, sitting on ridge tops or valley bottoms for up to six hours with a spotting scope and binoculars (Barrios and Rodrigues 2004). When a migratory raptor is spotted, flight behavior, direction and altitude are recorded and aided by instruments such as range finders, clinometers and compasses (Barrios and Rodrigues 2004). Reference structures such as existing wind turbines or meteorological towers have also been used to help estimate target altitude (Barrios and Rodrigues 2004). This technique will also work for seabirds that are day-active such as the study of tern colonies (Everaert and Stienen 2007).

### **1.5- Acoustic Monitoring of Birds**

Ornithologists have long used recording equipment to monitor nocturnal bird migration (Libby 1899, Ball 1952, Gruber and Cochrane 1959, Balcomb 1977, Thake 1981). The practice evolved from academic interest in vocalization behavior to a method of monitoring bird migration (Farnsworth 2005). Because many songbirds call frequently

at night and constitute the group most often detected (over other groups who call such as waterfowl and waders), most of the data found in the literature concern passerines (Farnsworth 2005).

The equipment necessary to acoustically monitor birds can be expensive, but is less costly than TADS. To conduct a good altitudinal study (where location and flight altitude data are collected and analyzed) requires the purchase of an array of high-quality microphones, recording equipment and cables. The equipment often needs to be elevated and stabilized using masts, towers and kites, and shelter from the elements must be provided. Outdoor researchers need to prepare for moisture, vandalism, lightning and physical abuse, and must be ready to stop and start the recordings hundreds if not thousands of times, change batteries, and control for wind and turbine noises (Kunz *et al.* 2007).

Field applications where high-quality recordings are required, also need to mitigate against the often overwhelming ambient noise present at wind farms due to wind, insects, waves (in offshore applications), turbine nacelle and rotors (Kunz *et al.* 2007). Systems are limited in range as the ability of auto-recognition software to pick up signals out of noise diminishes with distance (signal-to-noise ratio). Discriminating groups of species of flying wildlife is also challenging as the flight calls are often similar to the ear and similar-looking on sonograms. An expert may need to spend hundreds of hours listening and transcribing audio data in the laboratory. Complex computer voice recognition software can help in discriminating different avian species (Figueroa 2007) but research and development needs to be accomplished in order to reliably utilize sound analysis as an alternative to other tracking methodology (Kunz *et al.* 2007). Such software requires

ground-truthing of a confirmed recording of different individuals of a species to account for inter-individual variation in calls in order to develop recognition algorithms. Acoustic monitoring also doesn't give information on flight direction, a key piece of information for specific spatial analyses.

## 1.6- Radio Detection and Ranging

Radio detection and ranging (radar) has been used for decades to track nocturnal bird migration and to investigate their flight behavior (Eastwood 1967, Vaugh 1985, Diehl *et al.* 2003, Cooper *et al.* 2001a). It is only recently that this technique has been applied to wind-energy related research in order to investigate the flight behavior of aerial targets in the vicinity of wind turbines (Cooper 1995, Williams *et al.* 2001, Mabee and Cooper 2004, Desholm *et al.* 2006, Drewitt and Langston 2006 and Mabee *et al.* 2006). Radar functions by transmitting pulses of electromagnetic radiation (radio waves) to receive the reflected waves back from targets –such as bats, birds, insects, ships, boulders or trees– much like the biological sonar of bats. Since radio waves travel at the speed of light, the elapsed time it takes from transmission to reception can be used to calculate the location (distance and bearing from the radar) of the target. Detecting different targets can depend on many factors including the area of the radar cross-section of the object (Schmaljohann *et al.* 2008) and the wavelength and power output of the radar (Kunz *et al.* 2007). In the case of avian targets, the distance of detection can vary between a few hundred meters when using small high-resolution radars to over 200km when using long-range weather surveillance radars (Kunz *et al.* 2007).

### **1.6.1- Weather Surveillance Radar**

Weather surveillance radar (WSR) or more specifically WSR 1988 Doppler Radar (WSR-88D) is also known as Next Generation Radar (NEXRAD). These radars dot the United States landscape and provide useful information on the movement of different weather systems across the country to military, local television stations, municipal airports and national weather agencies. Similar systems exist in Canada as part of Environment Canada's Natural Radar Program. They can also provide information on the movement of birds, bats and insects over large areas within approximately 200km of individual stations (Gauthreaux and Belser 1998). However, only the data generated by national government weather agencies are available to scientists tracking bird migration. These data can be used to determine general migratory patterns, stopover sites, roost sites and nocturnal dispersal patterns. These data are especially useful to investigate the effects of weather conditions on the movement of aerial wildlife on larger scales covering hundreds of kilometers (Gauthreaux and Belser 1998, Diehl *et al.* 2003, Gauthreaux and Belser 2003).

Weather radars have limitations with high-resolution avian movement patterns over smaller areas of landscape, or on a finer resolution scale (e.g. the minimum resolution of NEXRAD is  $0.2 \text{ km}^2$  at 40 km range) (Kunz *et al.* 2007). The resolution of NEXRAD also makes it difficult to distinguish insect noise from bird and bat movement patterns as it does not provide information on individual targets (Kunz *et al.* 2007). Due to shadows behind hills or other large objects, NEXRAD radars typically cannot provide spatial coverage at or below wind turbine height; their power lies in discerning large migratory patterns over broad landscapes as opposed to fine movement patterns around individual wind installations.

### **1.6.2- Tracking Radar**

Tracking radar systems have been primarily utilized by the military to lock on, track and follow aircrafts and missiles. When used in wildlife applications, this is useful as it can provide information on altitude, speed, direction and even wing beat frequency of individual insects, birds and bats (Kunz *et al.* 2007). However, tracking radars are not readily available; they do not provide a broad view of migration over a given site and are expensive and difficult to maintain and repair (Kunz *et al.* 2007).

### **1.6.3- Marine Radar**

Both S- and X-band radar systems were originally designed to fit on marine vessels. They have also been used on mobile units on land to investigate and monitor airborne targets. These radars typically employ open-array antennas. In wildlife research, the information derived from these units includes passage rates, flight paths and directions when the antenna is oriented in the horizontal plane scanning the surrounding area (Harmata *et al.* 1999). Flight altitude of nocturnal migrants can also be collected when the antenna is tilted vertically (Harmata *et al.* 1999). To get altitudinal information, if the horizontal antenna is not tilted vertically, some have used radars equipped with a parabolic dish (Cooper 1995). Marine radars have been more widely used in wind farm applications over weather or tracking radars as the units are relatively inexpensive, are readily available in stores and require little or no modification or maintenance (Kunz *et al.* 2007). In addition, the units are dependable, highly portable (can be mounted on portable ground-based lifts, vehicles or trailers), easy to operate, have high resolution, can be modified to scan vertically and qualified repair personnel are readily available worldwide (Harmata *et al.* 1999, Mabee and Cooper 2004, Desholm *et al.* 2006, Kunz *et al.* 2007).

Marine radars, however, have been criticized like NEXRAD in their inability to differentiate between bird and bat targets (Kunz *et al.* 2007). One could theoretically deduce the flight path of a bird (straight line) from a bat (erratic flight path) but could never state with 100% certainty that the target on the display is a bat or a bird because not all migrating bats fly erratically (Kunz *et al.* 2007). Furthermore, marine radars can also detect insects which can often be distinguished from birds and bats from their low reflectivity or relatively slower flight speeds (Diehl *et al.* 2003, Kunz *et al.* 2007). Energy reflected from the ground or other surrounding objects such as man-made structures, hills and vegetation can also clutter the radar display and make targets less conspicuous. Clutter can be remedied by elevating the radar (e.g. on a hill) above other obstacles or minimized by elevating the forward edge of the antenna.

In a typical study at a wind farm site, radar is usually deployed at a central location to maximize observable airspace during both spring and fall migration for 30-45 days. Rarely has any study investigated bird and bat behavior at wind farm sites on a full annual cycle and the protocols been fashioned to address specific research questions. Using marine radars coupled with other methods such as night-vision goggles, TADS or acoustic monitoring can further improve our understanding of nocturnal animal movement around wind farms, yield better estimates of use and risk and also improve our ability to distinguish birds from bats on the radar displays (Kunz *et al.* 2007).

Finally, when conducting marine radar surveys, site selection is paramount if data quality and comparability are important. Sites must be chosen where ground clutter and shadow zones are minimal but at the same time, the chosen site must include important portions of the study area (areas with likely higher bird and bat activity). It is also

important that any radars must be calibrated prior to deployment in the field to ensure reliable data acquisition (Schmaljohann *et al.* 2008). Ground truthing with visually identified targets can help interpret both limitations in detections and also calibrate how different species appear as radar targets. All users must also be fully trained in field-sampling techniques to ensure the same quality (Kunz *et al.* 2007).

## **1.7- Project Outline**

I used a combination of marine radars (one scanning horizontally and one scanning vertically) to assess nocturnal migrant activity and raptor stand watch observations to assess diurnal bird activit. Marine radars were selected as they are better suited to answer the specific research questions. By providing data on avian spatial patterns of migration over specific topographical features, marine radars make it possible to study aerial wildlife's reaction to those geographical features as they move across the landscape (Bruderer 1997). Radars also make it possible to study avian behavior under the influence of different environmental conditions such as weather systems. Radars are expected to continue playing a key role in the analysis of flight and orientation strategies.

### **1.7.1- Radar Surveys**

Radar surveys of night-migrating landbirds were conducted between April 3<sup>rd</sup> - May 30<sup>th</sup> (2006) and April 15<sup>th</sup> - May 30<sup>th</sup> (2007) for spring migration and between August 1<sup>st</sup> - September 15<sup>th</sup> (2006) and August 19<sup>th</sup> - September 14<sup>th</sup> (2007) for fall migration at three proposed wind farm sites (Wartenbe Ridge, North and South Dokie) near Chetwynd, BC. Radars were operated (weather permitting) 3-5 nights per week and surveys were focused during the period of peak migration through the region.

To assess the migratory patterns of the birds, vertically- and horizontally-mounted scanning Furuno marine radars (model 1954C, 12kW, 6ft. open array antennas) were employed. Both radar units were used simultaneously at Wartenbe, and a single radar oscillating between vertical and horizontal mode each hour at the Dokie ridges. The horizontal marine radar was mounted on a portable drywall hoist elevated at ~2.5m above the ground and scanned a vertical arc of 22 degrees with a beam width of 1.9 degrees, rotating 360 degrees every 3 seconds. The vertical marine radar was mounted on a platform system, elevated at ~1.5m above the ground and scanned a horizontal arc of 22 degrees with a beam width of 1.9 degrees, rotating 360 degrees every 3 seconds. Scanning range was set at 1.5 nautical miles (2.8 km) for the horizontal radar and 0.5 nautical miles (1 km) for the vertical radar. Radars were set on short pulse length in both years of sampling, which allowed for a finer resolution and detection capacity. During daytime testing, these settings were confirmed to detect individual passerines such as tree swallows (*Tachycineta bicolor*), at distances over 1.2 km with clear resolution (sufficient to distinguish between two individuals close to one another). Larger species, such as bald eagles (*Haliaeetus leucocephalus*) appear as large targets even at ranges of >2 km.

Monitoring was done intensively during the peak migratory periods using 2-hour surveys starting at dusk and just prior to dawn on each day. It has been documented that it is during this critical peak period that most bird movement can be captured using radars, as birds are either incoming for landing or outgoing for migration (Burger 2001 and Cooper *et al.* 2001b). Based on consultations with Canadian Wildlife Service (CWS) personnel, dusk and dawn were selected for monitoring as these were the time periods (during take off and landing from overnight migration) that had highest aerial traffic in

heights that would overlap with wind turbines (Kingsley and Whittam 2001, Burger 2001 and Cooper *et al.* 2001b).

### **1.7.2- Raptor Stand Watch Surveys**

To assess hawk and raptor movement during the day, birds were observed for up to 6 hour shifts alternately at one of two vantage points along the ridge. Vantage points were selected based on the ability to see large areas of the ridgeline. Binoculars and spotting scopes were used to locate individuals and determine species and age. Time of detection was noted, and the compass bearing and distance from the observer were taken (the latter was determined using laser range finders (Bushnell Legend Yardage Pro –model #3) to measure the exact distance to reference landmarks). A clinometer (Suunto –model #3) was then used to determine the elevation angle of birds from the observer, which we later used to calculate height relative to the observation station (either above the ridgeline or below into the valleys).

### **1.7.3- Data Analysis**

Most studies on avian behavior at wind farms have been qualitative in nature (Barrios and Rodrigues 2004, Hoover and Morrison 2005). When radar data were collected, quantitative analyses were performed on counts per hour and flight speeds but not necessarily on the depiction of exact flight paths. In the case of my research, I will attempt to quantify individual flight paths and analyze these with respect to landscape features and weather patterns using circular statistics and information theoretic model comparisons. Additionally, I will attempt to integrate my avian track analysis with geographic information system (GIS) technology in order to gain a deeper, visual

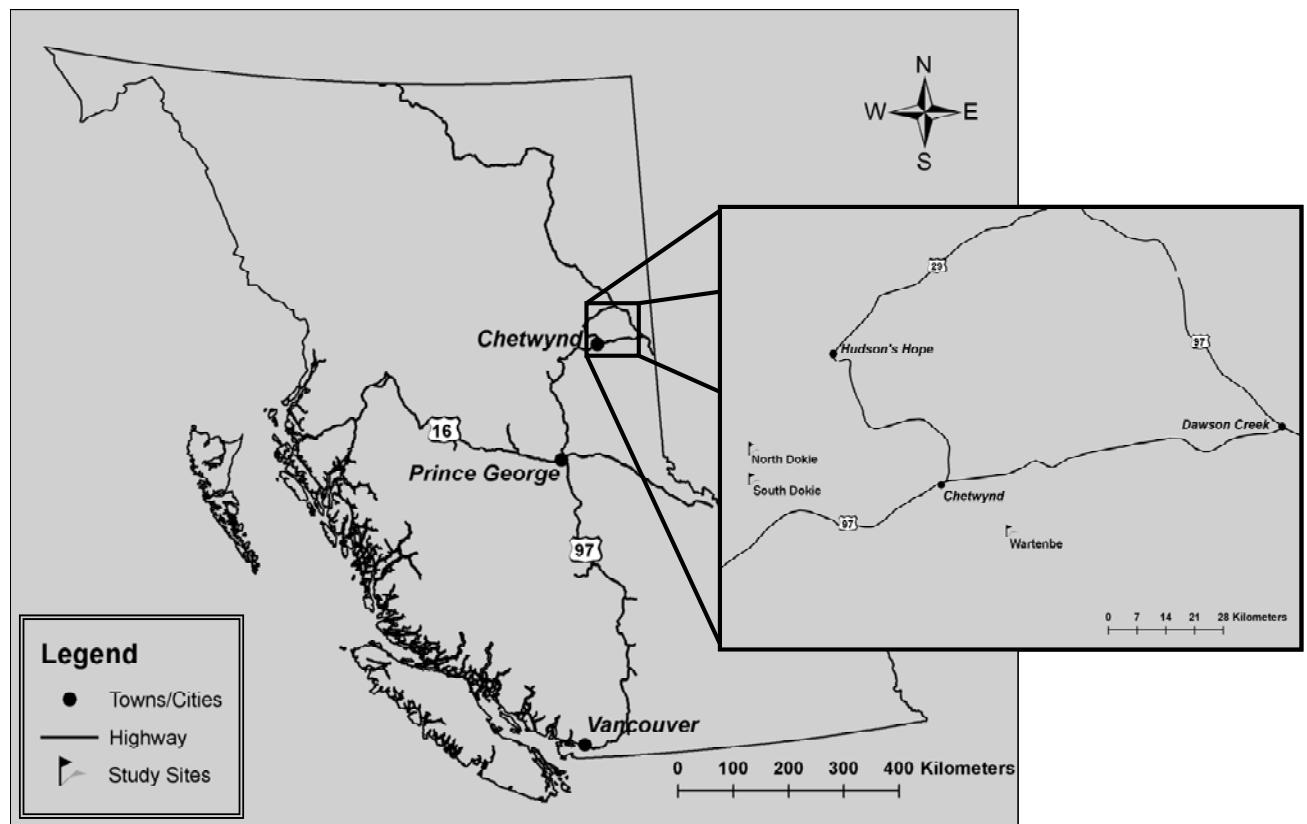
understanding of how exactly avian movement patterns are influenced by different topographical features, such as ridge edges.

#### **1.7.4- Study Sites**

The three study sites are part of a 300 MW wind energy project (Dokie Wind Energy) set for construction near Chetwynd, BC (see Figure 1). The North and South Dokie sites are located in the Peace River Regional District in northeastern British Columbia, about 40 km southwest of Hudson's Hope and 20 km west of Chetwynd. Ungulates such as moose (*Alces alces*), mule deer (*Odocoileus hemionus*), white-tail deer (*Odocoileus virginianus*) and elk (*Cervus Canadensis*) occur on all three ridges. The scarcer woodland caribou (*Rangifer tarandus*) can be found at South Dokie. Larger carnivores such as grizzly bears (*Ursus arctos horribilis*), black bears (*Ursus americanus*) and wolves (*Canis lupus*), along with smaller carnivores such as foxes (*Vulpes vulpes*), coyotes (*Canis latrans*) and marten (*Martes martes*) are present. Smaller prey such as Snowshoe hares (*Lepus americanus*), beavers (*Castor canadensis*), red squirrels (*Sciurus hudsonicus*) and hoary marmots (*Marmota caligata*) have been detected in previous site assessments (AXYS Environmental Consulting 2006). The aerial fauna at the three sites is diversified consisting of raptors, waders, waterfowl, owls and songbirds. The three sites are of concern to the industry as they are located in a region of British Columbia used as a migratory corridor by golden eagles (*Aquila chrysaetos*).

#### Wartenbe

Wartenbe ridge is located east of Chetwynd. The ridge is predominantly a flat plateau and is characterized by pasture land, most of which is occupied by local ranchers who graze cattle on low standing vegetation (shrubs and tall grasses) which makes up



**Figure 1-** Location of the three study sites in the province of British Columbia, Canada.

approximately 75% of the vegetation present. This ridge is the lowest elevation of the three ridges (1200m above sea level). The trees present are predominately newer coniferous re-growth from logging activities in the 1970s. There has been a history of forest fire activity, including burns during the study period in 2006. The ridge has a predominant NW – SE orientation and wildlife is scarce relative to the two Dokie sites.

#### North Dokie

North Dokie is located southwest of Hudson's Hope. Both North and South Dokie are characterized by several high ridges of the Rocky Mountain foothills. North Dokie is the median elevation site at 1300m above sea level. The ridge contains tall, mature coniferous trees dominated by Englemann spruce (*Picea engelmannii*) and to a lesser extent subalpine fir (*Abies lasiocarpa*). Lodgepole pine (*Pinus contorta*) are also common and at lower elevations, a mix of lodgepole pine and black spruce (*Picea mariana*) is present. Where cut blocks are present, low standing vegetation such as shrubs and grasses and smaller trembling aspen (*Populus tremuloides*) re-growth are abundant and thick. This ridge also has a predominant NW – SE orientation and wildlife is abundant relative to Wartenbe Ridge (AXYS Environmental Consulting 2006).

#### South Dokie

South Dokie is located southwest of Hudson's Hope next to North Dokie, separated by Moberly River. North Dokie is the highest study site at an elevation of 1600m, located above treeline in the alpine foothills of the Canadian Rockies. Barely any vegetation is present except for sparse stunted lodgepole pine (*Pinus contorta*) and black spruce (*Picea mariana*) trees along with mosses and lichens. Like Wartenbe and North Dokie, the ridge

has a predominant NW – SE orientation and wildlife is not as abundant as at North Dokie because of the elevation.

My research focuses on sites that differ from previously studied sites found in the literature. My three study sites are located on the foothills of the Canadian Rocky Mountains. The sites are different from previous studies as they are influenced by mountain meteorology which is often marked by unpredictable weather systems, high winds and lower temperatures. Mountainous topography is radically different than flat plains or oceans where wind farms are traditionally installed. Therefore, if the birds react to their environment (both physical and spatial) during migration, I would expect a change in flight behavior as they pass through the area.

### **1.8- Specifics of Thesis**

This thesis includes two main data chapters. Chapter two will investigate how birds move across the landscape. How do migrants respond to local topography and can this information be used to predict where birds can be found? By understanding how birds move in relation to topography, it may be possible to predict where areas of higher bird activity will be present in order to mitigate any adverse impacts (if any should arise) that wind turbines might have on migrating aerial wildlife.

Chapter three will investigate how weather patterns influence avian movement patterns. Which weather variables influence passage rates and can these be used to predict under which climatic conditions birds are most likely to migrate? By being able to understand the topography over which the birds fly and how the medium in which they fly (the atmosphere) fluctuates, I will build predictive models of passage rates over time

and examine how the placement of certain structures such as wind turbines could inadvertently affect the birds.

The final chapter, chapter four, will summarize key findings and the information provided by the two data chapters. The greater understanding of the birds' behavior around potential wind farm sites will allow project proponents to successfully mitigate negative impacts if they should arise at all.

## CHAPTER 2: THE EFFECTS OF TOPOGRAPHY ON FINE SCALE AVIAN MOVEMENT PATTERNS

### 2.1- Abstract

The interaction between wind turbines and wildlife, particularly the collisions of birds and bats with these structures, may depend on the landscape in which turbines are located. Wind farms in British Columbia are not proposed on flat plains but rather on mountain tops or rugged coastal areas marked by high (>6m/s) and consistent wind patterns. In turn, these areas offer good conditions that favour use by birds for migration and dispersion; this is especially true of raptors whose movement rely heavily on updrafts created by these topographic features. Using vertical and horizontal mounted marine radars, raptor stand watch observations and geographic information system (GIS) data analysis, I studied how landform features and wind direction over topography influenced bird migration at three inland ridges (Wartenbe, North and South Dokie) in Chetwynd, BC. I found evidence that raptor movement patterns were influenced by topography, as most were observed flying either parallel to the ridgelines or concentrated along the windward edge of the ridges; such areas correspond to where winds from valley bottoms deflect upwards as they travel perpendicular to the ridge. Nocturnal migrants were not as influenced by topography except at the higher elevation sites (N. & S. Dokie) where their movement patterns seemed to be “dissected” by the ridge tops. Moreover, direction of movement was correlated, either positively or negatively depending on season, with wind direction.

## 2.2- Introduction

Birds are known to adjust their migratory patterns in accordance with abiotic factors such as topography (Kingsley and Whittam 2001). Animals respond to landscape features when faced with the choice of migratory corridors, stopover sites during bad weather, or the selection of a certain site that would provide adequate resting and feeding habitat (Alerstam 1990). Understanding how landform features influence bird migration, therefore, may provide information for the erection of wind installations near mountain ranges.

The same wind flow patterns that make ridges amenable for wind farms (i.e. the updrafts created as wind is deflected up and over the tops of ridges, the stronger winds on the edges of mountains tangent to the flow created by the split around an elongated ridge and/or the increase in wind speeds with altitude) are also known to be used by migratory birds (Gill 1993, Whiteman 2000). Updrafts off ridges create lift that birds, especially migrating hawks, use to minimize their energy expenditure on long overland migrations, potentially putting them in conflict with structures on these landscapes (Barrios and Rodrigues 2004, Hoover and Morrison 2005). However, a detailed assessment of the position of moving birds in relation to these landscape features may provide the necessary information on how strategic turbine-placement could reduce the potential for conflict. It could also help outline how aerial wildlife might increase their energy expenditure if they move long distances to avoid these structures. Large detours to avoid turbine farms may cause birds to move out of wind corridors, and thus expend greater amounts of energy during migration or movement. If these are sufficiently large, and more wind farms are developed in migratory corridors, successive deflections could cumulatively affect the condition of migrants and negatively impact their fitness.

Both modified marine radars and weather radars have proven to be useful tools when monitoring bird migration or for ornithological research (Eastwood 1967). Although not the only means of tracking nocturnal migrants, radars have become a popular tool in tracking bird movement in relation to proposed wind installations in both North America and Europe (Bigger *et al.* 2006, Cooper 1995, Cooper *et al.* 2001a, Desholm *et al.* 2006). This sampling tool has proven to be reliable at providing detailed avian movement information within a few kilometers from the radar, especially at night when most passerines and waterfowl migrate and when visual observations are impossible (Cooper 1995, Cooper *et al.* 2001a, Mabee 2006). Along with daytime visual observations (Hoover and Morrison 2005) these techniques complement each other, especially in the framework of avian research and wind power developments.

I used a combination of modified marine radars and stand-watch observations tracking the movement of nocturnal and diurnal migrants, respectively, past three ridges slated for wind development in the foothills of the Rocky Mountains in northern British Columbia, Canada. My goal was to superimpose these flight paths over topographic and weather data to determine whether birds migrating through these foothills regions are using wind flow patterns caused or enhanced by topography during migration (such as updrafts, thermals, etc...). These data would then be used to look at micro-scale movement over the ridgelines where wind installations are proposed to determine the potential risk of development to migrants, and use this information to aid developers in mitigating these risks.

## 2.3- Methods

### **2.3.1- Avian Movement Data Collection- Radar Monitoring**

Radar surveys of night-migrating landbirds were conducted between April 3<sup>rd</sup> - May 30<sup>th</sup> in 2006 and April 15<sup>th</sup> - May 30<sup>th</sup> in 2007 (spring migration), August 1<sup>st</sup> - September 15<sup>th</sup> in 2006 and August 19<sup>th</sup> - September 14<sup>th</sup> in 2007 (fall migration) at a proposed wind farm site (Wartenbe Ridge) near Chetwynd, BC. Using the same protocols we developed, biologists at Jacques Whitford-Axys collected parallel data on two additional ridges (North and South Dokie) in the region during the same time periods for use in this analysis. In 2006, radars were operated (weather permitting) 3-5 nights per week, and in 2007 we focused surveys during the periods of peak migration through the region. All three sites are part of a 300MW wind project (Dokie Wind Energy).

To assess the migratory patterns of the birds, vertically- and horizontally-mounted scanning Furuno marine radars (model 1954C, 12kW, 6ft. open array antennas) were used. Both radar units were used simultaneously at Wartenbe, and a single radar oscillating between vertical and horizontal mode each hour at the Dokie ridges. The horizontal marine radar was mounted on a portable drywall hoist elevated at ~2.5m above the ground and scanned a vertical arc of 22 degrees, rotating 360 degrees every 3 seconds. The vertical marine radar was mounted on a platform system, elevated at ~1.5m above the ground and scanned a horizontal arc of 22 degrees, rotating 360 degrees every 3 seconds. Scanning range was set at 1.5 nautical miles (2.8 km) for the horizontal radar and 0.5 nautical miles (1 km) for the vertical radar. The scanning radius could change to yield the clearest picture depending on the topography of the sites and the presence of boulders, trees, or other large obstructions. Radars were set on short pulse length in both years of sampling, which allowed for a finer resolution and a detection capacity of even

small passerines, such as tree swallows (*Tachycineta bicolor*). Both radars were oriented to true north.

Monitoring was done intensively during the peak migratory periods using 2-hour surveys starting at dusk and just prior to dawn on each day. It is during this critical peak period that most bird movement can be captured using radars as birds are either incoming for landing or outgoing for migration (Burger 2001, Cooper *et al.* 2001b). During spring and fall 2006, if no birds were detected in the first hour of radar survey, radar monitoring was stopped. During 15 days, where no birds were observed in the first hour, we sampled the second hour in order to determine if passage rates would suddenly increase significantly. In all 15 days, the passage rates did not increase significantly in the second hour ( $t_{crit}=1.76$ ,  $n=15$ ,  $p= 0.17$ ). Conversely, in all situations where birds were detected in the first hour, rates of passage remained steady during the second sample hour. Based on consultations with Canadian Wildlife Service (CWS) personnel, dusk and dawn were selected for monitoring as these were the time periods (during take off and landing from overnight migration) with highest aerial traffic (in volume) at heights that would overlap with wind turbines (Kingsley and Whittam 2001, Burger 2001 and Cooper *et al.* 2001b).

Aerial wildlife appeared on the radar screen as small, medium or large targets relative to each other, moving typically in a straight line. A Global Positioning System (GPS) unit (Garmin GPS 76) was used to determine the location of the radars; the location of detected wildlife was made on the radar image by noting the bearing and distance relative to the radar. The time, number of targets, first and last bearing of the targets, first and last distance from the radar station, altitude of targets, number of radar returns, size of the targets and any other general notes were recorded. Tracking of individuals was aided by

built-in tail functions on the radar that connected moving objects between successive sweeps. We measured the horizontal position of targets on successive sweeps to determine exact trajectories. Heights of targets were assessed as they passed the sweep of the vertically-scanning radar.

### **2.3.2- Avian Movement Data Collection- Raptor Watch**

To assess hawk and raptor movement during the day, birds were observed alternately at two vantage points along the ridge for up to 6 hour shifts starting at 9am. Access to ridgelines (via snowmobile or helicopter) and heavy snow pack, especially in spring migration viewing, limited the use of radars for surveying. To obtain comparable data on tracks, I employed compasses, laser range finders (Bushnell Legend Yardage Pro) and topographic reference maps to determine bearings and distances to targets, and clinometers (Suunto) to assess height of the target relative to the position of the observer. Vantage points were selected based on the ability to see large areas of the ridgeline. For example, one raptor station was located at the north-western end of the main ridge on a slightly elevated bench, allowing one to see approximately the entire south facing ridge for four to six kilometres; it also provided a view of the north edge of the ridge and neighbouring ridges to both the north and the south. As the majority of raptor traffic appeared to occur in the valley to the south of the ridge, the second vantage point was selected approximately half way along this ridge on a small point that allowed one to simultaneously scan in both directions along the southern ridgeline. This vantage point had the advantage of being able to also see clearly into the valley to the south of the ridge. Each vantage point could be seen from the other vantage point.

Binoculars and spotting scopes were used to locate individuals and determine species and age. Time of detection was noted, the compass bearing to the target was taken and distance from the observer estimated via reference to previously-ranged landscape features. A clinometer was used to determine the elevation angle of birds from the observer, which we later used to calculate height relative to the observation station (either above the ridgeline or below into the valleys). The general direction of travel was noted, and if the bird continued in a straight trajectory a compass bearing and distance estimate was made on the final sighting of the bird from the vantage point. If the bird changed direction, bearing and distance measures were taken for each direction-change point in order to recreate the tracks.

### **2.3.3- Wind Data Collection**

Wind speed and direction (relative to true north) data were collected using a handheld weather station (Skymaster weather meter – model# SM-28). Surface wind data was collected above the head, with the arm extended at roughly 2.25m AGL. Data were collected every hour during radar and raptor watch surveys. If any drastic change in wind conditions was observed, new information was collected.

### **2.3.4- Data Analysis**

Track data were tabulated in a Microsoft<sup>®</sup> Excel spreadsheet. Using the observation vantage point UTM, bearings and distances measured, bird locations UTM were calculated in Excel using trigonometry:

$$\text{Easting} = \text{Observation station Easting} + \text{distance to target} * \text{Sin}(\text{Radians}(\text{bearing angle to target}))$$

and

$$\text{Northing} = \text{Observation station Northing} + \text{distance to target} * \text{Cos}(\text{Radians}(\text{bearing angle to target}))$$

This trig function allowed us to determine and tabulate the initial position, changed position (if applicable) and final position of the targets. UTM coordinates were then exported in the GIS software ArcMap version 9.2. Movement data were superimposed over GIS topographic layers.

The feature conversion function of XTools in ArcMap was used to convert the points to paths using the input features order, ensuring that the vectors were oriented in the right direction. After the polyline shapefile was created for the tracks, a bearing column was added to the attribute table and a python script was run in order to calculate the tracks' bearings. The bearing values were then copied into Oriana Ver.2 (Kovach 2006) for circular statistical analysis.

A map was generated to illustrate the tracks that were deemed to be potential turbine-bird conflict tracks (ie- tracks that cross the ridge and could come into contact with the wind turbines). To do this, all the tracks were projected for all the seasons and survey types. A linear shapefile following the top of the ridgeline (in the approximate position of the line of proposed turbines) was added with a 100m width to conform to the predicted sweep diameter of the blades. All avian tracks that overlapped the ridgetop shape file, indicating a crossing through the potential turbine placements, were isolated using the clip function in the GIS Toolbox. If there were more than 20 tracks, a line density function was employed (in order to obtain an index or gradient, of the airspace usage by aerial wildlife expressed as meters of avian track flown per square km) to reduce the visual clutter and to show the potential zones of turbine-bird collision risks over the ridge. The individual clipped tracks were then used to determine the distance of

each cross from the northern aspect of the ridge as well as identify whether the track was from a small, medium, large or raptor target.

The vertical radar (nocturnal migrants) and clinometer (diurnal migrants) data were used to determine the mean altitude (m) of migrants in each of the four categories: small, medium and large radar targets and raptor targets. We compared the heights of migrants in the different classes using Statistica (vs 6.1, Statsoft Inc).

The Oriana software was used to calculate the mean directional vector and this vector was then drawn in ArcMap using a modified point shapefile into an arrow that was manually oriented using the mean bearing. The data were then expressed as the meters of avian track flown per square kilometre. If there were less than 20 tracks, the tracks with arrows depicting flight direction are shown individually.

The mean bearing of the ridge was calculated using topographic relief lines: starting from the highest elevation, ten lines were drawn on either side of the ridge (where possible) along the 50 m topographic relief lines. After having drawn the lines, the bearings of each were calculated in ArcMap, the mean bearing was calculated in Oriana and the top of the ridge was drawn using the mean bearing. The length of the top of the ridge was drawn as long as possible (at the same elevation) but simultaneously not exceeding the 2776m (1.5 nautical miles) radius detection perimeter of the marine radars.

Using Oriana, basic statistics (mean vector, circular standard deviation, circular standards error, etc.) were performed on the ridge orientation data, the surface wind direction data and the avian movement data (bearings). A Rao's spacing test was performed on the data in order to detect directionality. If directionality was detected, a Watson's U<sup>2</sup> Test was performed to determine if the data fitted the von Mises (normal

circular) distribution. If the data did not fit the normal distribution, a square root transformation was used to normalize the data.

Finally circular-circular correlations using the Fisher & Lee (1983) method - comparable to the Pearson product moment correlation- were performed to detect whether there was a correlation between the ridgeline bearings, flight bearings and wind direction bearings. A positive correlation would indicate that as factor 1 increases in value, factor 2 also increases. A negative correlation would show that as factor 1 increases, factor 2 decreases or vice-versa. The significance of the correlation was tested using the jack-knife method (Mardia and Jupp 2000).

## 2.4- Results

### 2.4.1- Wartenbe

Wartenbe Ridge had the lowest altitude (1200m above sea level) of our three study sites. The ridge is characterized by a flat plateau located in pasture land and therefore, 75% of its vegetation is composed of low standing shrubs and grasses. Where there are trees, they are mostly newer coniferous re-growth from logging activities in the 1970s. There has been a history of forest fire activity so burnt tree remains are not uncommon and pepper the landscape. The ridge bearing runs from  $121^{\circ}$  to  $301^{\circ}$  relative to a position in the middle of the ridge where the radar station was located, and these angles were used to compare the southern and northern migrations, respectively.

#### Radar Monitoring

365 birds were detected migrating through the study area in the spring of 2006 and 2007. No birds were detected in the fall of 2006 and 2007 despite similar or even greater sampling intensity. The mean bearing for the flight vectors was  $359^{\circ}$  with a circular

standard deviation of  $66^\circ$  and a standard error of  $4^\circ$  (see Table 1). A Rao's spacing test showed the presence of directionality of the data ( $P < 0.01$ ).

In the spring, the bird tracks at Wartenbe were mainly concentrated on the southern side of the ridge (Figure 2). The mean flight vector was almost perfectly oriented north and the birds appear to be moving straight over the ridge. The rose diagram embedded in the figure shows that the bearings are variable and mostly located in the upper half of the rose diagram. Although variable, the predominant direction of all flights is northerly.

#### Raptor Watch

66 raptors were detected migrating through the study area in the spring of 2006 and 2007, while only 10 raptors were spotted in the fall of 2006 and 2007.

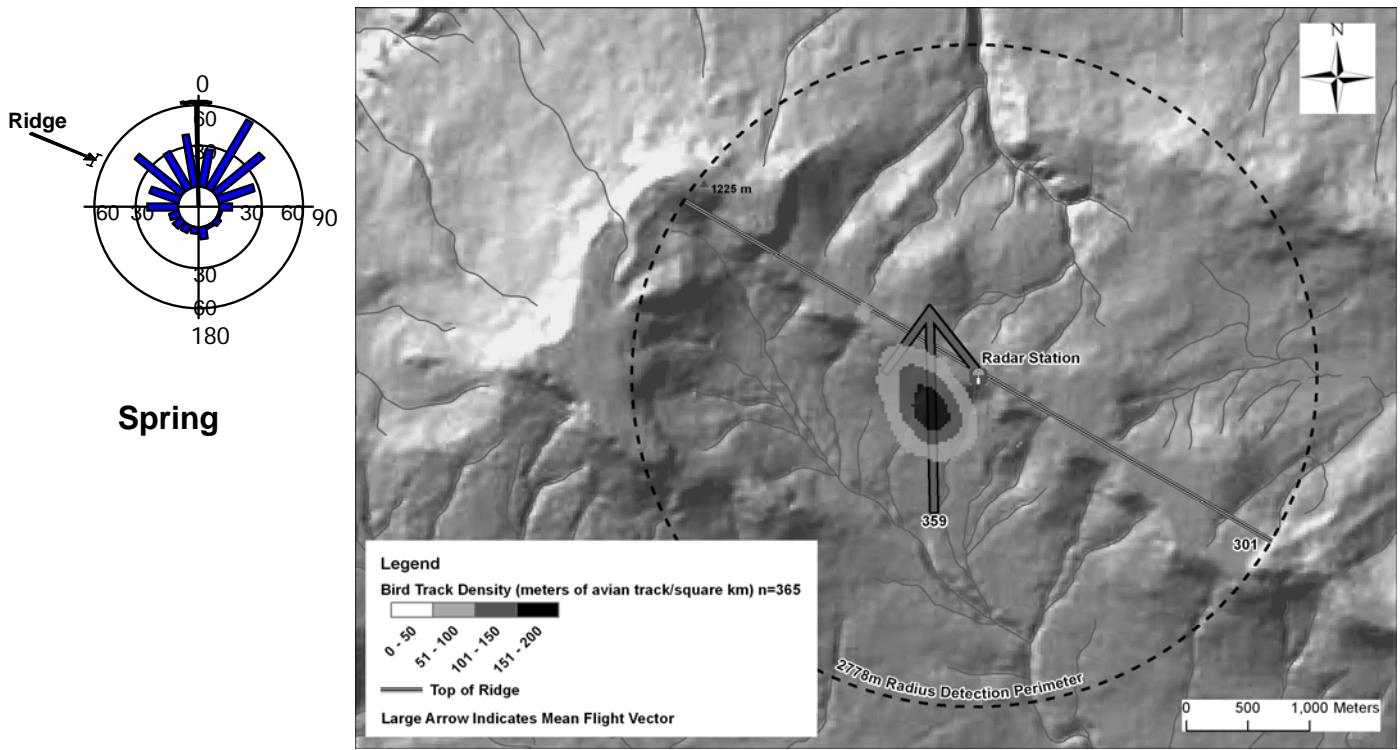
The mean bearing for the spring vectors is  $304^\circ$  with a circular standard deviation of  $21^\circ$  and a standard error of  $3^\circ$  (see Table 1). A Rao's spacing test showed the presence of directionality of the data ( $P < 0.01$ ).

The mean bearing for the fall vectors is  $176^\circ$  with a circular standard deviation of  $64^\circ$  and a standard error of  $24^\circ$  (see Table 1). Because of low concentration of the data (low sample size), there were problems with uniform distribution which makes it statistically unreliable, and was omitted of subsequent analysis.

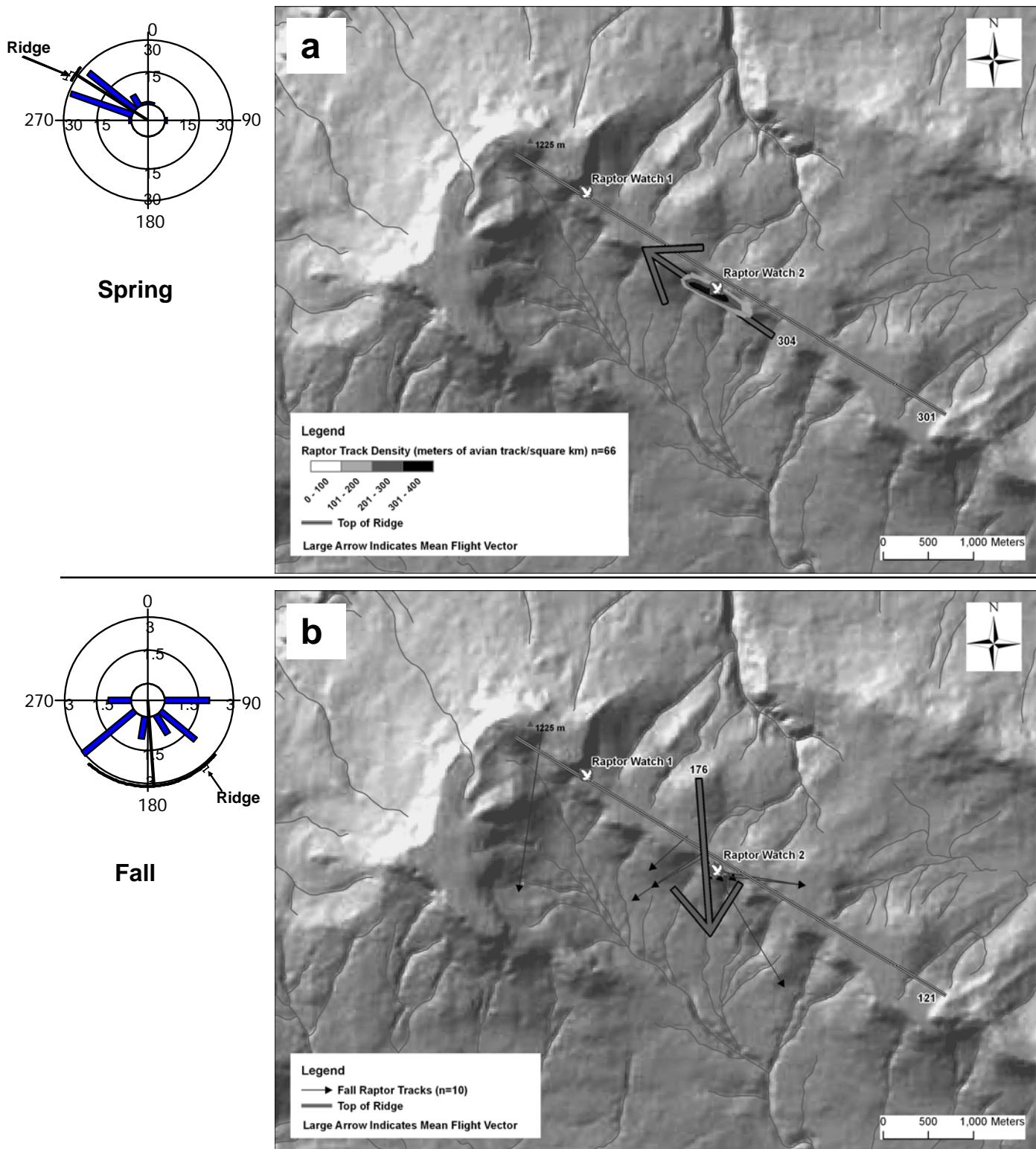
In the spring, the raptor tracks were also mainly concentrated on the southern side of the ridge (Figure 3a). The mean flight vector parallels the ridgeline. The rose diagram embedded in the figure shows that the bearings are consistent and not as variable as the radar data shown in figure 2. Conversely, in the fall, the ten raptors detected were mainly

**Table 1-** Descriptive statistical results for Wartenbe Ridge. Sample size, mean vector  $\pm$  SE and SD are represented. Results from Rao's Spacing Test (U) testing for uniform distribution of circular data and the presence of directionality are also shown. If  $p < 0.05$ , we reject the null hypothesis that the data is uniformly distributed and the data has no particular orientation. Data with low concentration (\*) were statistically unreliable and omitted from analyses.

	Spring Radar Bearings	Spring Raptor Bearings	Fall Raptor Bearings
<b>Number of Observations</b>	365	66	10
<b>Mean Vector (<math>\mu</math>)</b>	359°	304°	176°
<b>Circular Standard Deviation</b>	66°	21°	64°
<b>Standard Error of Mean</b>	4°	3°	*
<b>Rao's Spacing Test (U)</b>	177.49	286.18	*
<b>Rao's Spacing Test (p)</b>	< 0.01	< 0.01	*



**Figure 2-** Wartenbe Ridge monitoring results for the 2006 and 2007 field season: nocturnal migrant radar surveys in the spring are depicted. No birds were detected during fall migration. Circular histogram on the left side of table represents the number of tracks binned in 15° increments. Heavy black line in histogram represents mean vector ± standard deviation (horizontal lines on either side, at tip of mean vector). Mean ridge vector is also represented on outside of histogram for visual comparison



**Figure 3-** Wartenbe Ridge monitoring results for the 2006 and 2007 field season: diurnal raptor migrant radar surveys in the spring (a) and fall (b) are compared. Circular histograms on the left side of table represent the number of tracks binned in  $15^\circ$  increments. Heavy black line in histogram represents mean vector  $\pm$  standard deviation (horizontal lines on either side, at tip of mean vector). Mean ridge vector is also represented on outside of histogram for visual comparison.

seen crossing the ridge and flying in a southward direction. They were most likely not migrants as they were not flying with the same movement patterns as the spring migrants and they did not exhibit the same behaviour (typically these birds were hunting, exhibiting flapping flight rather than soaring, etc., common behaviours of resident, rather than migrating birds). The rose diagram embedded in figure 3b shows the main vector and the large standard deviation. In this instance, the flight bearing does not parallel the ridgeline bearing.

The spring raptors at Wartenbe migrated through the area at the southern edge of the ridge. Their movement pattern was concentrated in a very narrow corridor, statistically demonstrated by the low variance in table 1. The ridge and raptor movement appeared to be oriented in the same direction. In contrast, the spring migrants detected on radar were not oriented in the same direction. These night migrants were travelling northward. Their movement pattern was more spread out, evidenced by the higher variance, but still consistently oriented north.

The spring raptor bearings were found to be positively correlated to the spring diurnal wind direction (Fisher & Lee circular-circular correlation:  $P < 0.05$ ,  $r = 0.017$ ). The spring radar bearings were found to be negatively correlated with spring wind direction ( $P < 0.05$ ,  $r = -0.17$ ). In both cases, the flight angles of migrants did not parallel the wind bearings (av. wind bearings: spring nocturnal period  $252^\circ \pm 1^\circ$ , spring diurnal period  $244^\circ \pm 3^\circ$ ). Further, although the influence of wind direction is generally weakly correlated with flight angle, wind direction appears to have a larger effect on nocturnal migrants than diurnal migrants.

Among all categories of detected migrants, 47 birds were detected crossing the ridge, representing 10.6% of the total bird activity (see Figure 4a). The size classes of the birds that crossed over the ridge were determined. 76% of those birds that crossed the ridge were in the medium size class of the radar detections and 24% were of the small size class. The highest concentration of detected crosses was located between 1500m and 2500m from the northern section of the ridge (figure 4b). When assessing vertical flight data (Figure 5) all migratory birds typically fly above the heights of turbines: small birds were observed at mean  $225m \pm 25$  ( $n=49$ ), medium birds at approximately  $450m \pm 15$  ( $n=293$ ), large birds at approximately  $650m \pm 40$  ( $n=68$ ) while raptors were observed flying in the collision risk zone at roughly  $100m \pm 5$  above ground ( $n=107$ ). However, no raptors were detected crossing the ridgeline at Wartenbe during surveys.

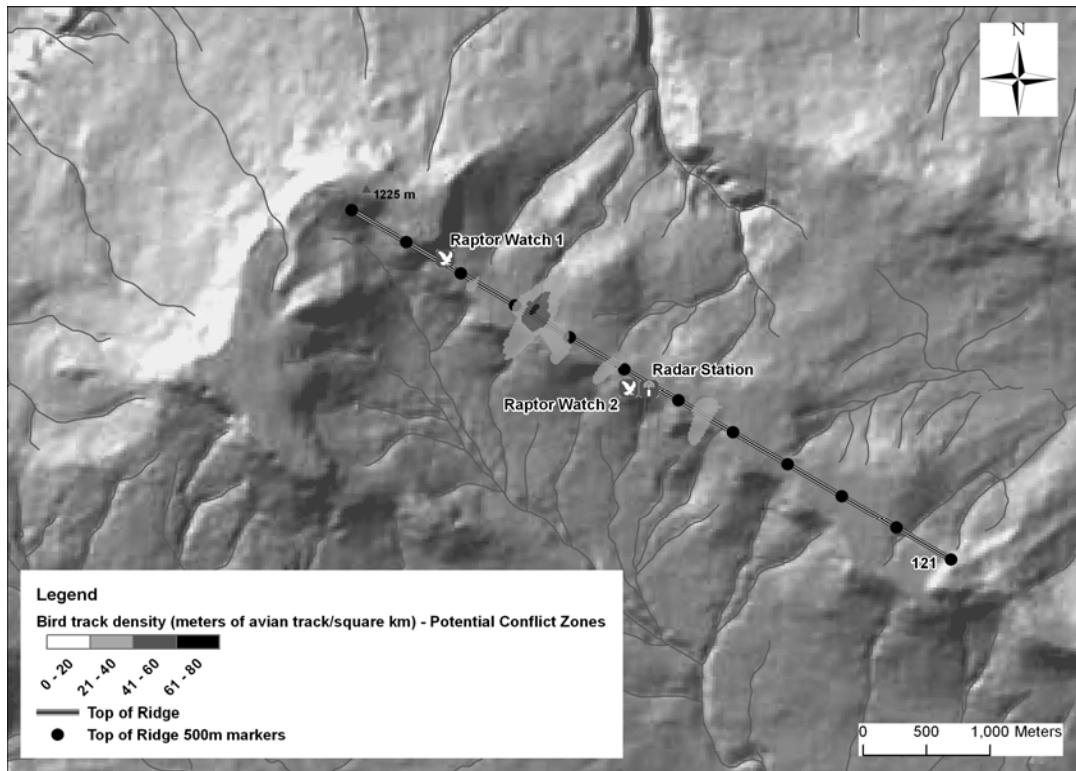
#### **2.4.2- North Dokie**

North Dokie Ridge is the second highest elevated site of our three at 1300m. The section of the ridge where the research was conducted was named Johnson Col. North Dokie is a site that is characterized by tall mature coniferous trees. Where there are no trees because of logging activity, the cut blocks are peppered with low standing vegetation such as shrubs and grasses and small poplar re-growth. This ridge is not a flat plateau such as Wartenbe and is located closer to the Canadian Rocky Mountains than the previous ridge. The ridgeline runs from  $160^\circ$  to  $340^\circ$ ; these bearings were used to compare against bird migration movement in a southerly and northerly direction.

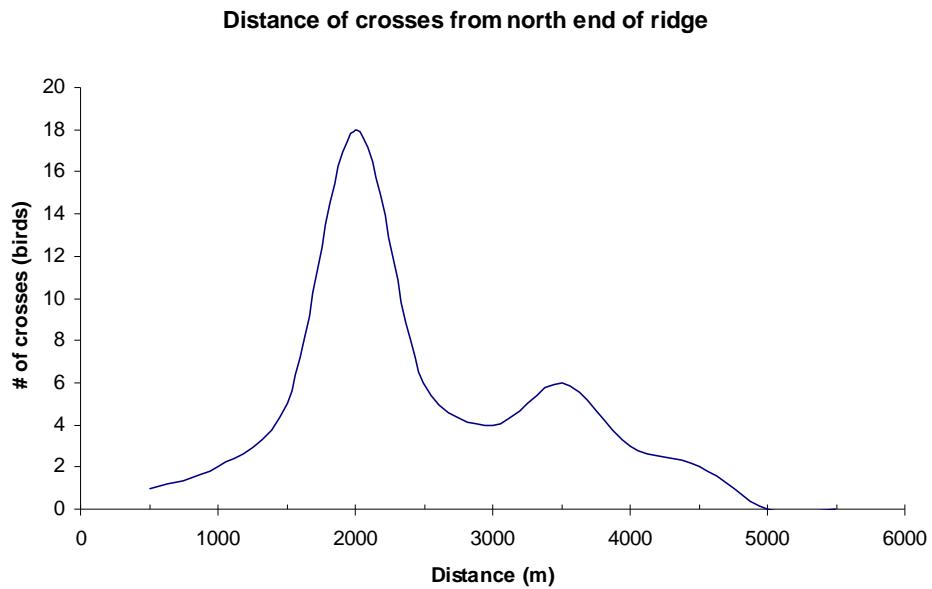
#### Radar Monitoring

114 birds were detected migrating through the study area in the spring of 2006 and 2007 (Figure 6a), while 452 birds were detected in the fall of 2006 and 2007 (Figure 6b).

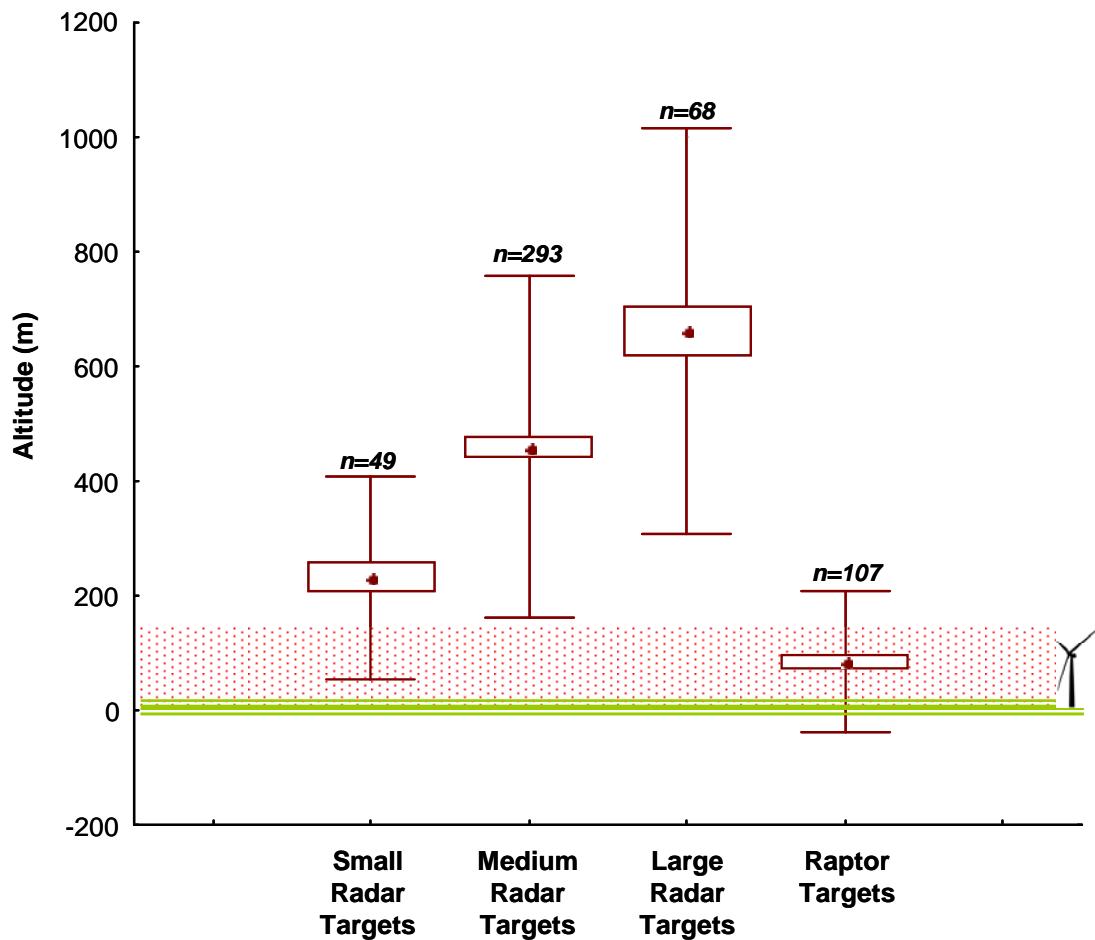
a



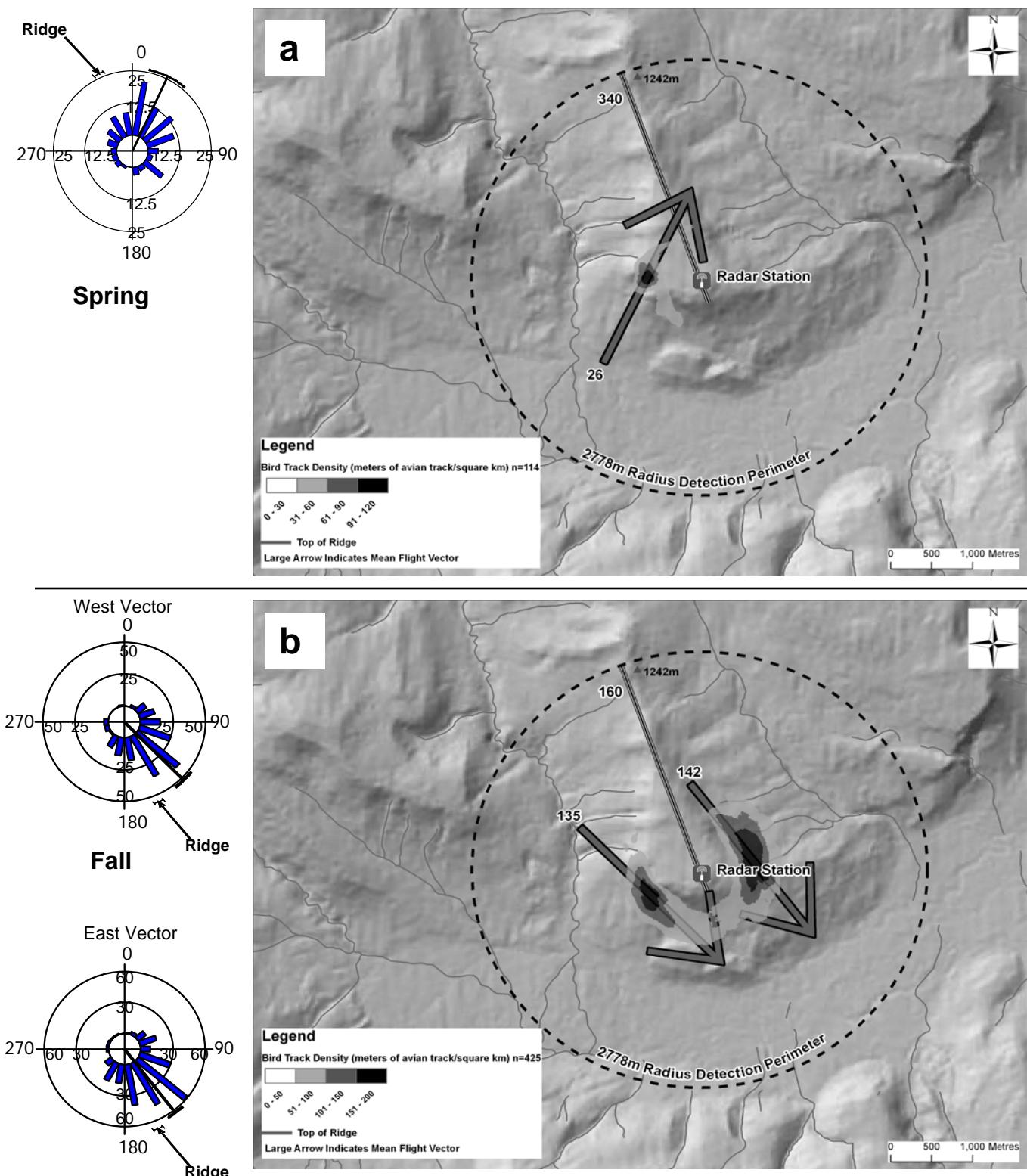
b



**Figure 4-** Wartenbe Ridge potential conflict zones where birds and raptors were observed (by visual raptor surveys or radar monitoring) crossing the ridge. (a) shows the visual representation of where potential zones of conflict are located (darker zones over top of ridge line). (b) shows the distance from the north end of the ridge of the bird crosses. Dangerous crosses (defined as birds flying and crossing over the ridge) represent only 10.6% (47/444) of total tracks for both spring and fall migration over 2006 and 2007.



**Figure 5-** Height of birds for both spring and fall migration during 2006 and 2007 for birds and raptors at Wartenbe Ridge. Turbine height (danger zone) is indicated by stippling and graphic of a turbine. N= the number of birds detected in each category. Mean altitude (m) is represented by diamond in the centre of box, standard error by upper and lower limit of box and standard deviation by upper and lower whisker.



**Figure 6-** North Dokie Ridge (Johnson Col section) monitoring results for the 2006 and 2007 field season: nocturnal migrant radar surveys in the spring (a) and fall (b) are compared. Circular histograms on the left side of table represent the number of tracks binned in  $15^\circ$  increments. Heavy black line in histogram represents mean vector  $\pm$  standard deviation (horizontal lines on either side, at tip of mean vector). Mean ridge vector is also represented on outside of histogram for visual comparison.

The mean bearing for the flight vectors of the spring migrants is  $26^\circ$  with a circular standard deviation of  $67^\circ$  and a standard error of  $7^\circ$  (see Table 2). A square root transformation was applied to this data as it did not meet the assumption of normality (von Mises distribution).

The fall radar data were in this case bimodal. The line density function of ArcMap revealed two regions of higher bird activity (Figure 6b). The mean vector for the western (west of the ridgeline) data is  $135^\circ$  with a circular standard deviation of  $47^\circ$  and a standard error of  $3^\circ$ . A square root transformation had to be applied here as the data did not meet the assumption of normality (von Mises distribution). The mean vector for the eastern (east of the ridgeline) data is  $142^\circ$  with a circular standard deviation of  $47^\circ$  and a standard error of  $3^\circ$ . A Rao's spacing test showed the presence of directionality of the spring and fall radar data ( $P < 0.01$  – Table 2).

In the spring, the bird tracks were mainly concentrated on the south-western side of the ridge (Figure 6a). The mean flight vector hints towards the possibility that the birds might be crossing the ridge from the southern aspect of the ridge. The rose diagram embedded in figure 6a shows that the bearings are mainly located in the upper right quadrant and seem to be consistent. The mean flight trajectory has not only greater variability (compared to the other migrants and seasons) but was also not oriented in the same direction as the ridge. In the southern migration (fall data, figure 6b), the rose diagram for the western vector indicates that the bearings of the bird tracks are less variable than those for the eastern vector. The mean flight vector is in the same quadrant as the ridgeline vector, but the flight and ridge bearings are not oriented in the same

**Table 2-** Descriptive statistical results for North Dokie Ridge (Johnson Col area). Sample size, mean vector  $\pm$  SE and SD are represented. Results from Rao's Spacing Test (U) testing for uniform distribution of circular data and the presence of directionality are also shown. If  $p < 0.05$ , we reject the null hypothesis that the data is uniformly distributed and the data has no particular orientation. \*\*\* indicates that a square root transformation has been applied so the data fit the von Mises (normal) distribution. Note the bimodality of the fall radar data. In this instance, results have been split into the western and eastern vector (see Figure 6).

	Spring Radar Bearings***	Fall Radar Bearings		Spring Raptor Bearings	Fall Raptor Bearings
		West ***	East		
<b>Number of Observations</b>	114	189	263	18	359
<b>Mean Vector (<math>\mu</math>)</b>	26°	135°	142°	281°	143°
<b>Circular Standard Deviation</b>	67°	47°	47°	60°	38°
<b>Standard Error of Mean</b>	7°	3°	3°	15°	2°
<b>Rao's Spacing Test (U)</b>	338.72	344.51	202.76	208.01	246.35
<b>Rao's Spacing Test (p)</b>	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

direction. The east of the ridge vector rose diagram shows the same pattern although with stronger variability in the data.

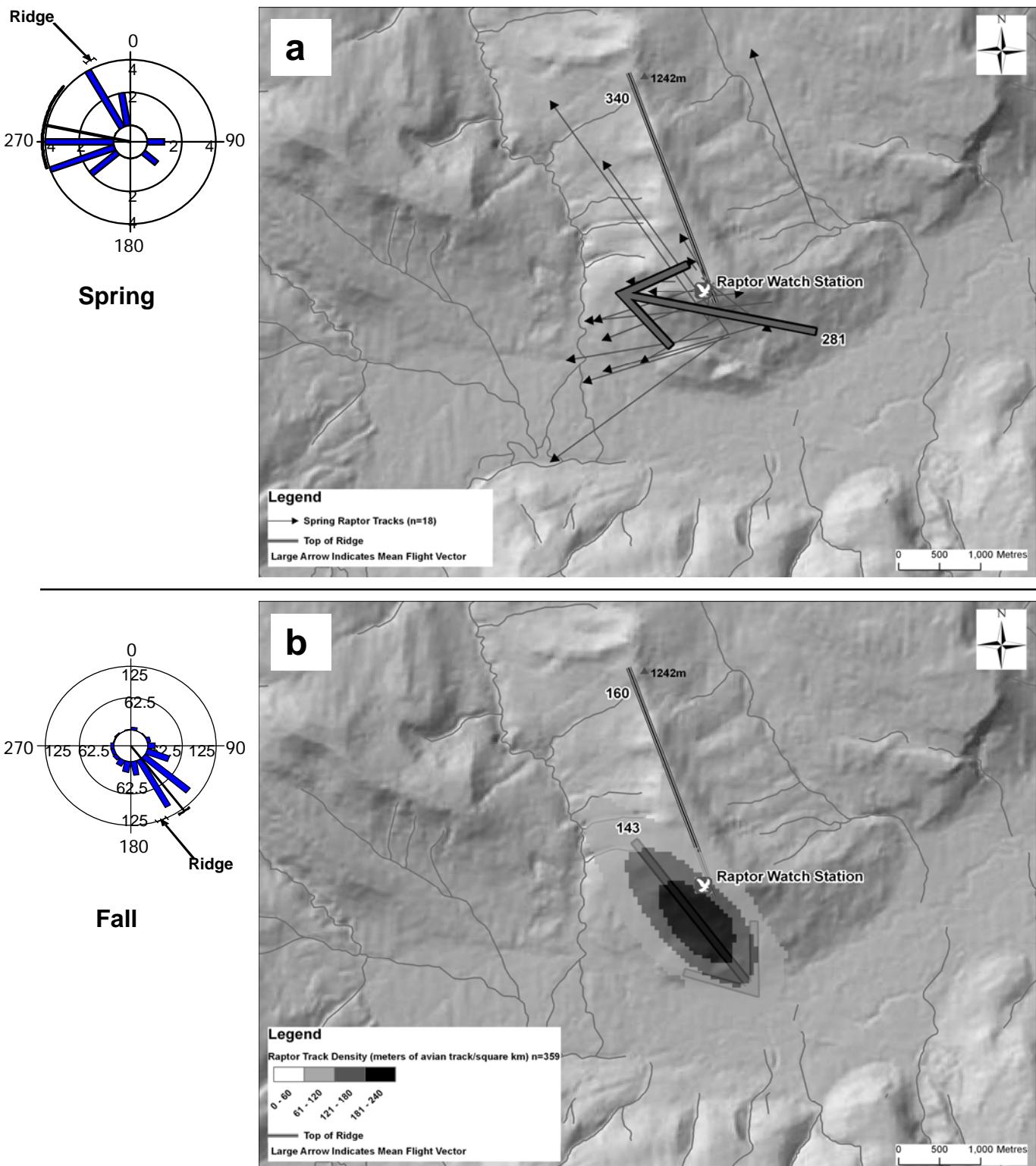
The spring radar bearings and the spring nocturnal winds were negatively correlated ( $P < 0.05$ ,  $r = -0.13$ ), but the two angles remained different from one another. The fall radar bearings and the fall nocturnal winds were more strongly, but negatively, correlated ( $P < 0.05$ ,  $r = -0.26$ ). Again, however, the two angles were different from one another indicating that the birds appear to be using the wind for migration, but are not necessarily moving in exactly the same direction as the wind (av. wind bearings: spring nocturnal period  $243^\circ \pm 3^\circ$ , fall nocturnal period  $221^\circ \pm 1^\circ$ ).

### Raptor Watch

18 raptors were detected migrating through the North Dokie area in the spring of 2006 and 2007 while 359 raptors were spotted in the fall of 2006 and 2007.

The mean bearing for the spring vectors is  $281^\circ$  with a circular standard deviation of  $60^\circ$  and a standard error of  $15^\circ$  (see Table 2). The mean bearing for the fall vectors is  $143^\circ$  with a circular standard deviation of  $38^\circ$  and a standard error of  $2^\circ$  (see Table 2). Both indicate the presence of directionality (Rao's spacing test:  $Ps < 0.01$ ).

In the spring, raptor migrant tracks were mainly concentrated on the south-western side of the ridge (Figure 7a). The mean flight parallels the ridgeline that runs east to west while at the same time, intersecting the top of the ridge vector line. The rose diagram embedded in the figure shows that the bearings are very inconsistent. This result can most likely be explained by the low sample size. Even though the mean vector is located in the same quadrant (upper left) as the ridgeline vector, the spring raptor bearings and ridgeline bearings appear to be oriented in different directions.



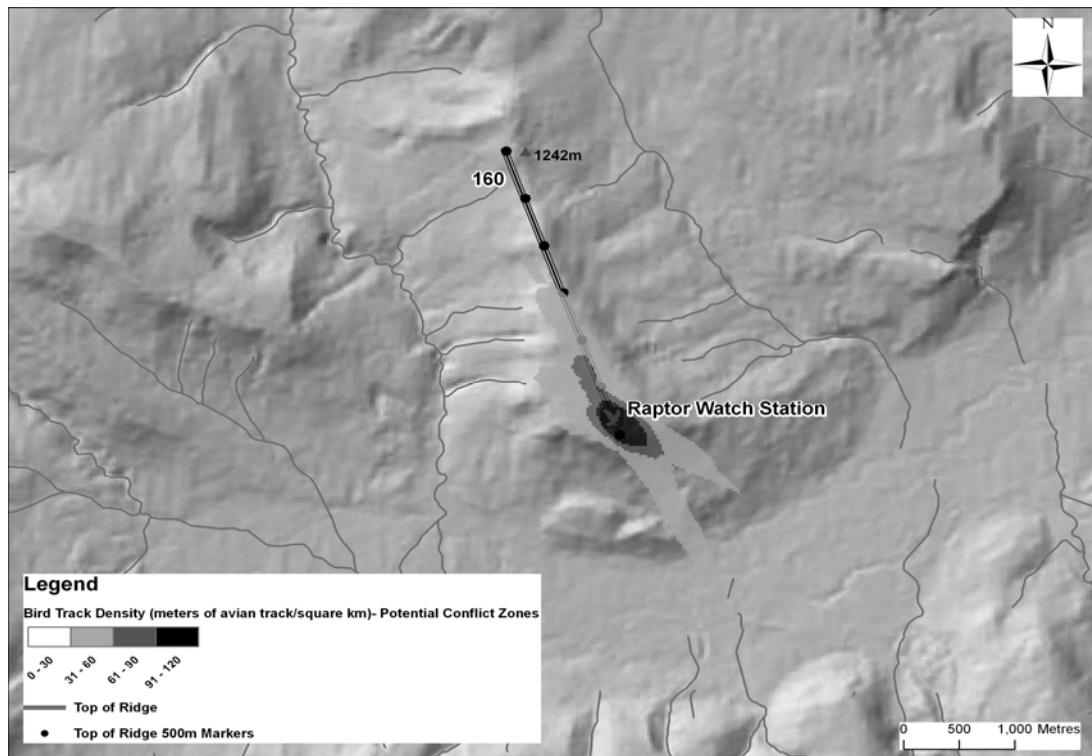
**Figure 7-** North Dokie Ridge (Johnson Col section) monitoring results for the 2006 and 2007 field season: diurnal raptor migrant radar surveys in the spring (a) and fall (b) are compared. Circular histograms on the left side of table represent the number of tracks binned in  $15^{\circ}$  increments. Heavy black line in histogram represents mean vector  $\pm$  standard deviation (horizontal lines on either side, at tip of mean vector). Mean ridge vector is also represented on outside of histogram for visual comparison.

In the fall, most raptors were heavily concentrated in the south-western side of the ridge (Figure 7b). Many raptors (ie- large sample size) were detected migrating and this is represented by the large density gradient cloud superimposed over the mean flight vector (Figure 7b). The rose diagram indicates the main vector in the bottom right quadrant of the diagram; the ridgeline vector and the mean flight vector also seem to be oriented in different directions.

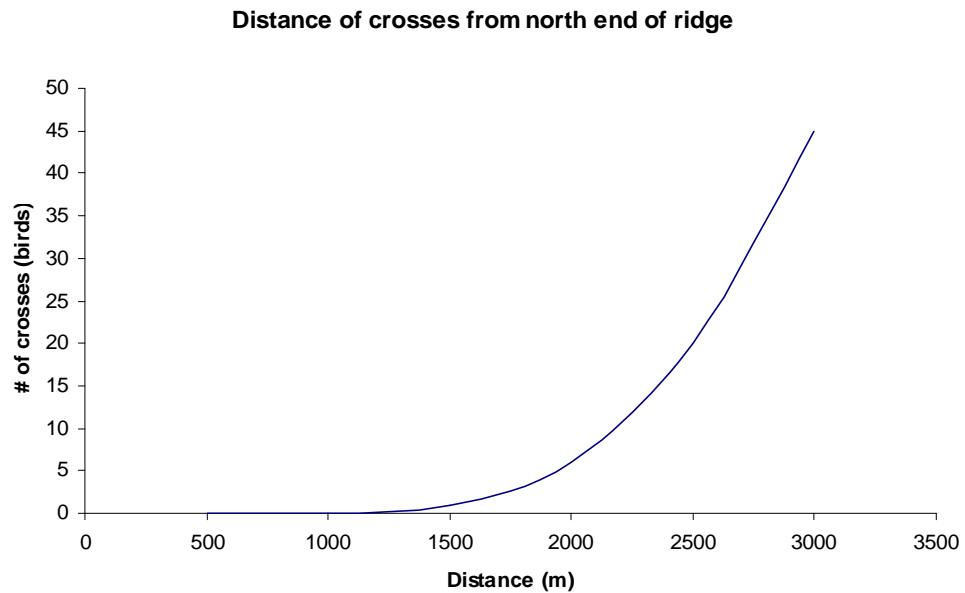
The spring raptor bearings were negatively correlated to the spring diurnal winds ( $P < 0.05$ ,  $r = -0.19$ ) despite the wind direction itself being different from the bearing angle of the spring migrating raptors. The fall raptor bearings and the fall diurnal winds were correlated, although this time, positively ( $P < 0.05$ ,  $r=0.1$ ) but again the wind direction was different from the migrants flight angle (av. wind bearings: spring diurnal period  $224^\circ \pm 14^\circ$ , fall diurnal period  $230^\circ \pm 3^\circ$ ). As opposed to the night migrants, the spring raptor bearings and wind bearings showed a higher degree of correlation than in the fall evidenced by the stronger  $r$  value.

Most of the ridgeline crosses at North Dokie were located at the very southern tip of the ridgeline (figure 8a & 8b). 72 birds were detected crossing the ridge, representing 7.9% of the total bird activity. Of these, 8% were small size, 13% were medium size, 7% were large size and the majority, 72% were raptors. Most of the nocturnal migrants, however, were flying at above the heights of potential turbines (represented by the stippling and the graphic of the turbine – Figure 9), but that isn't the case for raptors. Small birds were observed migrating at approximately 400m (n=51), medium birds at approximately 500m (n=418), large birds at approximately 575m (n=81) while raptors were observed flying at roughly 200m above ground (n=378) (Figure 9).

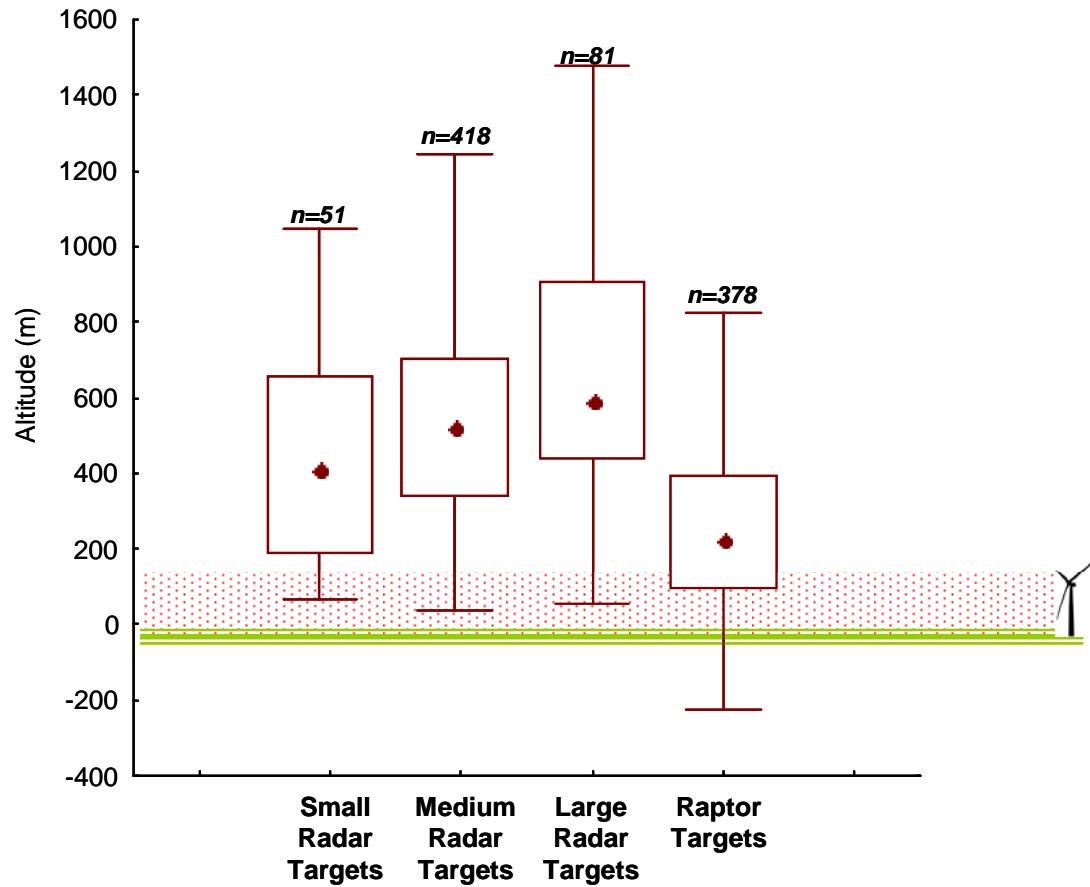
a



b



**Figure 8-** North Dokie Ridge (Johnson Col section) potential conflict zones where birds and raptors were observed (by visual raptor surveys or radar monitoring) crossing the ridge. (a) shows the visual representation of where potential zones of conflict are located (darker zones over top of ridge line). (b) shows the distance from the north end of the ridge of the bird crosses. Dangerous crosses (defined as birds flying and crossing over the ridge) represent only 7.9% (72/913) of total tracks for both spring and fall migration over 2006 and 2007.



**Figure 9-** Height of birds for both spring and fall migration during 2006 and 2007 for birds and raptors at North Dokie Ridge (Johnson Col section). Turbine height (danger zone) is indicated by stippling and graphic of a turbine. N= the number of birds detected in each category. Mean altitude (m) is represented by diamond in the centre of box, standard error by upper and lower limit of box and standard deviation by upper and lower whisker.

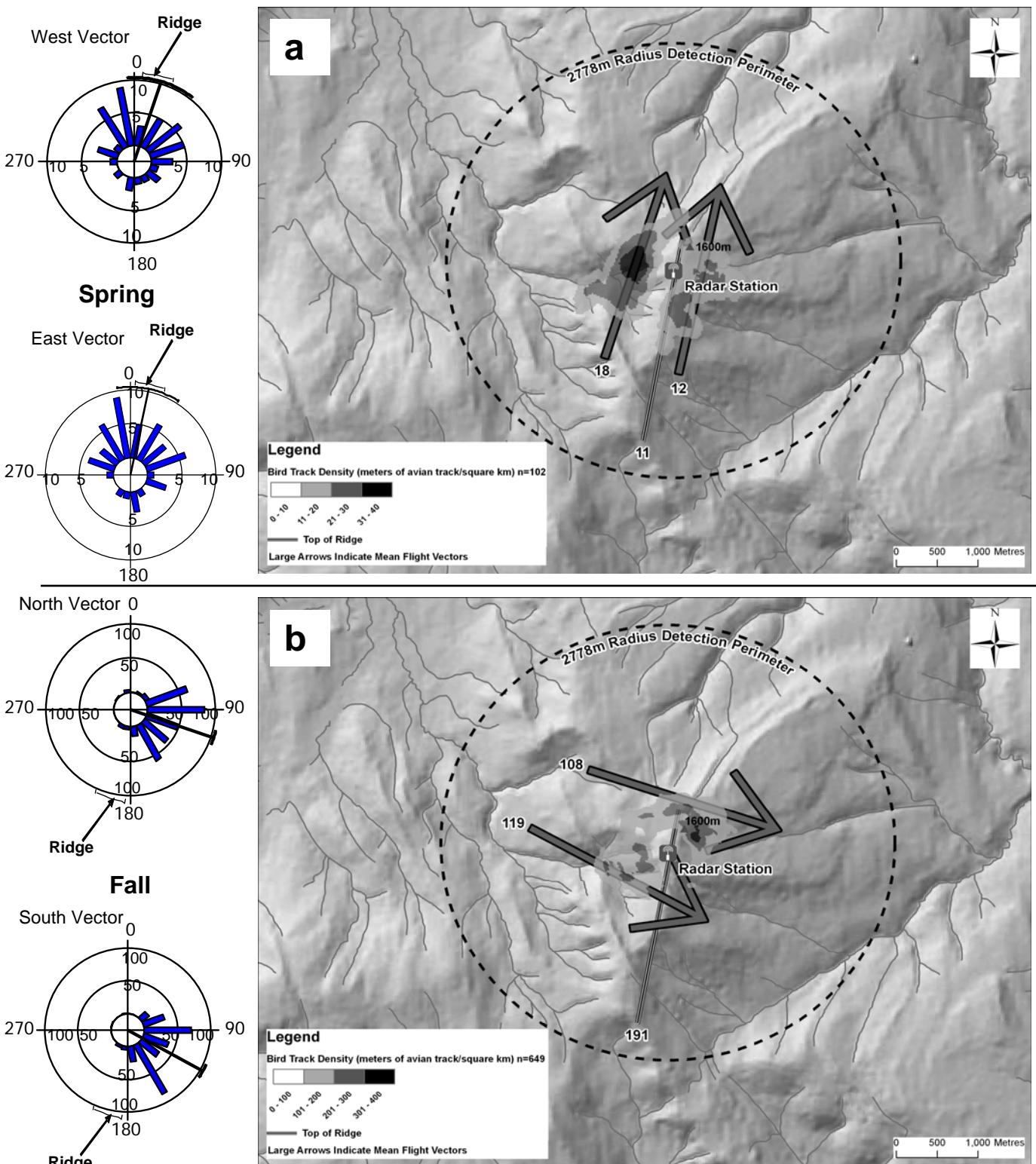
### **2.4.3- South Dokie**

South Dokie was the highest site of our three study areas at 1660m. The site was located above treeline in the alpine subzone of the foothills of the Canadian Rockies. Barely any vegetation was present except for a few sparsely-spaced, stunted coniferous trees, mosses and lichens. The site was rocky and windy. Most days were spent doing our observations above the cloud layer and bad weather systems moving through the area were not uncommon.

#### Radar Monitoring

105 birds were detected migrating through the study area in the spring of 2006 and 2007, while 622 birds were detected in the fall of 2006 and 2007. As was the case for the North Dokie fall radar data, the South Dokie spring radar data were bimodal (Figure 10a). For both western and eastern mean vectors, a square root transformation had to be applied in order to meet the assumption of normality. The mean bearing for the western (west of the ridgeline) flight vector of the spring migrants is  $18^\circ$  with a circular standard deviation of  $70^\circ$  and a standard error of  $11^\circ$  (see Table 3). The mean bearing for the eastern (east of the ridgeline) flight vector of the spring migrants is  $12^\circ$  with a circular standard deviation of  $69^\circ$  and a standard error of  $11^\circ$ .

The fall radar data were also bimodal (Figure 10b). The southern (south of the ridgeline) mean vector is  $119^\circ$  with a circular standard deviation of  $38^\circ$  and a standard error of  $2^\circ$ . The northern (north of the ridgeline) mean vector is  $108^\circ$  with a circular standard deviation of  $37^\circ$  and a standard error of  $2^\circ$ . A Rao's spacing test showed the presence of directionality of both the spring and fall radar ( $P_s < 0.01$ ).



**Figure 10-** South Dokie Ridge monitoring results for the 2006 and 2007 field season: nocturnal migrant radar surveys in the spring (a) and fall (b) are compared. Circular histograms on the left side of table represent the number of tracks binned in  $15^\circ$  increments. Heavy black line in histogram represents mean vector  $\pm$  standard deviation (horizontal lines on either side, at tip of mean vector). Mean ridge vector is also represented on outside of histogram for visual comparison.

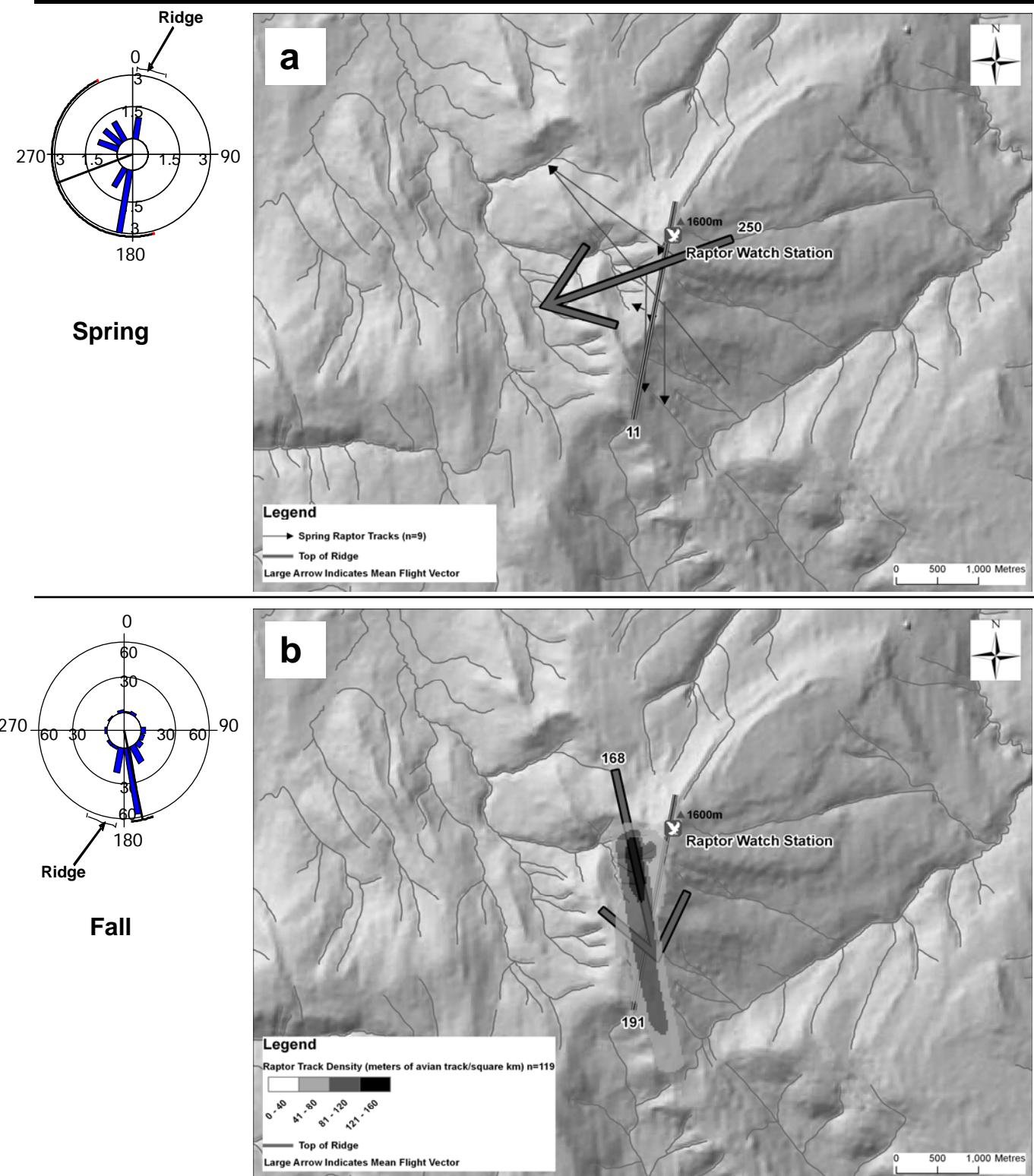
**Table 3-** Descriptive statistical results for South Dokie Ridge. Sample size, mean vector  $\pm$  SE and SD are represented. Results from Rao's Spacing Test (U) testing for uniform distribution of circular data and the presence of directionality are also shown. If  $p < 0.05$ , we reject the null hypothesis that the data is uniformly distributed and the data has no particular orientation. \*\*\* indicates that a square root transformation has been applied so the data fit the von Mises (normal) distribution. Note the bimodality of the radar data. In this instance, results have been split into the western and eastern vector (see Figure 10 and 11). Data with low concentration (\*) were statistically unreliable and omitted from analyses.

	Spring Radar Bearings		Fall Radar Bearings		Spring Raptor Bearings	Fall Raptor Bearings
	West ***	East ***	South	North		
<b>Number of Observations</b>	51	54	311	311	8	118
<b>Mean Vector (<math>\mu</math>)</b>	18°	12°	119°	108°	250°	168°
<b>Circular Standard Deviation</b>	70°	69°	38°	37°	78°	38°
<b>Standard Error of Mean</b>	11°	11°	2°	2°	*	3°
<b>Rao's Spacing Test (U)</b>	335.85	337.24	230.83	230.62	*	243.91
<b>Rao's Spacing Test (p)</b>	< 0.01	< 0.01	< 0.01	< 0.01	*	< 0.01

In the spring, both the eastern and western mean flight vectors were oriented northward. The flight trajectories and the ridgeline appear to be heading in the same direction but with greater variability in the spring movement data evidenced by the rose diagrams. This observation can suggest that the birds may be using ridge topography in focusing movement. In the southern migration (fall data – Figure 10b), however, there is a lesser amount of variation in flight trajectories, with the movement in the northern vector rose diagram showing greater variability than tracks in the southern vector. In both instances, the mean flight vectors were visually different than the ridgeline orientation as the birds were travelling perpendicular to the ridge. Unlike the spring migration, birds appear to be flying over this high altitude ridge in the fall. The spring radar bearings were found to be negatively correlated to the spring nocturnal winds ( $P < 0.05$ ), but the correlation was fairly weak ( $r = -0.09$ ) (av. wind bearing: spring nocturnal period  $266^\circ \pm 5^\circ$ ).

#### Raptor Watch

8 raptors were detected migrating through the study area in the spring of 2006 and 2007 (Figure 11a). The mean bearing for the spring vectors is  $250^\circ$  with a circular standard deviation of  $78^\circ$  and a standard error of  $43^\circ$  (see Table 3). However, these results were not reliable because of low concentrations (low sample size) and had problems with uniform distribution. Therefore, the spring raptor watch data was omitted from any subsequent statistical analysis. It seems, however, that for the majority of the cases the raptors seemed to be flying parallel to the top of the ridge at very close range. The rose diagram embedded in the figure shows that the bearings are inconsistent (by the large standard deviation bars). This result is attributable to the low sample size. Not



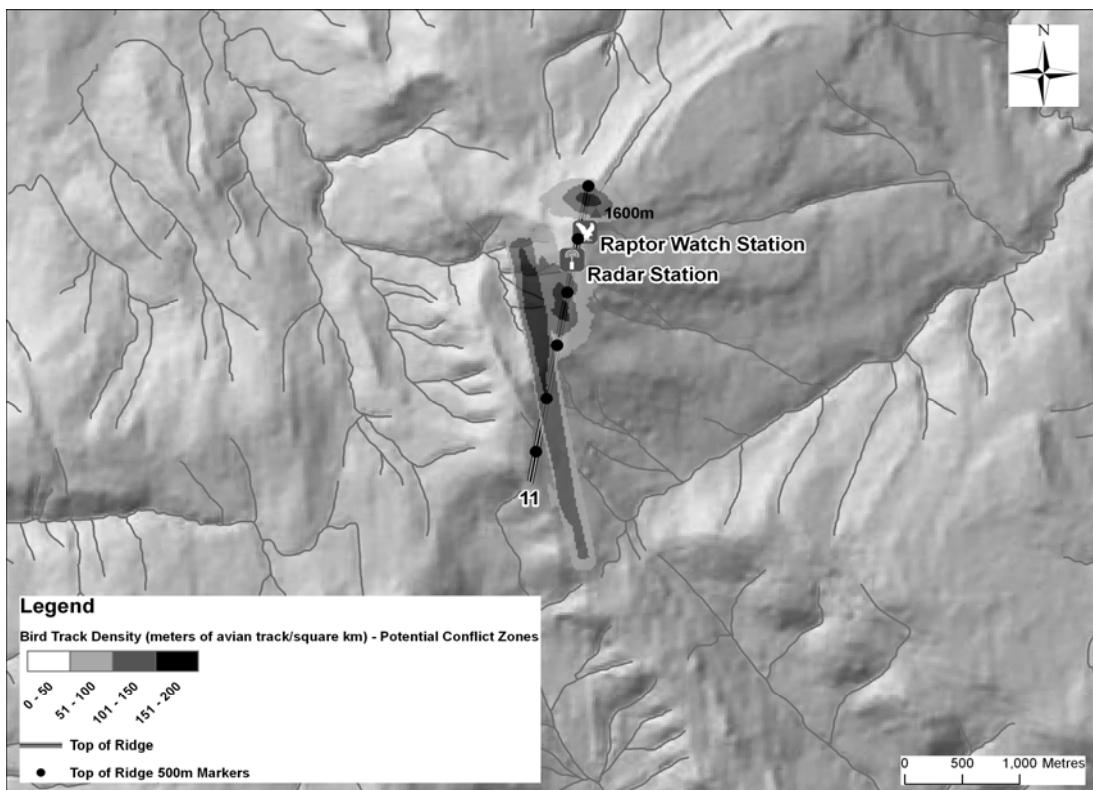
**Figure 11-** South Dokie Ridge monitoring results for the 2006 and 2007 field season: diurnal raptor migrant radar surveys in the spring (a) and fall (b) are compared. Circular histograms on the left side of table represent the number of tracks binned in  $15^\circ$  increments. Heavy black line in histogram represents mean vector  $\pm$  standard deviation (horizontal lines on either side, at tip of mean vector). Mean ridge vector is also represented on outside of histogram for visual comparison.

surprisingly, the mean ridge vector is not located in the same quadrant as the mean flight vector.

Conversely, 118 raptors were spotted in the fall of 2006 and 2007 (Figure 11b). The mean bearing for the fall vectors is  $168^\circ$  with a circular standard deviation of  $38^\circ$  and a standard error of  $3^\circ$  (see Table 3). A Rao's spacing test showed the presence of directionality of the fall raptor data ( $P < 0.01$ ).

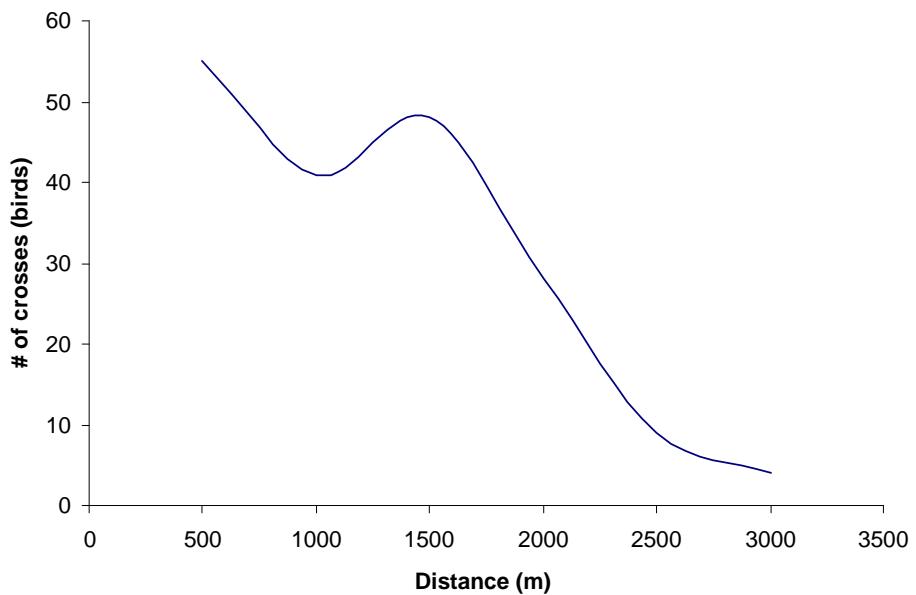
In the fall, most raptors were heavily concentrated in the south-western side of the ridge, a result consistent with North Dokie Ridge (Johnson Col area). Many raptors were detected (large sample size) migrating and this is represented by the large density gradient cloud superimposed over the mean flight vector. It is interesting to see this density gradient cloud take the shape of a “corridor”, indicating that raptor activity is consistent and predictable in this area. The rose diagram embedded in figure 11b shows the main vector in the bottom right quadrant of the diagram. The mean flight trajectory is not parallel to the ridgeline, as the two angles appear to be oriented in different directions, and the birds appear to cross the ridgeline in a very narrow region. Their movement pattern is very consistent with low variation evidenced in the rose diagram. Most of these crosses appear to be located at the very northern edge of the ridgeline with peaks at 500m & 1500m from the northern end of the ridge (Figure 12b). 185 birds were detected crossing the ridge, representing 21.05% of the total bird activity. Of these, 14% were small size, 39% were medium, 10% were large and the balance or 37% were raptors. Most of the nocturnal birds are flying above the potential collision zone (represented by the stippling and the graphic of the turbine – Figure 13). However, as at the two other ridges, raptors migrate through the potential collision zone, and these

a

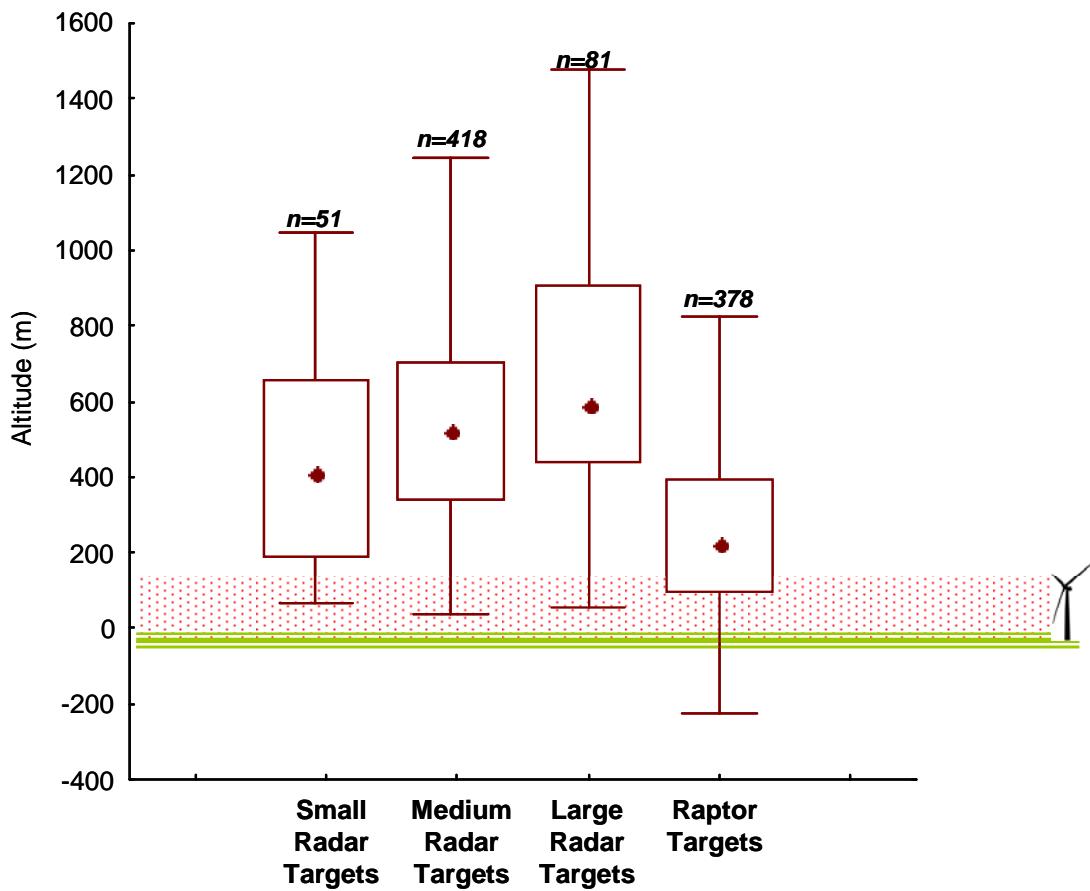


**Distance of crosses from north end of ridge**

b



**Figure 12-** South Dokie Ridge potential conflict zones where birds and raptors were observed (by visual raptor surveys or radar monitoring) crossing the ridge. (a) shows the visual representation of where potential zones of conflict are located (darker zones over top of ridge line). (b) shows the distance from the north end of the ridge of the bird crosses. Dangerous crosses (defined as birds flying and crossing over the ridge) represent only 21.05% (185/879) of total tracks for both spring and fall migration over 2006 and 2007.



**Figure 13**-Height of birds for both spring and fall migration during 2006 and 2007 for birds and raptors at South Dokie Ridge. Turbine height (danger zone) is indicated by stippling and graphic of a turbine. N= the number of birds detected in each category. Mean altitude (m) is represented by diamond in the centre of box, standard error by upper and lower limit of box and standard deviation by upper and lower whisker.

represented a fair proportion of those birds observed crossing the ridge. Small birds were observed migrating at approximately 400m (n=96), medium birds at approximately 600m (n=285), large birds at approximately 600m (n=102) while raptors were observed flying at roughly 50m above ground (n=102).

The fall raptor bearings and the fall diurnal winds were found to also be negatively ( $P < 0.05$ ) but weakly correlated ( $r = -0.11$ ). The fall radar bearings and the fall nocturnal winds had a much stronger, and positive correlation ( $P < 0.05$ ,  $r = 0.68$ ) (av. wind bearings: fall diurnal period  $23^\circ \pm 1^\circ$ , fall nocturnal period  $281^\circ \pm 1^\circ$ ). Compared to North Dokie, the correlation is much stronger in the South Dokie fall night migrants (larger  $r$  value = 0.68) than in the spring night migrants (smaller  $r$  value = -0.09).

## 2.5- Discussion

### 2.5.1- Diurnal Stand Watch Observations

Raptors and other diurnal migrants are predicted to use topographic features in the landscape during migration, specifically those that are conducive to the formation of updrafts and thermals upon which birds gain lift during soaring flight. These physical attributes of the landscape will allow birds to travel over longer distances while using less energy (Barrios and Rodrigues 2004, Hoover and Morrison 2005). Night migrants on the other hand, such as passerines and waterfowl, may rely less heavily on topography. Williams *et al.* (2001) found that birds that fly at lower elevations are more subject to the influence of the topography. Raptors in our study had the lowest flight heights of any category of migrants. At the height that most of the medium and larger sized migrants detected on radar were flying, small updrafts created by thermals may have less effect on

creating lift, and birds may be less likely to follow topography rather than the predominant wind patterns.

We found fairly strong evidence for the use of topography in shaping raptor movements at Wartenbe ridge, but the ridge angle and raptor bearings did not overlap as closely at the two Dokie sites and points of intersection occurred. Despite this, raptors tended to fly parallel to the ridgelines to a large extent, particularly in the larger fall migrations at both of these ridges – at North and South Dokie the birds tended to follow the ridgeline on the southwestern side during southern migration and either crossed the ridge on the southern edge (North Dokie) or in a fairly narrowly defined area of the ridgeline (South Dokie). This might suggest raptors are using the thermals generated in the valleys that create updrafts along the ridge edges. The concentrations on the southwestern edges of ridgelines would support this, as this is the predominantly windward edge of the ridges in both the spring and fall migration periods. The southern aspect of mountains is also the side that is best exposed to sunlight during the day. Heating of these southern slopes generates anabatic winds that diurnal migrants could utilize to help generate lift during migration (Whiteman 2000). In all three sites, the wind tended to hit these southwestern faces at oblique angles, suggesting that this side of the ridge would be the most likely location for updrafts during the day. Further, we found that flight direction in raptors was correlated with wind direction at all three ridges, yet the flight angles differed from the actual wind direction, suggesting that the birds were not flying directly into or with the wind. Rather, the flight paths follow the predominant ridgeline where updrafts would be expected.

### **2.5.2- Radar Monitoring**

Night migrants such as passerines and waterfowl did not utilise the topography as much during migration, with the exception of fall radar movement at South Dokie. When the birds did appear to fly parallel to topography, as in the spring migrations at South Dokie and fall migrations at North Dokie, the migration patterns were bimodal on either side of the ridgeline. This would suggest that the birds were less subject to using vertically moving winds located in valleys. During the night, air on mountain slopes cools quickly because of longwave radiation loss (Pidwirny 2006). As the air cools and becomes denser, it starts descending the mountains. The convergence of air, usually in valleys, creates upward moving air that birds could utilize during migration to help generate lift (Pidwirny 2006). The birds also may not rely as much on vertically moving air being deflected upwards by the mountain on the windward edge of the ridgeline (Whiteman 2000). Nocturnal migrants seem to react more to the wind direction than to the topography directly, as I found stronger correlation between the wind patterns and the avian movement patterns in this group as compared to similar correlations between wind direction and raptor movements.

This does not mean that topography has no influence on nocturnal migration in the study. For example, during the fall migration at North Dokie, the bimodality of the data suggests that the ridge has a “funnelling” effect on the birds. As they are moving south, birds on either side of the ridge converge together at the southern terminus of the ridge. The same holds true for fall migration at South Dokie. The data are bi-modal and suggests that the ridge “cuts” the movement pattern in two. This observation is most likely due to the high altitude of the ridge; during poorer weather, birds may be forced to fly at lower elevations and may tend to fly parallel to, rather than over the ridgeline.

Williams *et al.* (2001) found that birds reacting to topography could indeed be moving up and over a ridge to meet migrants flying at higher altitude. This result seems consistent with our observations at South Dokie, especially when considering the timing of our monitoring - prior to sunrise and right after sunset when the birds are presumed either landing or taking off, respectively, for their night movements.

In our study, at all three sites, nocturnal migrants were the highest flying group. It has been speculated that flying at higher altitudes at night allows the birds more time to feed during the day, allows the birds to fly in a more stable atmosphere and that flying at night and at higher altitudes reduces the stress associated with heat and dehydration (Able 2004). Winds are also faster at higher elevations (Whiteman 2000). Birds could utilize those faster moving winds at higher altitudes in order to increase their flight speed. Able (2004) and Beason (1978) have shown that waterfowl and passerines fly over land at altitudes of 700m-800m and even as high as 3500m above sea level for larger waterfowl. Our results show that the night migrants detected were flying at approximately the same altitudes (400-600m above the ridges, roughly 2000- 2600m above sea level). Even if there is a detection bias (with the marine radar scanning at 0.75nm or 1400m above ground level), these results show that topography can influence the birds' movement patterns, at least at higher elevations. At higher elevation sites, there exists the potential of influence of the topography on migrating wildlife as prominent landscape features (such as mountain peaks) are located directly into the zones (or altitude levels) the birds are flying through. A bird might choose a path in order to fly around higher landscapes in order to avoid flying directly over a mountain where unpredictable conditions could be encountered. North and South Dokie observations show that conducting such studies as

this is important, especially at high-elevation landscapes, as the movement patterns are not as consistent and predictable as they would be over flat landscapes such as the prairies.

Many studies document bird fatalities resulting from collisions with wind turbines (Thomas 1999, Erickson *et al.* 2001, BirdLife International 2003, Tingley 2003). But only a few studies have looked at the behaviour of birds around wind installations. Hoover and Morrison (2005) studied the behaviour of red-tailed hawks around a potential wind farm site, and found that raptors do rely on topography and wind patterns during such activities as soaring and kiting. In that study most of the data collected were qualitative. The authors conducted visual observations of whether birds tended to follow ridgelines, but did not make quantitative measurements of the proximity or height of the birds relative to these landscape features. A study by Barrios and Rodrigues (2004) also arrived at the same conclusions. It is important, however, to have a more detailed understanding of wildlife movement around potential wind farm sites if a successful management program is to be implemented. The better our understanding of avian movement patterns around wind farms, the greater our ability to advise wind development on management strategies to minimize the conflict between turbines and migrating birds.

### **2.5.3- Wartenbe Ridge**

The potential for conflict appears to be minimal at Wartenbe Ridge. Migrating raptors were not observed crossing the ridgeline, despite most of these tracks occurring within 150m elevation above the ridge. The birds that did cross the ridge and could come into contact with the wind turbines were nocturnal migrants. Even then, crosses over the ridge

represented only 10.6% of the total tracks, and the vast majority of these crossing-tracks occurred in medium sized targets that tend to fly well above the heights of turbines. If a wind farm proceeds, the proponents may wish to focus some of their monitoring efforts at turbines placed between 1000m and 2000m from the northern-most end of the ridge; 18 birds crossed the ridge out of the 47 total bird crosses in 2006 and 2007 in this region, and this may constitute a focal site for extra carcass searches to detect whether crosses are translating into collisions. However, the small proportion of crosses detected and the height of the typical group crossing suggest that collision risk on this ridge will be relatively low.

#### **2.5.4- North Dokie**

For North Dokie, the potential for conflict is higher than at Wartenbe. The risk, however, is still relatively low considering that only 7.9% of the 913 total birds detected crossed the ridge. Crosses tended to be concentrated on the southern-most aspect of the Johnson Col ridgeline; the highest concentration of movement occurred between 500m to 1000m from the southern edge of the ridge, upwards of 45 birds crossed the ridge in this stretch, out of the 72 total bird crosses detected in 2006 and 2007. Most significant is the high proportion of these crosses that were diurnally moving raptors, as these birds tend to cross within the potential collision zone with turbines. Raptor migration, however, tends to be fairly concentrated temporally in the region, especially in the fall migration that was heaviest on this ridge. The birds move through in a strong pulse over a two to three week period and migration rates tend to peak at mid-day (Pomeroy *et al.* 2007). This temporal and spatial constriction of the raptor migration may allow for mitigation strategies to

reduce the potential for collisions (such as the strategic idling of particular turbines during particularly sensitive migration times).

### **2.5.5- South Dokie**

South Dokie may represent the ridge with the highest probability of bird mortality, especially for raptors. During their northward and southward migration, raptors tend to fly at approximately 75m above ground, coming into the same airspace with the turbines, whose blade sweep covers the area between 25-125m above ground. The fall raptor migrants move through a narrow area concentrated on the western side of the ridge. The nocturnal migrants are more diffused but the crossing data suggests that the main nocturnal migrants that are crossing are in the mid-size category and flying above the potential conflict zone. The dangerous crosses represent 21.05% of the 879 total number of nocturnal and diurnal migrants detected; the highest proportion of these crosses were among raptors, the group whose flight elevation puts them most at risk of collision. Like North Dokie, however, most raptors are concentrated over a smaller proportion of the ridge and the risk could be mitigated strategically. If a wind farm proponent wished to be conservative, I would recommend turning problematic turbines (located between 500m and 1500m from north end of ridge) on idle mode during the peak movement period for the raptors, or from March 15<sup>th</sup> to April 15<sup>th</sup> during the spring migration and September 15<sup>th</sup> to October 15<sup>th</sup> during the fall migration. If this is not economically feasible, a wind farm proponent may wish to concentrate its carcass searches around the same problematic turbines in order to evaluate how many actual raptors are colliding with the structures. Raptors could exhibit similar avoidance behaviour as has been documented in waterfowl

by Desholm and Kahlert (2005) at offshore wind farms and idling turbines during peak raptor migration may, in fact, be unnecessary.

### ***2.5.6- Implications for Management***

The interaction between wind turbines and wildlife, particularly their collisions into these structures, may depend on the landscape in which turbines are located. Wind farms in BC are not proposed on flat plains but rather on interior or coastal mountain tops marked by high and consistent wind patterns. These are areas that offer good conditions for bird migration and dispersion, especially raptors that rely heavily on wind currents for movements (Hoover and Morrison 2005). Thus, these sites have been identified as sites where the greatest risk of collisions between wildlife and turbines occur (GAO 2005).

Through tracking individual targets, we have been able to identify concentrations of movement and ridge crossings that can aid managers in identifying areas with farms where bird/turbine conflicts are more likely to occur. These can be used to influence decisions for turbine siting, or for mitigation measures, such as idling specific turbines that may pose higher risk without necessarily impeding the entire installation. Finally, combining track patterns with identifying typical height of different classes of migrants can further clarify potential risk even among birds that cross intended turbine paths.

By coupling these studies with post construction surveys, one can then assess whether the risk is further reduced by wildlife adopting avoidance behaviour, thus refining the recommendations for mitigation measures.

## CHAPTER 3: THE EFFECTS OF WEATHER ON FINE SCALE AVIAN MOVEMENT PATTERNS

### 3.1- Abstract

Weather has been documented to be one of the main causes of the variation in the number of birds aloft during migration or nesting at stopover sites. In fact, the number of birds aloft can vary 10-fold to even 100-fold from one day/night to the next depending largely on meteorological conditions. With the popularity of wind energy increasing globally, concerns surfaced in the 1980s as to the potential adverse effects wind turbines may have on migrating avian wildlife. It is therefore important to understand how weather conditions influence passage rates, as this can dictate the potential for higher numbers of avian-turbine collisions. Using vertical and horizontal mounted marine radars, raptor stand watch observations and portable handheld weather stations, I studied how temperature, cloud cover, barometric pressure, wind direction and wind speed affected avian passage rates over three ridges (Wartenbe, North and South Dokie) in Chetwynd, BC. An Akaike's Information Criterion (AIC) was used to determine that the reduced model combining wind speed, barometric pressure and cloud cover was best at explaining and predicting higher passage rates (expressed as the # of birds /hour) in the fall migration for both diurnal and nocturnal migrants, wind speed for spring nocturnal migrants and a combination of cloud cover, temperature and wind direction for diurnal spring migrants. This information coupled with migration timing and topographical areas of higher migrant activity (see chapter 2) can be useful to wind farm proponents who wish to follow Environment Canada's mandate to preserve and enhance the quality of the natural environment, including migratory birds and other fauna.

### **3.2- Introduction**

Three main factors have been identified as possible contributors to avian fatalities at wind farms: density of birds; topography; and weather (Kingsley and Whittam 2005). Although independent, these three factors can often have interactive effects. Bird kills through collisions with tall structures, such as meteorological towers, wind turbines, power lines and tall buildings, increase during periods of fog, low cloud cover and precipitation (Case *et al.* 1965, Seets and Bohlen 1977, Elkins 1988, Erickson *et al.* 2001 and Johnson *et al.* 2002). This may be due to reduced visibility making structures more difficult to detect, birds flying at lower altitudes, attraction to lighting of these structures or combinations of these factors. Further, weather can affect migration patterns themselves. The flux of migration is known to be flexible and can be adjusted in response to local weather conditions present on particular migratory routes (Marra *et al.* 2005). Therefore, given the presence of migration, understanding how weather affects avian passage rates can help predict potential risks of wind turbines on aerial wildlife.

Weather varies daily as high and low pressure systems move through different regions, generally from West to East (Richardson 1978). Migrating birds might fly hundreds of kilometres in one day and then rest for a short period, resuming migration when the weather conditions are favourable. Thus, the number of birds at stopover sites may vary daily from 10 to 100-fold depending on weather (Richardson 1978, Bruderer 2003, Hüppop *et al.* 2006). There are some exceptions, but most species of birds will tend to fly with light winds or tail winds in order to either save energy or fly faster when travelling over long distances (Gill 2006). Flight with light headwinds or tail winds may also reduce navigational problems (Richardson 1978). Other variables such as temperature, dew-point, humidity and pressure associated with pressure systems may also be correlated to

bird movement patterns, flux and timing. For example, the winds are almost always from the northwest after the passage of a cold front at night. Birds whose preferred trajectory is southeast are then most likely to fly under these conditions.

The number of migrating birds also appears to vary depending on visibility. Birds tend to avoid flying when visibility is reduced by rain, fog or snow, associated with lower pressure systems (Richardson 1978). However, some birds may depart during favourable weather which later turned foul, resulting in bird migration occurring in periods of low visibility. Under such circumstances, the birds may continue to fly despite poor weather conditions, remaining aloft until visibility improves and a safe landing becomes possible (Richardson 1978). In other instances, when the weather turns for the worse, weather conditions may force the birds to reduce their altitude and find a safe spot to land (Gordo 2007). It is in those cases, where the birds are forced to fly at lower elevations under unfavourable weather conditions, that the collision risks are higher; especially during fall migration periods in North America (Kingsley and Whittam 2005). It is therefore important to understand how weather affects passage rates as foul weather may result in higher probabilities of avian-turbine collisions.

This chapter will attempt to uncover which weather variable (temperature, wind speed and direction, cloud cover and barometric pressure) accounts for most of the variation in the migratory fluxes over our three study sites near Chetwynd, BC in both spring and fall migration periods. By using locally collected weather data from a handheld weather station and coupling it to avian movement data collected using portable marine radars, I will develop fine-scale predictive models of the flux of bird migration as influenced by weather systems. I hypothesize that large numbers of migratory birds (defined as passage

rates or # of birds/hour) will be observed before or immediately following the passage of unfavourable weather. Birds that are travelling north will migrate with northward tail winds and vice-versa. I also predict that during the day, when the cloud cover is at a minimum and the conditions are favourable to the creation of thermals and updrafts (favourable winds perpendicular to linear features such as ridge edges along with higher temperatures), that diurnal migrants such as raptors and hawks will be observed migrating in larger numbers than when conditions are unfavourable.

### **3.3- Methods**

Avian movement patterns were collected via both radar (nocturnal) and visual (diurnal) surveys as previously described (see chapter 2 for more details).

#### ***3.3.1- Avian Movement Data Collection- Radar Monitoring***

Radar surveys of night-migrating landbirds were conducted between April 3<sup>rd</sup> - May 30<sup>th</sup> (2006) and April 15<sup>th</sup> - May 30<sup>th</sup> (2007) for spring migration and between August 1<sup>st</sup> - September 15<sup>th</sup> (2006) and August 19<sup>th</sup> - September 14<sup>th</sup> (2007) for fall migration at Wartenbe Ridge near Chetwynd, BC. Using the same protocols, biologists at Jacques Whitford-Axys collected parallel data on two additional ridges (North and South Dokie) in the region during the same time periods for use in this analysis. In 2006, radars were operated (weather permitting) 3-5 nights per week, and in 2007 I conducted surveys nightly during the period of peak migration through the region.

Vertically- and horizontally-mounted scanning Furuno marine radars (model 1954C, 12kW, 6ft. open array antennas) were used simultaneously at Wartenbe, and a single radar oscillating between vertical and horizontal mode each hour was used at the Dokie ridges. The horizontal marine radar was mounted on a portable drywall hoist elevated at

~2.5m above the ground and scanned a vertical arc of 22 degrees, rotating 360 degrees every 3 seconds. The vertical marine radar was mounted on a platform system, elevated at ~1.5m above the ground and scanned a horizontal arc of 22 degrees, rotating 360 degrees every 3 seconds. Scanning range was set at 1.5 nautical miles (2.8 km) for the horizontal radar and 0.5 nautical miles (1 km) for the vertical radar. The scanning radius could change to yield the clearest picture depending on the topography of the sites and the presence of boulders, trees, or other large obstructions. Radars were set on short pulse length in both years of sampling, which allowed for a finer resolution and a detection capacity of even small passerines, such as tree swallows (*Tachycineta bicolor*). Both radars were oriented true north.

Monitoring was done intensively during the peak migratory periods using 2-hour surveys starting at dusk and just prior to dawn on each day as described in chapter 2.

### **3.3.2- Avian Movement Data Collection- Raptor Watch**

To assess hawk and raptor movement during the day, birds were observed alternately at two vantage points along the ridge for up to 6 hour shifts starting at 9am. Vantage points were selected based on the ability to see large areas of the ridgeline.

Binoculars and spotting scopes were used to locate individuals and determine species and age. Time of detection was noted, and the compass bearing and distance from the observer were taken (the latter was determined using laser range finders (Bushnell Legend Yardage Pro) to measure the exact distance to reference landmarks). A clinometer (Suunto) was then used to determine the elevation angle of birds from the observer, which we later used to calculate height relative to the observation station (either above the ridgeline or below into the valleys). The general direction of travel was noted,

and if the bird continued in a straight trajectory a compass bearing and distance estimate was made on the final sighting of the bird from the vantage point. If the bird changed direction, bearing and distance measures were taken for each direction-change point in order to recreate the tracks.

### **3.3.3- Weather Data Collection**

Weather data were collected using a handheld weather station (Skymaster weather meter – model# SM-28). Weather data were collected every hour during radar and raptor watch surveys. If any drastic change in weather conditions was observed between these hourly intervals, new weather information was collected. Additional data were also collected for every raptor observation during the day. Relevant data such as temperature ( $^{\circ}\text{C}$ ), wind speed (km/h) and direction relative to true north along with barometric pressure (calibrated for local elevation) were measured. Percentage cloud cover was estimated visually.

### **3.3.4- Data Analysis**

Since high and low pressure areas often cover whole regions, I combined data from all three neighbouring ridges for analysis (Skinner *et al.* 1999, Whiteman 2000). However, spring migration passage rates were analysed independently of fall migration passage rates as birds rarely exhibit the same behaviour given the differing spring and fall weather conditions (Able 2004). This way, I was able to compare both spring and fall migration to determine if the same weather variables influence migration. Diurnal and nocturnal migrants were also analyzed independently. Weather conditions vary between night and day (Skinner *et al.* 1999, Whiteman 2000) and could have an effect avian flight behavior.

The number of targets detected was summed for every sampling hour in order to obtain the passage rates, expressed as the number of birds detected per hour. For every sampling hour, the measured weather variables such as temperature, wind speed and direction along with barometric pressure and cloud cover were averaged. In instances where the weather conditions changed or in instances where more than one measure of the climatic conditions were taken, means were calculated for every weather parameter. Since wind bearing data are circular; where large values are very close to small values, the data needed to be linearized. Wind bearing data were transformed using the trigonometric Sin and Cos functions. This way, two variables were created and used simultaneously in my models, “northness” ( $y=\cos(\alpha)$ ) and “eastness” ( $x=\sin(\alpha)$ ). All statistics were completed using Intercooled Stata (ver. 7.0, Stata Corp, 2000).

### **3.3.5- Model Development**

Since the calculated passage rates were derived from count data, count models were developed. Depending on the distribution of the count data, one can fit either Negative Binomial Regression Models (NBRM) or Poisson Regression Models (PRM). PRM models are however not recommended as they do not take into account the overdispersion of the data, or in our case, the high frequency of low passage rates (ie- the variance not equal to the mean) (Long and Freese 2006). Since zero counts were not collected during our study, we did not need to take into account that NBRM and PRM models tend to under-predict the occurrence of zero counts and zero-inflated versions of these models were therefore not considered. As suggested by Long and Freese (2006), the more conservative approach of using NBRM models was chosen for our analysis. After

performing the NBRM regressions, the presence of collinearity was investigated using variance inflation factors (VIF) and was found to be non-existent.

### **3.3.6- Models**

I developed a set of candidate models (a combination of my five weather parameters measured) that could potentially impact avian migration (Skinner *et al.* 1999, Whiteman 2000, Able 2004). A total of 11 models were developed including the full model with all weather parameters (see Tables 4 & 5). By using the information theoretic model comparison (ITMC) technique, an Akaike's Information Criterion (AIC) value for each model was calculated from the log likelihoods obtained from fitting the NBRM regressions. In lieu of using the standard AIC, I used the small-sample bias correction form ( $AIC_c$ ) which has been shown to converge to the standard AIC value as you increase sample size (Burnham and Anderson 2004). The formula to calculate  $AIC_c$  is:

$$AICc = -2LL + 2K + 2K\left(\frac{K+1}{n-K-1}\right)$$

where: LL = log likelihood, K = # of parameters and n= sample size.

$AIC_c$  has been shown to be useful in situations with a small sample where the sample size divided by the number of parameters in the model is higher than 40 ( $n/K > 40$ ) (Burnham and Anderson 2004). In fact, most of the AIC criticism stems from the fact that researchers should have used  $AIC_c$  instead of the standard AIC to account for the effect of the small sample sizes (Burnham and Anderson 2004).

Since the actual  $AIC_c$  value is less important than the change in the  $AIC_c$  value between different models, the difference, or  $\Delta_i$ , between the best model (lowest  $AIC_c$

value) and model  $i$  was calculated. The “best” model will have a delta  $AIC_c$  equal to 0 (Burnham and Anderson 2004). This value represents the information lost if model $_i$  was used instead of the “best” model. Anderson *et al.* (2000) stipulate that as a general rule of thumb, if  $\Delta_i < 2$ , the models compared are too similar to be ranked by the  $AIC_c$  value (or  $\Delta_i$ ) and the most parsimonious model should be selected. However, Guthery *et al.* (2005) cautioned that from a biological standpoint, especially in the field of conservation biology, being able to statistically unravel the “best” model is not the most important result. It is the model’s predictive ability that will determine how it will hold up against what is happening in “real world” situations. Thus, it is necessary to cross-validate the models, and also consider parsimonious models against a strong full model that includes all variables. In situations where my full model (all variables) was deemed by as my best model, I also investigated my second-ranked model’s predictive ability regardless of whether its  $\Delta AIC_c$  exceeded the 2.0 cut off.

### **3.3.7- Cross-Validation**

A common criticism of using the ITMC technique of AIC is that even if the models can be ranked from the “best” to the “worst”, this ranking is relative and often times the models still lack predictive ability (Guthery *et al.* 2005). I therefore used the Stata program “*prcounts.ado*” (Long and Freese 2006) to determine the accuracy of my top model in predicting the passage rates given the weather parameters. “*prcounts.ado*” is a script written by J. Scott Long and Jeremy Freese from the University of Indiana for use in Intercooled Stata (ver. 7.0, Stata Corp, 2000). The program computes the predicted rate and the probabilities of counts from 0 to a user-specified maximum, based on the last estimates from the count models. Because in the field of wildlife management and

conservation it is not only important to unravel the statistical significance of a model but the amount of data variability accounted for by the statistical model,  $R^2$  values were computed and compared for every significant model. These  $R^2$  values were obtained after fitting curvilinear trend lines to both the observed and predicted passage rate values generated by “*prcounts.ado*”.

### **3.4- Results**

Based on my  $AIC_c$  scores for both spring and fall migration, a combination of barometric pressure, cloud cover and wind speed was best able to explain the passage rates over our three ridges in both diurnal and nocturnal fall migrants (Tables 4 and 5). In the spring raptor migrants (Table 5), the full model and the combination of cloud cover, temperature and wind direction models had a  $\Delta AIC_c$  value < 2. Since the reduced model is more parsimonious even if it ranked 2<sup>nd</sup>, I selected this model as the “top” model. In the spring nocturnal migrants (Table 4), the pressure, cloud cover and wind speed model along with the wind speed alone models had a  $\Delta AIC_c$  value < 2. The more parsimonious wind speed model was therefore selected as my “top” model.

98% of the variance was explained by the predicted wind speed model values in spring nocturnal (radar) migrants ( $R^2= 0.98$ ) after fitting a curvilinear trend line to the data. In the fall, the values became smaller, where 93% of the variance was explained by the predicted pressure, cloud cover and wind speed model in nocturnal migrants ( $R^2= 0.93$ ).

**Table 4-** Summary of AIC<sub>c</sub> statistics for the candidate NBRM regression models to predict night migrant passage rates (# birds/hour) given migration and certain weather parameters over three ridges located in Chetwynd, British Columbia. Spring and fall are presented along with sample sizes (n). \*\*\* indicates the significant or “best” model(s). Models are presented from best (lowest Δ AIC<sub>c</sub> value) to worst (highest Δ AIC<sub>c</sub> value).

Negative Binomial Regression Model	Log Likelihood	AIC <sub>c</sub>	Δ AIC <sub>c</sub>
<b>Spring (n=62)</b>			
<i>Press + Cloud + Wind Speed***</i>	-207.23	420.88	0
<i>Wind Speed***</i>	-209.73	421.53	0.65
<i>Wind Speed + Wind Dir</i>	-208.37	423.16	2.28
<i>Full Model</i>	-205.69	424.9	4.02
<i>Temp + Wind Dir + Wind Speed</i>	-208.28	425.27	4.39
<i>Cloud</i>	-214.46	430.98	10.1
<i>Press</i>	-215.65	433.36	12.48
<i>Temp</i>	-215.72	433.50	12.62
<i>Wind Dir</i>	-215.15	434.51	13.63
<i>Cloud + Temp + Wind Dir</i>	-213.84	436.39	15.51
<i>Temp + Wind Dir</i>	-215.09	436.6	15.72
<b>Fall (n=26)</b>			
<i>Press + Cloud + Wind Speed***</i>	-120.04	247.16	0
<i>Full Model</i>	-118.78	253.98	6.81
<i>Cloud</i>	-129.39	260.96	13.79
<i>Press</i>	-130.60	263.36	16.2
<i>Cloud + Temp + Wind Dir</i>	-127.12	264.15	16.99
<i>Temp</i>	-132.36	266.88	19.72
<i>Temp + Wind Dir</i>	-131.35	269.80	22.64
<i>Wind Dir</i>	-133.21	270.94	23.78
<i>Temp + Wind Dir + Wind Speed</i>	-131.29	272.49	25.32
<i>Wind Speed + Wind Dir</i>	-133.11	273.3	26.14
<i>Wind Speed</i>	-135.74	273.64	26.48

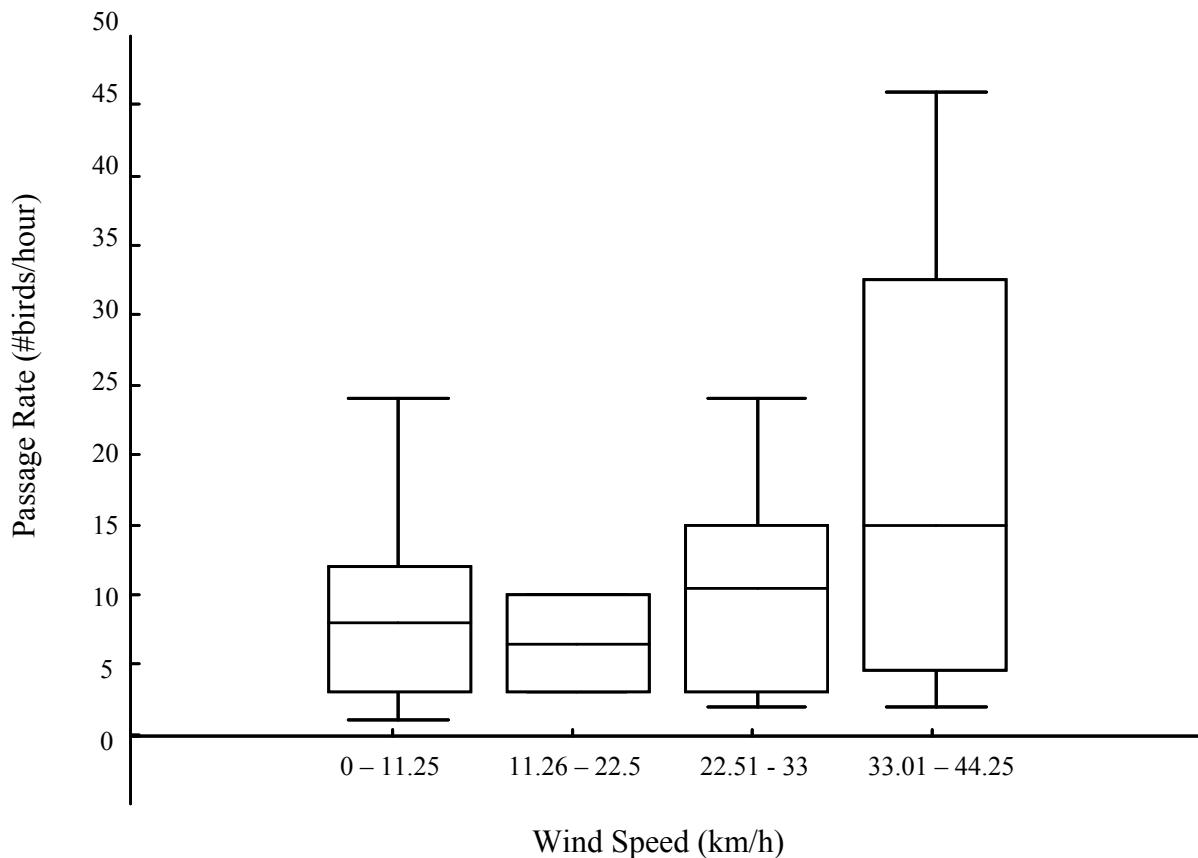
**Table 5-** Summary of AIC<sub>c</sub> statistics for the candidate NBRM regression models to predict raptor passage rates (# birds/hour) given migration and certain weather parameters over three ridges located in Chetwynd, British Columbia. Spring and fall are presented along with sample sizes (n). \*\*\* indicates the significant or “best” model(s). Models are presented from best (lowest Δ AIC<sub>c</sub> value) to worst (highest Δ AIC<sub>c</sub> value).

Negative Binomial Regression Model	Log Likelihood	AIC <sub>c</sub>	Δ AIC <sub>c</sub>
<b><u>Spring (n=54)</u></b>			
<i>Full Model***</i>	-88.07	189.93	0
<i>Could + Temp + Wind Dir***</i>	-91.44	191.70	1.77
<i>Press + Cloud + Wind Speed</i>	-93.05	192.58	2.65
<i>Cloud</i>	-97.09	196.26	6.33
<i>Wind Speed + Wind Dir</i>	-95.73	197.93	8.00
<i>Temp + Wind Dir + Wind Speed</i>	-95.72	200.27	10.34
<i>Wind Speed</i>	-99.25	200.57	10.64
<i>Wind Dir</i>	-100.79	205.82	15.89
<i>Press</i>	-102.77	207.62	17.69
<i>Temp + Wind Dir</i>	-100.78	208.03	18.10
<i>Temp</i>	-105.22	212.51	22.58
<b><u>Fall (n=108)</u></b>			
<i>Press + Cloud + Wind Speed***</i>	-272.10	550.44	0
<i>Full Model</i>	-271.12	555.07	4.63
<i>Wind Speed + Wind Dir</i>	-275.76	557.74	7.31
<i>Temp + Wind Dir + Wind Speed</i>	-274.78	557.94	7.51
<i>Wind Speed</i>	-278.07	558.17	7.74
<i>Press</i>	-281.11	564.27	13.83
<i>Temp</i>	-290.02	582.08	31.65
<i>Cloud + Temp + Wind Dir</i>	-286.94	582.28	31.84
<i>Temp + Wind Dir</i>	-288.40	583.03	32.59
<i>Wind Dir</i>	-292.23	588.58	38.14
<i>Cloud</i>	-293.96	589.97	39.53

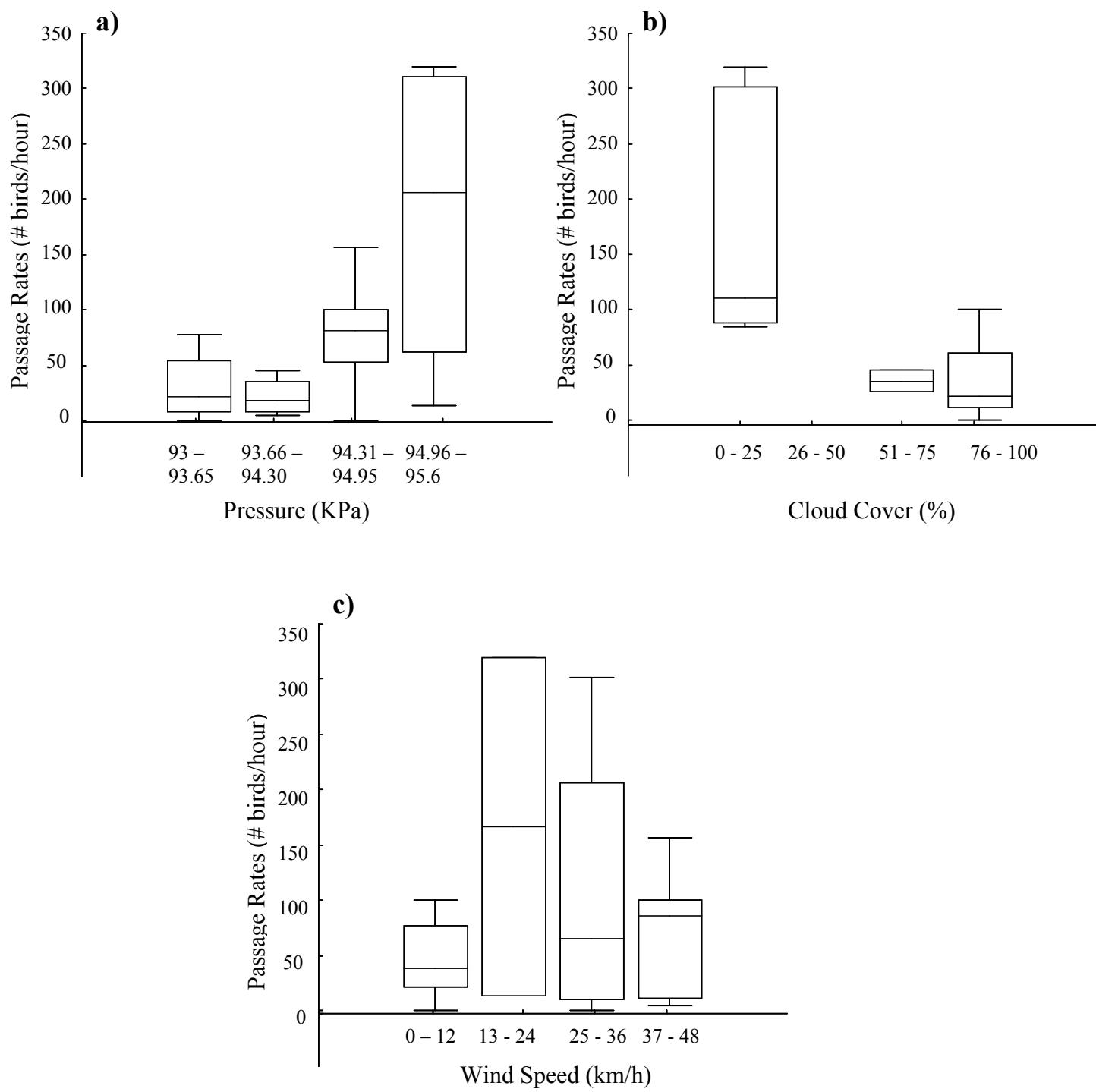
65% of the variance was explained by the predicted cloud cover, temperature and wind direction model values in spring diurnal (raptor watch) migrants ( $R^2= 0.65$ ) after fitting a curvilinear trend line to the data. In the fall, the  $R^2$  values increased, where 95% of the variance was explained by the predicted pressure, cloud cover and wind speed model in diurnal migrants ( $R^2= 0.95$ ).

A closer look at the trends of the individual contributing variables reveals how the different weather parameters influence passage rates in different seasons amongst different groups of migrants (nocturnal and diurnal).

A positive relationship was found between wind speed and passage rates in the spring nocturnal migrants (Figure 14). The passage rates were the highest at wind speeds between 33.01 – 44.25 km/h. In the nocturnal fall migration, a positive relationship was also present between pressure and passage rates. The rate of migration seemed to be the highest at higher pressures between 94.96 – 95.6 kPa. Fall passage rates were the highest on clear nights, or when the sky was covered with 0 – 25% clouds. As cloud cover increased, passage rates decreased. Finally, nocturnal night migrants were observed having higher passage rates at wind speeds between 13-36 km/h, a more moderate wind speed than in the spring migration. The relationship between passage rates and wind speeds seem to take the shape of an inverse parabola with passage rates being smaller at low wind speeds, increasing at moderate wind velocity and finally decreasing at higher wind speeds (Figure 15).

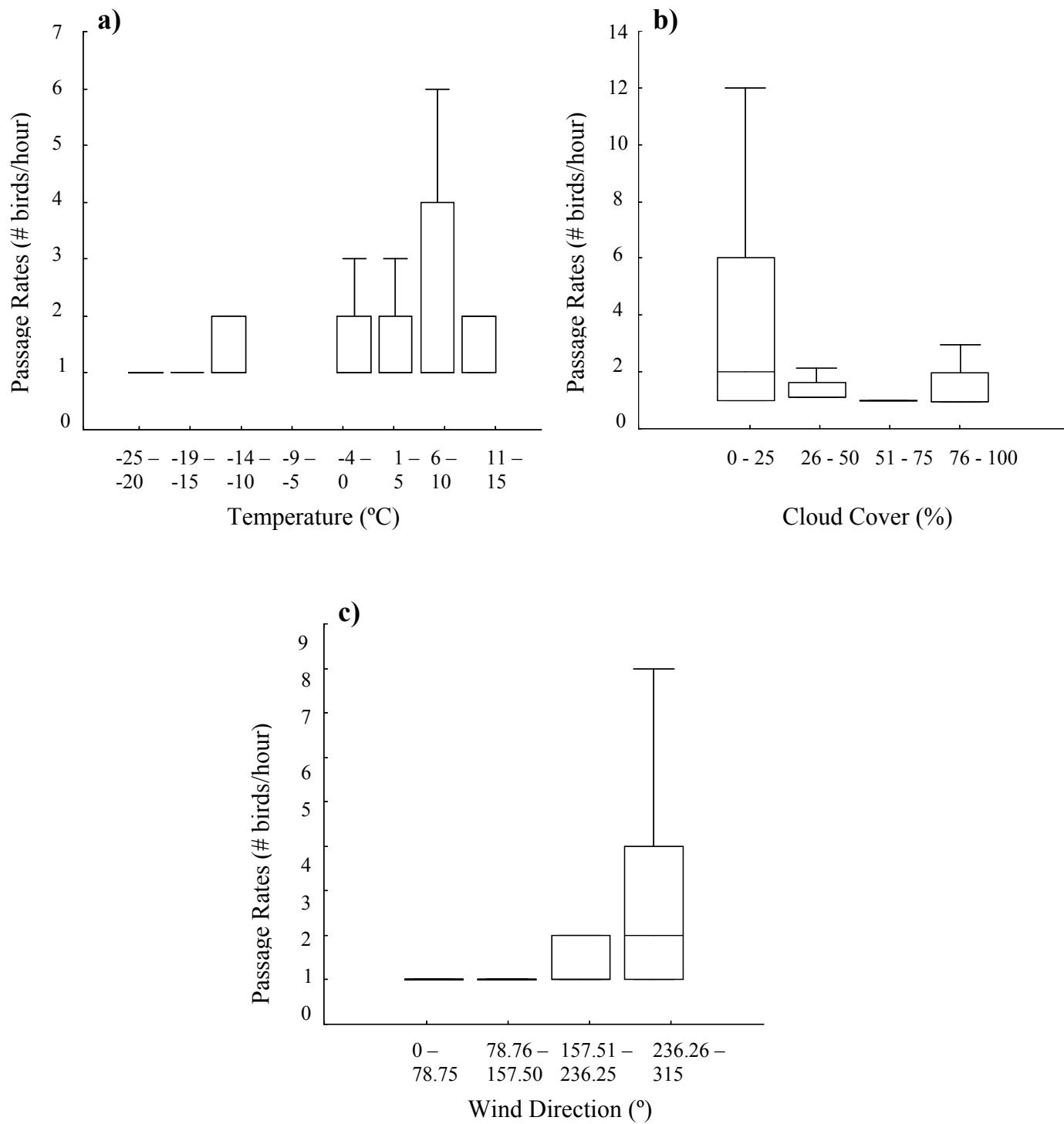


**Figure 14-** Passage rates (# birds/hour) as a function of wind speed (km/h) is illustrated for spring nocturnal migrants. Sample size is 62. Data covers all three neighboring ridges near Chetwynd, BC. Line in the middle of the box represents median value; box represents the upper and lower quartiles and the whiskers, upper and lower 90% inclusion limits.

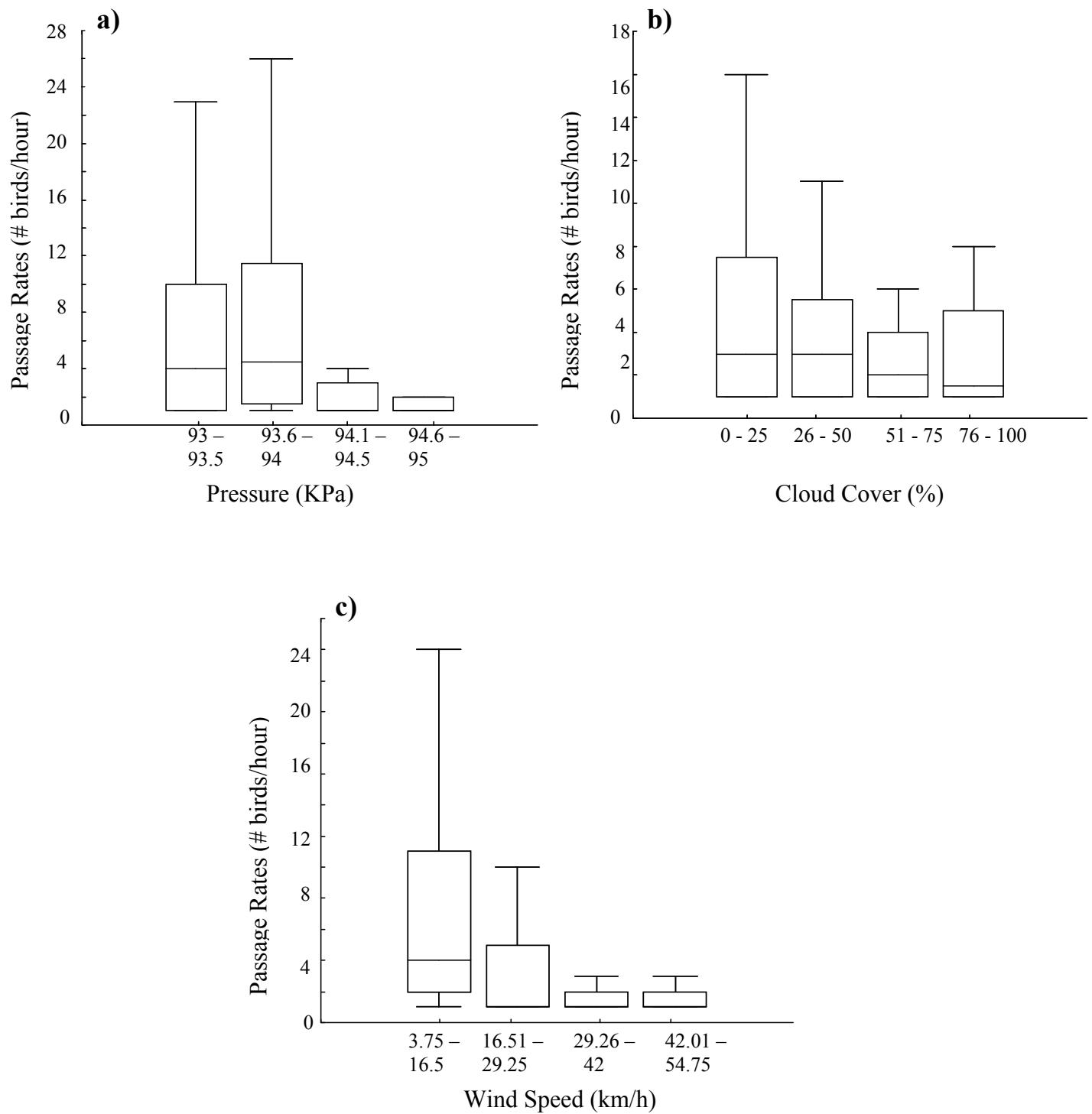


**Figure 15-** Passage rates (# birds/hour) as a function of a) pressure (kPa), b) cloud cover (%) and c) wind speed (km/h) is illustrated for fall nocturnal migrants. Sample size is 26. Data covers all three neighboring ridges near Chetwynd, BC. Line in the middle of the box represents median value; box represents the upper and lower quartiles and the whiskers, upper and lower 90% inclusion limits.

A positive relationship was found between temperature and passage rates in the spring diurnal (raptor) migrants (Figure 16). The passage rates were the highest on warmer days with temperatures between 6 – 10 °C but diurnal migrant numbers decreased between 11 – 15 °C. On clear days, with a cloud cover between 0-25%, diurnal migrants were observed flying at higher passage rates. As cloud cover increased, migratory flux decreased. Raptors also flew in higher numbers when the wind was blowing from the west, or between angles of 236.26° - 315°. In the diurnal fall migration, raptors flew at lower pressures; their numbers being the highest between 93 – 94 kPa. As pressure increased, migratory flux decreased. As was common in the spring passage rates were the highest when clouds covered 0 – 25% of the sky. As cloud cover increased, passage rates decreased but remarkably less so than in the spring migration. Finally, diurnal migrants in the fall preferred flying at lower wind speeds, favoring wind velocities between 3.75 – 16.5 km/h. As wind speeds increased, raptor passage rates decreased (Figure 17).



**Figure 16-** Passage rates (# birds/hour) as a function of a) temperature ( $^{\circ}\text{C}$ ), b) cloud cover (%) and c) wind direction ( $^{\circ}$  relative to true north) is illustrated for spring diurnal migrants. Sample size is 54. Data covers all three neighboring ridges near Chetwynd, BC. Line in the middle of the box represents median value; box represents the upper and lower quartiles and the whiskers, upper and lower 90% inclusion limits.



**Figure 17** -Passage rates (# birds/hour) as a function of a) pressure (kPa), b) cloud cover (%) and c) wind speed (km/h) is illustrated for fall diurnal migrants. Sample size is 108. Data covers all three neighboring ridges near Chetwynd, BC. Line in the middle of the box represents median value; box represents the upper and lower quartiles and the whiskers, upper and lower 90% inclusion limits.

### **3.5- Discussion**

My results revealed that a combination of pressure, cloud cover and wind speed was able to predict when passage rates were the highest during fall diurnal and nocturnal migration. During spring migration in nocturnal migrants, wind speed alone accounted for most of the variance in passage rates while a combination of cloud cover, temperature and wind direction was the best statistical model.

#### **3.5.1- Nocturnal Migrants**

Wind speed was a common weather variable in our spring and fall passage rate models. In fact, wind speed alone was able to account for the majority of the variance in the spring model. Wind speed is therefore a very important factor when one wishes to predict higher pulses of birds during migration.

It makes sense that higher wind speeds in both spring and fall nocturnal migration are associated with higher passage rates. The higher the wind speed, the greater the tail wind, therefore, lesser energy is spent during flight. The more energy a bird has arriving at its destination, the greater is its capacity at securing prime breeding grounds. Able (1973) found migration was heaviest after the passage of a cold front, which is often marked by strong gusty winds. Richardson (1978) discusses that certain groups of birds such as diurnal migrants prefer to fly on days where the winds are strong and consistent and are oriented in a fashion to produce strong updrafts, as was the case in our spring raptor migrants discussed later on. Soaring hawks and eagles were always seen surfing these updrafts as flapping flight is energetically costly to these larger birds. Some studies have reported a different result. Zehnder *et al.* (2001) reported a decrease in migration intensity with an increase in wind speeds, arguing that stronger winds are inconsistent and therefore not favoured by migrating birds. This can explain the curvilinear trend

present in the wind speed data of my fall nocturnal migrants. When wind speeds became too high (>44 km/h), the air flow became unpredictable and erratic and would not result in prime flying conditions for avian migrants (Zehnder *et al.* 2001). However, Richardson (1978) and Erni *et al.* (2002) support our findings and conclude that stronger tailwinds do tend to increase the number of migrating birds aloft, although this relationship was not as strong as is usually accepted,. There is the obvious presence of a trade-off when it comes to favourable wind conditions. Different species of migrants are expected to be selective of wind conditions to different degrees (Alerstam 1979). In fact, it has been shown that adult birds and migrants having successfully completed a leg of their journey (as opposed to the ones who were delayed by unfavourable winds) will be highly selective of wind conditions in order to ensure the successful arrival at their destination (Alerstam 1978).

Akesson and Hedenstrom (2000) found that birds will choose to depart after resting when the winds were significantly stronger and blowing in the same direction as the direction of travel. The inclusion of wind as a possible predictor of higher passage rates is an important parameter, but should typically not be considered on its own. For example, birds who are delayed on their migratory journey will depart irrespective of wind conditions as the urgency to arrive at their destination increases (Akesson and Hedenstrom 2000).

Another significant variable that predicted avian passage rates in fall nocturnal migrants was barometric pressure. Falling or rising barometric pressure is an index of the approaching or departing low pressure systems. Low pressure systems across North America are particularly important to migrating birds (Able 1973, Richardson 1978, Erni *et al.* 2002, Able 2004, Mara *et al.* 2005, Gordo 2007). These large pressure systems are

composed of cold and warm air masses that circulate around a low pressure area usually located in the centre of the system (Skinner *et al.* 1999, Whiteman 2000). They usually travel from west to east with winds blowing counter-clockwise around the low pressure area in the Northern Hemisphere. In the system, when the warm air masses overtake the colder air masses, a warm front is created. In this instance, the cold denser air pushes the warm air upwards, is cooled and forms cloud and often precipitation (Skinner *et al.* 1999, Whiteman 2000). On the other hand, when the cold air masses overtake the warmer air masses, a cold front is created. The dense cold air wedges itself under the warm air, abruptly pushes it upwards, cools it faster and often creates heavy precipitation and thunderstorms (Skinner *et al.* 1999, Whiteman 2000). In the fall, southbound birds take flight after the passage of a cold front, when the skies are clear and the north winds provide an adequate tail wind (Able 2004). In this case, pulses of migrants will be detected after the passage of a low pressure system and before a high pressure system. This was the case in my study; passage rates increased with an increase of pressure in fall nocturnal migrants.

Finally, the last parameter that influenced migrant passage rates in the nocturnal fall migrants was cloud cover. Higher pulses of migrants will obviously be detected on clear nights and days. It may be argued that my data set is biased because no surveys were done in extremely low visibility due to the inability of our radars or visual surveys to penetrate fog, rain and snow and therefore, not able to detect bird passages. However, my data reflect variation in cloud cover during conditions when I had confidence in detecting migrants. Able (2004) reported that birds use the stars as a navigational aid. On clear nights, stars are more visible to birds and shorter flight time resulting from excellent

navigation would therefore be expected. Clear days also aid in the warming of the topography and the formation of thermals and updrafts (Whiteman 2000). Diurnal migrants would take full advantage of these prime flying conditions, especially along linear topographical features, such as ridge edges, when the wind direction is perpendicular. As cloud cover increases and descends in altitude, birds are forced to decrease their flight altitude in order to avoid flying “blind”; it is in these instances that they are prone to collision with wind turbines (Case *et al.* 1965, Seets and Bohlen 1977, Elkins 1988, Erickson *et al.* 2001, Johnson *et al.* 2002)

### **3.5.2- Diurnal Migrants**

Diurnal migrants were the lowest flying birds and thus subject to the finer-scale effects of topography on their flight behaviour (see Chapter 2). It is then not surprising that two new variables were added to our significant model in the spring diurnal migrants; temperature and wind direction.

As was discussed previously, Richardson (1978) reported that diurnal migrants prefer to fly on days where the winds are strong and oriented in a fashion to produce strong updrafts. In chapter 2, I have shown that most migrants were concentrated on the south western slopes of the ridges. It is on these slopes that updrafts and thermals are more likely to be formed. Warmer days in the spring, low cloud cover and wind blowing from a westerly direction were perfect conditions for the creation of strong thermals and updrafts in our study ridges.

In the fall diurnal migrants however, pressure, cloud cover and wind speed is again our significant model. Surprisingly, higher pulses of migrants were detected on days with lower barometric pressure as was not the case in the fall nocturnal migrants. Lower

pressure systems are associated with northwesterly/westerly winds (Skinner *et al.* 1999, Whiteman 2000). These are similar to the winds in the spring that were conducive to the formation of thermals the animals used to minimize energy expenditure (Able 2004). Thus, at mild to moderate wind speeds (that are more stable than high gusty winds), under low cloud cover with low barometric pressure (and associated westerly winds), higher pulses of diurnal migrants were detected because of the presence of the superior flying conditions.

Although only five weather parameters were measured, other factors may influence movement, such as dew point and relative humidity. Measures such as dew point and relative humidity were not available on the equipment used in this study. These variables have been documented to favour migration by reducing dehydration (Richardson 1978). Collecting movement data using higher resolution radars or weather radars capable of seeing larger areas, along with weather patterns would also have been interesting as one could have observed avian behaviour on a macro-scale as meteorological conditions change. Future research should aim at determining if birds still fly in bad weather or if they simply choose the safer alternative of waiting out the storm. Our results were, however, consistent with the literature.

### ***3.5.3- Implications for Management***

By understanding these weather parameters and the interaction of these parameters, wind farm proponents can help mitigate negative impacts wind installations might have on migrating aerial wildlife during their northward or southward journeys. With a careful study of migration timing over a proposed wind farm site along with predictive modelling studies such as mine, one can predict when pulses of migrants are likely to occur and

collision risks are higher, as certain weather patterns are likely to put more birds at risk. For example, after considering our results, a wind farm proponent might choose to idle some of his turbines located in regions of higher activity (where the probability of a bird flying over the site is high – see chapter 2) during a migration pulse. Therefore, in the spring, during peak migration and when wind speeds are increasing with clearing skies and warming temperatures, it may be strategic to idle problematic turbines in order to mitigate any potential collision risk. In the fall, during peak migration and when a low pressure system is either coming or leaving (increasing or decreasing barometric pressure) with moderately high winds and clearer skies, the same mitigation strategy could apply. If idling is not an option, a wind farm proponent could choose to concentrate their carcass search efforts immediately after the occurrence of weather associated with high passage rates to determine whether birds are colliding with the turbines.

## CHAPTER 4: GENERAL DISCUSSION

As hypothesized, avian movement patterns are influenced by abiotic factors such as weather (wind speed, pressure, cloud cover and temperature) and topography (thermals, updrafts and higher wind speeds resulting from landscape features).

### 4.1- Movement Patterns and Topography

In chapter 2, I showed that birds were predictably concentrated over areas that offered favorable wind conditions, such as thermals, updrafts and higher wind speeds, on either side of linear features of the topography (such as ridges). The birds are not necessarily directly reacting to the topography they are flying over, but most likely to the winds that are influenced and created by the topography (Gill 1993, Whiteman 2000, Barrios and Rodrigues 2004, Hoover and Morrison 2005).

Birds rarely crossed the ridges (10.6% of total birds at Wartenbe, 7.9% of birds at North Dokie and 21% at South Dokie). Most nocturnal migrants detected crossing the ridges were flying above turbine height, reducing the danger of collision. Diurnally migrating raptors presented the greatest risk of collisions when crossing ridges, but such occurrences were uncommon or absent on these three ridges. When raptor crosses do occur, they tend to be in narrowly defined areas of the ridge, thus lending themselves to mitigation planning.

My study presented a valuable methodology to assess where possible zones of conflict exist by mapping any crosses over linear features (top of ridge, turbine location, etc.). This ability to predict and investigate what portions of the topography the birds are utilizing during migration can help wind farm proponents strategically place their wind turbines in order to mitigate potential negative impacts, or at least be alerted to where

migrant corridors are concentrated. Continuing this work during post-construction could further illuminate the patterns by determining whether birds continue to use these same corridors, or shift corridors to avoid individual turbines (Desholm and Kahlert 2005, Desholm *et al.* 2006). If horizontal detours are not noted, focusing on whether migrants adjust heights to fly above turbines should be conducted. Finally, determining the extent of such detours and potential energetic expenditure on migrants would be useful in understanding indirect impacts of wind installations on birds.

## **4.2- Movement Patterns and Weather**

In chapter 3, I showed that the passage rates (expressed as the number of birds per hour) were mostly influenced by a combination of pressure, wind speed and cloud cover (wind speed alone being the only factor in spring nocturnal migrants and wind direction and temperature being thrown into the mix in spring diurnal migrants). Higher avian passages were detected on clear nights and days with increased wind speeds.

Coupling the information provided by the findings in chapter 3 to the findings in chapter 2 allows a wind farm proponent to minimize overall turbine downtime during peak migration periods. Spatial (Chapter 2) and temporal studies (Pomeroy *et al.* 2007) can help predict when and where birds are more likely to fly through the area during migration. By adding the weather modeling data (Chapter 3), a wind farm proponent could target specific times of the year, specific turbines to idle (or carcass search) under specific weather conditions. This could effectively mitigate or more accurately document the potential for adverse effects a wind farm might have on aerial wildlife.

### **4.3- Wind as a Selective Agent**

One of the most intriguing findings of this research project was that wind direction influenced movement patterns in chapter 2 but did not seem to be as strong a factor in chapter 3. This observation can be explained by lateral wind drift that aerial wildlife experience during flight.

Migration is a task that involves a destination, a route and a period of time. Birds have in fact a specific time window they need to respect in order to secure prime breeding or wintering grounds (Liechti 2006). To achieve this task, birds need to be able to fly efficiently through highly dynamic airspace, a simple task that becomes rather complex when you consider they need to navigate while at the same time, ration the energy available on their journey.

Winds are often unpredictable and out of the birds' control. If they wait for favorable wind conditions, they may never reach their destination. Birds try to avoid wind drift, but when that is not feasible, they need to compensate for wind drift displacement (Liechti 2006). Studies have shown that birds have a large lateral view and fixate distant ground objects (Güntürkün 2000). This would allow birds to estimate wind displacements quickly by considering the difference in the motion of objects to the left and right of their field of view (Liechti 2006). Having this ability would allow a bird to estimate its ground speed relative to the wind speed and make any necessary angular adjustments in order to reach its destination. Being able to accurately modify flight behavior under specific wind conditions allows a bird to reduce the flight cost considerably. Therefore, in theory, under strong ( $> 6 \text{ m/s}$ ) wind conditions (often present at our wind farm sites) birds should have to compensate for lateral wind drift more than when under weaker wind conditions (Liechti 2006). This phenomenon allows a bird to save energy by choosing to drift in

unfavorable wind direction conditions (by not correcting for lateral wind drift) to then bring the necessary navigational adjustments (or angular corrections) when the winds are predominately weaker.

It is then not surprising that bird movement patterns (mean flight vectors) are either positively (increase in wind direction results in an increase in flight bearing) or negatively (increase in wind direction results in a decrease in flight bearing) correlated to wind direction. The birds aloft were either exposed to stronger or weaker winds and either compensated or not for lateral wind drift to minimize energy expenditure. If flight direction is molded by wind direction as the birds have the ability to correct for any consequence of unfavorable wind direction, then one would expect that this factor is not a strong predictor of avian passage rates. The birds will fly under unfavorable wind directions when time is a concern.

#### **4.4- Conclusion**

It would be interesting to take this one step further. Do these movement patterns change after the turbines have been erected? Do the birds exhibit avoidance behavior as has been documented at offshore wind farm sites by Desholm and Kahlert (2005) and Desholm *et al.* (2006)? Acquiring both the pre- and post-construction aerial wildlife movement data would yield greater insight in their behavior around wind farm sites and the subsequent risk to which they are exposed.

## LITERATURE CITED

- Able, K.P. 2004. **Birds on the move: flight and migration.** Handbook of Bird Biology, second edition. Princeton University Press pp: 5.1-5.100.
- Able, K.P. 1973. **The role of weather variables and flight direction in determining the magnitude of nocturnal bird migration.** Ecology. 54: 1031-1041.
- Akesson, S. and Hendenstrom, A. 2000. **Wind selectivity of migratory flight departures in birds.** Behavioral Ecology and Sociobiology. 47: 140-144.
- Alerstam, T. 1979. **Wind as a selective agent in bird migration.** Ornis Scandinavica. 10: 76-93.
- Alerstam, Thomas. 1990. **Bird Migration.** Oxford. Oxford University Press 420 pp.
- Anderson, D.R., Burnham, K.P. and Thompson, W.L. 2000. **Null hypothesis testing: problems, prevalence and an alternative.** Journal of Wildlife Management. 64: 912-923.
- AXYS Environmental Consulting Ltd. 2006. **Dokie wind energy project – technical assessment report: biophysical environment for the Dokie wind project.** Report prepared for Dokie Wind Energy. Calgary, Alberta. January 2006.
- Balcomb, R. 1977. **The grouping of nocturnal passerine migrants.** The Auk. 94: 479–488.
- Ball, S.C. 1952. **Fall migration on the Gaspe peninsula.** Peabody Museum Natural History Bulletin. 7: 1–211.
- Barrios, L and Rodrigues, A. 2004. **Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines.** Journal of Applied Ecology. 41: 72-81.
- Beason, R.C. 1978. **The influences of weather and topography on water bird migration in the southwestern United States.** Oecologia. 32: 153-169.

- Betke, M., Hirsh, D.E., Makris, N.C., McCracken, G.F., Procopio, M., Hristov, N.I., Teng, S., Bacchi, A., Reichard, J.D., Horn, J.W., Crampton, S., Cleveland, C. J. and Kunz, T.H. 2008. **Thermal imaging reveals significantly smaller Brazilian free-tailed bat colonies than previously estimated.** Journal of Mammalogy. 89: in press.
- Bigger, D., Peery, M.Z., Chinnici, S. and Courteney, S.P. 2006. **Efficacy of audiovisual and radar surveys for studying marbled murrelets in inland habitats.** Journal of Wildlife Management. 70: 505-516.
- BirdLife International. 2003. **Wind farms and birds: an analysis of the effects of wind farms on birds and guidance on environmental assessment criteria and site selection issues.** Stasbourg: RSPB/BirdLife. 58 pages.
- Bruderer, B. 2003. **The radar window to bird migration.** In: Avian Migration. Berlin, Heidelberg: Springer-Verlag. Pp: 347-358.
- Bruderer, B. 1997. **The study of bird migration by radar.** Naturwissenschaften. 84: 45-54.
- Burger, A.E. 2001. **Conservation assessment of marbled murrelets in British Columbia, part 1: biological review.** Report to the Marbled Murrelet Recovery Team and Min. Environ., Lands and Parks. Victoria, BC.
- Burnham, K.P. and Anderson, D.R. 2004. **Multimodel inference: understanding AIC and BIC in model selection.** Sociological Methods and Research. 33: 261-304.
- CanWEA website, visited on February 27<sup>th</sup>, 2006 @ URL <http://www.canwea.ca/en/>
- Case, L.D., Cruickshank, H., Ellis, A.E. and White, W.F. 1965. **Weather causes heavy bird mortality.** Florida Naturalist. 38: 29-30.
- Cooper, B.A., Day, R.H., Ritchie, R.J. and Cranor, C.L. 2001a. **An improved marine radar system for studies of bird migration.** Journal of Field Ornithology. 62: 367-377.
- Cooper, B.A., Raphael, M.G. and Evans Mack, D. 2001b. **Radar-based monitoring of marbled murrelets.** Condor 103: 219-229.

- Cooper, B.A. 1995. **Use of radar for wind power-related avian research.** National Avian-Wind Power Planning Meeting Proceedings. 15 p.
- Desholm, M., Fox, A.D., Beasley, P.D.L. and Kahlert, J. 2006. **Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review.** *Ibis.* 148: 76-89.
- Desholm, M. and Kahlert, J. 2005. **Avian collision risk at an offshore wind farm.** *Biology Letters.* 1: 296-298.
- Diehl, R.H., Larkin, R.P. and Black, J.E. 2003. **Radar observations of bird migration over the Great Lakes.** *The Auk.* 120: 278-290.
- Drewitt, A.L. and Langston, R.H.W. 2006. **Assessing the impacts of wind farms on birds.** *Ibis.* 148: 29-42.
- Dunn, E.H., Hussell, D.J.T. and Adams, R.J. 1997. **Monitoring songbird population change with autumn mist netting.** *Journal of Wildlife Management.* 61: 389-396.
- Eastwood, E. 1967. **Radar Ornithology.** Methuen, London, U.K. 278 p.
- Elkins, N. 1988. **Weather and Bird Behaviour.** Second Edition. Staffordshire, England. 239 pp.
- Erickson, W.P., Good, R.E., Johnson, G.D., Sernka, K.J., Strickland, M.D., and Young Jr., D.P. 2001. **Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of avian collision mortality in the United States.** National Wind Coordinating Committee Resource Document. 67 pages.
- Erni, B., Liechti, F., Underhill, L.G. and Bruderer, B. 2002. **Wind and rain govern the intensity of nocturnal bird migration in central Europe – a log-linear regression analysis.** *Ardea.* 90: 155-166.
- Everaert, J. and Stienen, E.W.M. 2007. **Impact of wind turbines on birds in Zeebrugge (Belgium): significant effect on breeding tern colony due to collisions.** *Biodiversity Conservation.* 16: 3345-3359.

- Farnsworth, A. 2005. **Flight calls and their value for future ornithological studies and conservation research.** The Auk. 122: 733–746.
- Figueroa, H. 2007. **XBAT**, ver. 5. Bioacoustic Research Program – Cornell Laboratory of Ornithology. Ithaca, New York, U.S.A.
- GAO. September 2005. **Wind power: impacts on wildlife and government for regulating development and protecting wildlife.** A Report to Congressional Requesters: 59 pages.
- Gauthreaux, S. A., Jr. 1969. **A portable ceilometer technique for studying low level nocturnal migration.** Journal of Field Ornithology. 40: 309–319.
- Gauthreaux, S.A. and Belser, C.G. 1998. **Displays of bird movements on the WSR-88D: patterns and quantification.** Weather and Forecasting. 13: 453-464.
- Gauthreaux, S.A., Jr., and Belser, C.G. 2003. **Radar ornithology and biological conservation.** The Auk 120: 266–277.
- Gill, F.B. 2006. **Ornithology.** 3<sup>rd</sup> Edition. New York: W.H. Freeman & Co. 720 pp.
- Gordo, O. 2007. **Why are birds migration dates shifting? A review of weather and climate effects on avian migratory phenology.** Climate Research. 35: 37-58.
- Graber, R.R. and Cochran, W.W. 1959. **An audio technique for the study of nocturnal migration of birds.** The Wilson Bulletin. 71: 220–236.
- Güntürkün, O. 2000. **Sensory physiology: vision.** In: Sturkie's Avian Physiology. San Diego, California: Academic Press. Pp: 1–14.
- Guthery, F.S., Brennan, L.A., Petersen, M.J., and Lusk, J.J. 2005. **Information theory in wildlife science: critique and viewpoint.** Journal of Wildlife Management. 69: 457-465.
- Harmata, A.R., Podruzny, K.M., Zelenak, J.R. and Morrison, M.L. 1999. **Using marine surveillance radar to study bird movements and impact assessment.** Wildlife Society Bulletin. 27: 44–52.

- Hoover, S.L. and Morrison, M.L. 2005. **Behavior of red-tailed hawks in a wind turbine development.** Journal of Wildlife Management. 69: 150-159.
- Hüppop, O., Dierschke, J., Exo, K.-M., Fredrich, E. and Hill, R. 2006. **Bird migration studies and potential collision risk with offshore wind turbines.** Ibis. 148: 90-109.
- Johnson, G.D., Erickson, W.P., Strickland, M.F., Shepherd, D.A., Shepherd, S.A. and Sarappo, S.A. 2002. **Collision mortality of local and migrant birds at a large-scale wind-power development on Buffalo Ridge, Minnesota.** Wildlife Society Bulletin. 30: 879-887.
- Kingsley, A. and Whittam, B. 2005. **Wind turbines and birds: a background review for environmental assessment.** Gatineau, Quebec: Environment Canada/ Canadian Wildlife Service.
- Kingsley, A. and Whittam, B. 2001. **Potential impacts of wind turbines on birds at North Cape, Prince Edward Island.** Sackville, New Brunswick: Bird Studies Canada.
- Kovach, W.L. 2006. **Orianna – circular statistics for windows**, ver. 2. Kovach Computing Services, Pentraeth, Wales, U.K.
- Kunz, T.H., Arnett, E.B., Cooper, B.M., Erickson, W.P., Larkin, R.P., Mabee, T., Morrison, M.L., Strickland, M.D. and Szewczak, J.M. 2007. **Assessing impacts of wind-energy development on nocturnally active birds and bats: a guidance document.** Journal of Wildlife Management. 71: 2449-2486.
- Kuvlesky, W.P.Jr, Brennan, L.A., Morrison, M.L., Boydston, K.K., Ballard, B.M. and Bryant, F.C. 2007. **Wind energy development and wildlife conservation: challenges and opportunities.** Journal of Wildlife Management. 71: 2487-2498.
- Libby, O.G. 1899. **The nocturnal flight of migrating birds.** The Auk. 14: 40–146.
- Liechti, F. 2006. **Birds: blowin' by the wind?** Journal of Ornithology. 147: 202-211.
- Long, J.S. and Freese, J. 2006. **Regression models for categorically dependent variables using Stata.** Second Edition. College Station, TX: Stata Press.

- Lowery, G. H. 1951. **A Quantitative Study of the Nocturnal Migration of Birds.** Museum of Natural History, University of Kansas Publications. 3: 361–472.
- Mabee, T.J., Plissner, J.H., Cooper, B.A. and Barna, J.B.. 2006. **A radar and visual study of nocturnal bird and bat migration at the proposed Clinton county windparks, New York, spring and fall 2005.** Unpublished report prepared for Ecology and Environment, Inc., Lancaster, NY, and Noble Environmental Power LLC, Chester, Connecticut, USA. ABR, ForestGrove, Oregon, USA. Available at <http://www.noblepower.com/our-projects/clinton/documents/NEP-ClintonDEIS-SecF-Avian-Appendices72-Q.pdf>.
- Mabee, T.J., Cooper, B.A., Plissner, J.H., Young, D.P. 2006. **Nocturnal bird migration over an Appalachian ridge at a proposed wind power project.** Wildlife Society Bulletin. 34: 682-690.
- Mabee, T. J., and Cooper, B.A. 2004. **Nocturnal bird migration in northeastern Oregon and southeastern Washington.** Northwestern Naturalist. 85: 39–47.
- Manley, I. 2006. **Inventory methods for marbled murrelet radar surveys.** Report prepared for the Ecosystem Branch of the Ministry of Environment for the Resources Information Standards Committee. Standards for Components of British Columbia's Biodiversity No. 10a.
- Mardia, K.V. and Jupp, P.E. 2000. **Statistics of directional data.** Chichester, John Wiley. pp: 429.
- Marra, P.P., Francis, C.M., Mulvihill, R.S. and Moore, F.R. 2005. **The influence of climate on the timing and rate of spring bird migration.** Oecologia. 142: 307-315.
- NWCC (National Wind Coordinating Committee). 2004. **Wind turbine interactions with birds and bats: a summary of research results and remaining questions.** National Wind Coordinating Committee. November 2004. Available at [www.nationalwind.org](http://www.nationalwind.org).
- Pidwirny, M. 2006. **Local and regional wind systems.** Fundamentals of Physical Geography, 2nd Edition. Viewed on September 1<sup>st</sup> 2008. Available at <http://www.physicalgeography.net/fundamentals/7o.html>.

- Pomeroy, A.C., Thomas, P., Morcos, C., Labrosse, A., Preston, J., Bryden, C., d'Entremont, M. and Otter, K. 2007. **Wildlife monitoring report 2007 – Dokie and Wartenbe wind energy projects.** Technical Data Report for EarthFirst Canada Inc. Jacques-Whitford/AXYS Ltd., Burnaby, BC and the Center for Wind Energy and the Environment, University of Northern British Columbia. pp. 72.
- Richardson, John W. 1978. **Timing and amount of bird migration in relation to weather: a review.** Oikos. 30: 224-272.
- Russell, RW. 1991. **Nocturnal flight by migrant “diurnal” raptors.** Journal of Field Ornithology. 62: 505-508.
- Schmaljohann, H., Liechti, F., Bachler, E., Steuri, T, and Bruderer, B. 2008. **Quantification of bird migration by radar- a detection probability problem.** Ibis. 150: 342-355.
- Seets, J.W. and Bohlen, H.D. 1977. **Comparative mortality of birds at television towers in central Illinois.** Wilson Bulletin. 89: 422-433.
- Skinner, B.J., Porter, S.C. and Botkin, D.B. 1999. **The blue planet: an introduction to Earth system science.** Second Edition. John Wiley and Sons, Inc. pp: 551.
- Thake, M.A. 1981. **Calling by nocturnal migrants: a device for improving orientation?** Vogelwarte. 31: 111.
- Thomas, R. 1999. **An assessment of the impact of wind turbines on birds at ten windfarm sites in the UK.** University College London, UK: Sustainable Development International. 6 pages.
- Tingley, M.W. 2003. **Effects of offshore wind farms on birds: “cuisinarts of the sky” or just tilting at windmills?** (Bachelors thesis, Harvard University). 122 pages.
- Vaughn, C. R. 1985. **Birds and insects as radar targets: a review.** Proceedings of the Institute of Electrical and Electronics Engineers 3: 205–227.
- Whiteman, D.C. 2000. **Mountain meteorology: fundamentals and applications.** Oxford University Press, Inc. pp: 354.

## Literature Cited

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Williams, T.C., Williams, J.M., Williams, P.G. and Stokstad, P. 2001. **Bird migration through a mountain pass studied with high resolution radar, ceilometers and census.** The Auk. 118: 389-404.

Young, Jr D.P., Erickson, W.P., Strickland, M.D., Good, R.E. and Sernka, K.J. 2003. **Comparison of avian responses to UV-light-reflective paint on wind turbines.** Subcontractor report- National Renewable Energy Laboratory. 67 pages.

Zehnder, S., Akesson, S., Liechti, F. and Bruderer, B. 2001. **Nocturnal autumn bird migration at Falsterbo, south Sweden.** Journal of Avian Biology. 32: 239-248.