

# **TECHNICAL REPORT SERIES**

NO 1 - MAY 2014

# AVIAN MOVEMENT AT THE DOKIE I WIND ENERGY PROJECT 2008-2012: ANALYSIS OF POTENTIAL CONFLICT BETWEEN WIND DEVELOPMENT AND AVIAN MIGRATION IN THE NORTHERN ROCKY MOUNTAINS

By

KEN A. OTTER, M. ISOBEL HARTLEY, MARC D'ENTREMONT, NAIRA N. JOHNSTON, JAMES BRADLEY, DUSTIN WALSH, MEGAN WILLIE\* & ANDREA C. POMEROY This technical report is based on research conducted between 2007 to 2012 under industry/academic/government partnership grants investigating wind development in the south Peace Region of northeastern British Columbia.

Dr. Otter is a Professor in the Ecosystem Science and Management Program, University of Northern British Columbia and a member of the NRES Institute. Marc d'Entremont is a PhD candidate and Naira Johnston an MSc recipient and research associated with the NRES Graduate Program, University of Northern British Columbia. Isobel Hartley and James Bradley were research associates at the University of Northern British Columbia. Dustin Walsh completed a BSc in Wildlife & Fisheries, University of Northern British Columbia. Dr. Andrea Pomeroy completed a NSERC Industrial Research & Development Fellowship with Stantec/UNBC, and she and Megan Willie are with Stantec Consulting Ltd., Burnaby BC .

The correct citation for this paper is: Otter, K.A., Hartley, M.I., d'Entremont, M., Johnston, N.N., Walsh, D, Bradley, J., Willie M., & Pomeroy, A.C. 2014. Avian Movement at the Dokie 1 Wind Energy Project 2008-2012: analysis of potential conflict between wind development and avian migration in the northern Rocky Mountains. Natural Resources & Environmental Studies Institute (NRESi) Technical Report #1. University of Northern British Columbia. Prince George, B.C., Canada.

This paper can be downloaded without charge from http://www.unbc.ca/nres-institute/publication-series



The Natural Resources and Environmental Studies Institute (NRES Institute) is a formal association of UNBC faculty and affiliates that promotes integrative research to address natural resource systems and human uses of the environment, including issues pertinent to northern regions.

Founded on and governed by the strengths of its members, the NRES Institute creates collaborative opportunities for researchers to work on complex problems and disseminate results. The NRES Institute serves to extend associations among researchers, resource managers, representatives of governments and industry, communities, and First Nations. These alliances are necessary to integrate research into management, and to keep research relevant and applicable to problems that require innovative solutions.

For more information about NRESI contact:

Natural Resources and Environmental Studies Institute University of Northern British Columbia 3333 University Way Prince George, BC Canada V2N 429

Email: nresi@unbc.ca URL: www.unbc.ca/nres-institute

## CONTENTS

Executive Summary	2
Background and Objectives	4
History of the project, Study Site and Objectives	4
Background of Primary Concerns and comparisons with other similar studies.	4
Methodology	6
Diurnal Migration – Golden Eagle Surveys	6
Nocturnal Migration - Radar and Night Vision Surveys	9
Radar	9
Movement patterns of migrants	12
Golden Eagle Migration	12
Pre-construction eagle movement patterns	12
Pre- vs post-construction eagle movement patterns	12
Recorded eagle collisions during post-construction	16
Conclusions for Eagle Collision Risk	16
Nocturnal Migration	17
Passage Rates – Horizontally-tracking radars	17
Mortality estimates of tracked migrant cohort	20
Heights of Migrants – Vertical Radar	20
Cumulative Mortality Modelling	23
Discussion and recommendations	27
Eagles	27
Nocturnal Migration	30
Literature Cited	32
Acknowledgements	35

### **Executive Summary**

As part of an industry/academic/Canadian Wildlife Service partnership to assess the effects of wind energy development on avian movement patterns and collision risk, we used visual observations and radars to track the avian migrants at the Dokie I Wind Energy Project from 2008 to 2012.

This constituted a before-after-control-impact (BACI) design to determine the preconstruction movement patterns and passage rates (2008-2009), and whether changes occurred in these patterns during either the construction phase (2010) and/or postconstruction operational phases (2011 & 2012) of the wind facility.

One of the critical focal impact groups determined from early site monitoring in 2006-2007 was a large golden eagle migration corridor through the region. The second focal group was the large passage rates of nocturnal migrants detected during the peak periods associated with passerine and bat migrations.

Sampling was conducted in both spring and fall migration periods for both groups. This constituted mid to late March (Spring) and late Sept to late Oct (Fall) for golden eagles, and mid to late May (Spring) and late Aug to early Sept (Fall) for nocturnal migrants. Eagles were sampled by visual observations and tracks recreated in ArcGIS software for analysis. Nocturnal migrants were detected using marine radars and tracks automatically extracted using avian tracking software (radR) consolidated with **R**-software and into individual tracks.

Golden eagle passage rates were highest in the fall migration, and were concentrated on the

southern aspects of Johnson Col - the smaller of the two ridgelines in the development. This appears to be associated with the predominant locations of updrafts the birds use to gain lift during migration, which are concentrated on the steep southwestern facing slopes of Johnson Col. Passage was highest under cross-wind conditions that likely created good conditions of orographic lift. Heights at which the birds crossed the ridgeline during preconstruction tended to be lower under headwind conditions, putting the birds into greater potential conflict with heights of turbines. However, during post-construction monitoring, there was no evidence for changes in passage rates through the site, suggesting little evidence of displacement. Further, eagles adjusted the heights at which they crossed the ridgeline during post-construction, so as to use the airspace above the turbines. This suggests that the birds were detecting and avoiding the turbines during the operational phase. This also matches data from carcass searching that detected no collisions involving raptor species the two years of post-construction in monitoring.

Nocturnal migrant passage rates were significantly higher in the spring than fall migration. During the fall, up to 50,000 tracks were detected on overnight radar samples. Passage rates were high in the vertical airspace between 0-900m agl (above ground level), particularly in the 0-600m agl heights. We did not, however, detect differences between passages rates or heights of migrants during the pre- vs post-construction years, suggesting little evidence of displacement away from the Very low collision rates were detected site. during the post-construction periods when the cohort of migrants were tracked, resulting in a detected mortality rate below 0.005%.

Cumulative impacts on nocturnal migrants were forecast in light of the amount of wind development proposed for the lower Peace region in northeastern British Columbia. These proposed facilities are sequentially aligned along the migratory axis in the region. We tested the impact of both increasing and decreasing mortality rates against up to 15 hypothetical facilities that a single cohort of migrants would have to traverse. Even under exponential increases of 25% in mortality rates with each successive installation, the overall forecast mortality rates of the cohort remained below 1%.

Notably, two thirds of the collisions that were detected at the Dokie I Wind Energy Project

were bat species. While the rates of bat mortality at this facility are very low relative to other reported sites, cumulative mortality of bats should be assessed with other wind development sites in the same migratory corridors of the larger Peace region. In addition, pre- vs post-construction monitoring on *both* passage rates and carcass searching should be applied with each new installation in this migratory corridor, as was conducted in the current study, so as to determine whether mortality rates are increasing, decreasing or stable between facilities. From this data, the true cumulative impact of wind development on bird/bat species can be better deduced for the region.

### **Background and Objectives**

# *History of the project, Study Site and Objectives*

In 2005/2006, a partnership was formed between researchers at UNBC, industry and the Canadian Wildlife Service to address the issue of bird mortality rates with the expansion of wind energy in British Wind energy development in Columbia. Canada at the time was growing rapidly, but still encountered concerns over the potential for conflict with migratory bird populations (GAO 2005; Kingsley & Whittam 2007). Of major concern within this report was the lack of detailed study on whether ridgelines concentrated migratory populations and the effect of weather and other variables on the heights of migrants. On-shore wind development in British Columbia is largely focused on ridgeline installations, but as such installations were uncommon in Canada at the time and few studies from other jurisdictions in North America had associated research, the research partnership was established to address these issues. Our work became focused from 2007 onwards at the site of the Dokie I Wind Energy Project operated by the Dokie General Partnership, Alterra Power Corp, situated in the southern Peace region of northeastern BC (55°48'26.90"N, 122°11'33.21"W). The project consists of a 144 MW wind installation consisting of 48 3M wind turbines distributed over two neighbouring ridgelines - Johnson Ridge (33 turbines) and Johnson Col (15 turbines). The site is situated southwest of Moberly Lake within the traditional territories of the West Moberly First Nation, and approximately 37 km NW of the town of Chetwynd, BC.

Our objective on the project was to document the passage rates and behaviours of avian migrants through the site during the prethrough post-construction phases of the project. We had two primary focuses, based on groups identified in the early analysis as constituting the highest concern for aerial migrants – golden eagles (*Aquila chrysaetos*), which have a concentrated migration corridor traversing the eastern foothills of the Rocky Mountains (McIntyre et al. 2008), and nocturnal migrants (passerines/bats) which early radar surveys suggested to be prolific in the region.

# Background of Primary Concerns and comparisons with other similar studies.

Wind energy is currently viewed as a viable means of sustainable and clean energy production, and electricity generation from wind has exponentially increased within the last few decades (Kikuchi 2008). European nations are among the leaders in wind energy development, with some nations already achieving more than 20% of their power generation from wind energy.

However, wind energy development has not occurred without controversy (Drewitt & Langston 2006; Kuvlesky et al. 2007). One of the earliest large-scale wind facilities -Altamont Pass. California – has had significant problems with avian collisions, particularly with raptors wintering in the region, and these continue into the past decade (Thelander et al. 2003; Smallwood & Thelander 2005). Further, significant mortality rates on other raptor species are known from wind energy installations worldwide - for example griffon vultures in Spain (de Lucas et al. 2007; de Lucas et al. 2008; Carrete et al. 2009, 2012) and whitetailed sea eagles in Norway (Dahl et al. 2013).

Near-shore installations situated between seabird breeding colonies and foraging sites have also resulted in pronounced fatality rates for tern species (Everaert & Stienen 2007). Bats have emerged as one of the highest atrisk groups (Barclay et al. 2007; Kunz et al. 2007a & b; Arnett et al. 2008) due to the structure of their respiratory system making them highly susceptible to barotrauma sudden expansion and bursting of blood capillaries in the lungs caused when flying through the negative pressure zone created by a moving turbine blade (Baerwald et al. 2008). Other research has found evidence of detection and avoidance of constructed wind facilities (Desholm & Kahlert 2005; Desholm et al. 2006), but while this might decrease collision risk it may also alter spatial movement patterns and preclude birds gaining access to required resources, or increase energetic expenditures by causing alterations to preferred migration routes (Fox et al. 2006; Kuvlesky et al. 2007).

Recent studies have estimated mortality rates of passerines and other nocturnally-migrating species from wind farm collisions are likely a small fraction of overall population sizes (Loss et al. 2013; Zimmerling et al. 2013), and less significant than losses from other sources (Calvert et al. 2013). Never-the-less, detailed studies on how wind energy facilities affect flight paths of nocturnal migrants are still lacking (Kuvlesky et al. 2007), especially with respect to whether construction alters passage rates or flight altitude of migrants.

Our studies focused on determining the micropatterns of movement of diurnal and nocturnal migrants around the Dokie I Wind Energy Project starting with pre-construction patterns and employing the same tracking techniques through post-construction analysis (Kuvlesky et al. 2007). The research is divided into two monitoring themes – visual-tracking of migration patterns of Golden Eagles, and radar-tracking of migration patterns of nocturnal migrants. We use this dataset to report not only on the potential impacts of the Dokie I Wind Energy Project, but also to model the potential cumulative impact on larger wind energy development within the region.

### Methodology

Monitoring at the North Dokie study site began in 2008 with spring nocturnal surveys using radars, and continued through 2012 to fall nocturnal surveys. Spring 2008 eagle migration was conducted in early April of 2008 under the direction of our partner agency, Stantec Consulting Ltd., but was subsequently determined to likely have missed the peak pulse of migration, and so will not be included in the reporting framework.

We conducted migration monitoring in four periods each year - diurnal migration golden eagles involving was typically conducted from mid-March to early April (spring eagle migration) and again in late Sept through Oct (fall eagle migration). Nocturnal migration involving passerines and other night-flying migrants was conducted during mid-May to early June (spring nocturnal migration) and mid-Aug to early Sept (fall These periods were nocturnal migration). used as they coincided with peak periods of movement for target groups, as determined from pilot surveys at the site coordinated by Stantec Consulting in 2006 and 2007.

Construction on the site started with road access in spring 2008, with roads and pads completed in that year. The first turbine towers were erected in fall 2008, and three widely-spaced standing turbines on Johnson Col and two turbines on the opposite ends of Johnson Ridge were completed but not operational by summer of 2009 (Fig. 1). At this point, construction on the installation was halted as the parent company changed hands. Alterra Power Corp. resumed construction activities in the summer of 2010, with the entire 44 turbine site completed by Nov 2010, but not fully operational until Feb. 2011. Thus, our survey periods noted above placed 2008 and 2009 under categories of preoperational, early construction phase, which we will categorize as Pre-construction for analytical purposes. 2010 was a bridging year with heavy construction, but a pre-operational period for nocturnal surveys and spring eagle migration, and bordering full construction and early operational testing for fall eagle migration. We classify 2010 as a period of Construction for nocturnal and spring eagle migration, but it has been grouped as Postconstruction for the fall eagle migration analysis due to the advanced state of the facility during this survey period and because early testing of the turbines was conducted within the eagle migration period. All survey periods starting with Spring 2011 eagle migration and thereafter were considered Postconstruction as well, and we continued all surveys through Sept 2012 to have two years of post-construction monitoring for all The Dokie General Partnership datasets. continued eagle migration surveys through fall 2012 but UNBC was not formally involved in this data collection period and the data from that migration will not be included in this report. However, the patterns of migration and responses to turbines of eagles during this period appear to mirror the results of fall 2011 presented below (pers comm).

### Diurnal Migration – Golden Eagle Surveys

We conducted stand-watch surveys using the same pair of observers as in previous years, so as to standardize methods across pre- and post-construction. Starting in Spring 2009, we modified the previous protocols used by Stantec Consulting in 2006-2008, so as to gain a greater coverage of the ridge areas, and to focus most of our survey activity on movement along Johnson Col which had been identified from previous surveys as the area of greatest concentrated eagle movement (Figure 1). Surveys used 2.5 hour watches rotating between three observation locations (JC02, JC12 and JR28), which provided the best unobstructed view of the landscape. The first observation sets started at 9:00, and second at 12:00 each day. As noted above, observations for Spring movement were conducted from mid-March to early April, and Fall movements from late Sept to late Oct - exact dates associated with each year are presented in Table 1. These dates were adjusted slightly pending weather between vears and monitoring of the migration movement being detected at other survey centres. In each

migration period per year, we endeavored to start surveys to coincide with the periods when movement was beginning to be detected, and continued the surveys until there was a noticeable cessation of activity – in this manner we are confident we captured the peak periods of migration between the six Spring/Fall surveys conducted from Spring 2009 through Fall 2011. The differences in length of data spans over which surveys were conducted between Spring and Fall was associated with the fall migration having a much larger number of birds than spring migrations.



Figure 1 – Location of eagle observation sites in relation to turbine strings on Johnson Col and Johnson Ridge at the Dokie I Wind Energy Installation. For eagle observations, we focused on passage over Johnson Col (lower ridge), which both observational studies in 2007-2008 and wind modelling studies (Ainsley et al. 2014) identified as the main area of eagle movement through the region. This appears due to the locations of prevailing updrafts occurring around on the southwestern edge of this ridge (Ainsley et al. 2014). Locations of "proposed turbines" were constructed in 2010, and operational by spring 2011. (from Johnson et al. 2013)

For each raptor detected, the observers sampled repeated points of the bird's movement by taking multiple measures of bearing, inclination and estimated distance from observer along the flight path. Detailed flight path information was collected only on birds that approached within 2km of the survey ridge, and distance estimation was aided by use of visible landmarks. Independent studies in 2010 using radars suggest this technique is accurate to  $\pm$  100m at 1km. Height and path information was deduced by projecting these points into connected 3-D UTMs using ArcGIS and ET-Geowizard. From this data, we were able to identify any tracks that entered within a 100m buffer zone placed around the turbine strings on the ridge, and query the height of these



Figure 2 - Golden Eagle flight tracks through the Dokie 1 Wind Energy Project site during fall 2009 migration separated by migratory experience: a) experienced migrants (individuals with adult and subadult plumage - yellow track lines); and b) inexperienced migrants (juvenile plumage – white track lines). Track lines in black represent birds of unknown age. c) Spring 2010 migration includes only experienced and unknown migrants, as no birds with juvenile plumage were detected during these migrations. (from Johnson et al. 2013)

crosses in relation to the danger of collision risks with turbines (examples of such tracks are shown in Fig. 2). To account for error in distance estimation (which will affect to a lesser degree height estimation), we considered any flights within 150m above ground within rotor swept area.

# Nocturnal Migration - Radar and Night Vision Surveys

#### Radar

Two radars were operated simultaneously – one oriented to sweep in a vertical plane, the other in a horizontal plane. The vertical radar was oriented so that the long axis of the rotation was aligned parallel to the ridgeline – this created a detection zone approximately 3.0km along the ridge (centred on the radar), 500m wide and to a height of 1.5km above the radar. The Horizontal radar was mounted to sweep to 1.5km radius, and angled to increase the above-ground detection. Testing of the detection range of the radar is approximately 600m agl at the 1500m range, and approximately 500m agl as close as 250m range.

Radars were operated with the Russell Technologies Inc digitization box (X1R3000) operated in slave mode, and recorded onto portable hard-drives. Radars were generally operational from 21:00 to 05:00 each night in the spring and 20:00 to 06:00 in the fall (due to shifts in the timing of dusk). Recording dates vary slightly between years, but surveys were timed to coincide with the peak periods of spring migration (mid to late May) and fall migration (late Aug to early Sept) each year – these date ranges were determined from preliminary radar surveys conducted by Stantec Consulting Ltd. in 2006 and 2007. Radars sites were selected near turbines JC03, JC15 and J33 – surveys were conducted for typically 3-4 nights at each location, sequentially across the sampling season, unless we encountered either mechanical problems or heavy precipitation, which precluded sampling for the night.

Recorded radar data was analyzed with radR software (Taylor et al. 2010) utilizing a tested configuration of settings that maximized the correspondence between known and auto-tracked targets (Fig. 3 - d'Entremont et al. submitted). When tested on twenty-nine 15-min periods that were both auto-tracked and hand scored, the correspondence between the two techniques was both extremely strong ( $R^2$ =0.94; intercept= -61.38, slope=1.56) and linear, allowing for a simple correction factor to be applied to the data to correct for auto-tracked vs actual passage rates.

Auto-tracked Target Number = -61.38 + 1.56 (Actual Target Number)

#### therefore,

Actual Target Number = (Auto-tracked Target Number -61.38) / 1.56



Figure 3. The correlation between auto-detected targets from radar recordings using parameter settings in radR described in d'Entremont et al. (submitted). This combination of settings allowed correction factors to be applied to our data to better approximate number of avian targets being tracked.

Insect detections can also influence the ability to track vertebrates. We took advantage of differences in the echo-signatures of insects vs birds, as insect targets typically are smaller, more diffuse targets. By applying a logical filter expression (perim<sup>2</sup>/(area \* (4 \* pi)) <5) which removed targets of irregular and diffuse shape coupled with an intensity filter (targets with low signal return intensity excluded - int >0.3), we assessed the ability of radR to ignore non-avian targets. This was tested by selecting a number of periods where field observations detected high insect abundances, which peak at dusk/dawn on warm nights and drop off sharply in the middle hours of the night, and contrasting these with periods of colder weather in the middle of the night when the majority of detected targets had characteristic avian shape and speed profiles. Application of the filter sharply reduced number of tracked targets in files dominated by insect activity, but had a

significantly lesser effect of reducing targets in files dominated by avian targets. Thus, this logical expression was applied to all datafile processing of the radar data from 2012, as well as all files from 2009-2011 re-processed with these same file parameters.

Finally, we used R statistical software (R core Development vs 3.1.0) to consolidate sequential hits on each target into linear tracks, from which we could calculate total track length and speed, and then also compile this into hourly averages for each night of monitoring. For the vertical radar, this was further summated into total tracks detected into vertical height categories with increasing distance above ground level (agl). We broke these into 300m height bins corresponding to activity patterns in 0-300m agl, 301-600m agl, 601-900m agl, 901-1200m agl, and 1200-1500m agl. Due to the potential difficulties associated with the detection of passerinesized targets beyond 1200m, and the small

Table 1 – Total detections of raptor species across both Spring and Fall migration periods in 2009-2012. Fall Migration in 2008 and 2012 were conducted only on a shortened observation period, and so are not included in this table. This table includes all raptors seen, regardless of their relative position or closest approach to the study ridge.

	20	009	2010		2011		2012
Species	SPRING	FALL	SPRING	FALL	SPRING	FALL	SPRING
	29 Mar- 20 April	13 Sept – 24 Oct	17-28 Mar	1 - 19 Oct	16-30 Mar	20 Sept-	18-30 Mar
Golden Eagle	57	449	118	524	80	471	86
Sharp-shinned Hawk	1	70		12		16	
Northern Harrier	2	19	1	6		1	
Rough-Legged Hawk	3	10		2		7	
Bald Eagle	11	8	5	8	5	5	2
American Kestrel		8				1	
Merlin	3	7	1	3		5	1
Red-Tailed Hawk	1	7		2		4	
Osprey		5					
Northern Goshawk	2	4		1		2	
Cooper's Hawk		3				1	
Gyr Falcon	1	1					
Northern Hawk Owl							1
Buteo sp.		2	1				
Eagle Sp.	2		1			1	1
Accipiter sp.	1			1			
Falco sp.		1					
Unidentified raptor	1	4		1			
Grand Total	85	598	127	560	85	514	91

survey area in the 1200-1500 range of the outer circle of radar image, we analyzed passage data only up to the 901-1200m agl area.

To compare targets/hr detected in the various height categories across both season (spring vs fall) and Operational Phase (Pre-construction vs Construction vs Post-construction), we used Generalized Linear Models with Negative Binomial Distributions. Data from 2008 & 2009 were considered Pre-Construction, 2010 was Construction, and 2011 & 2012 were considered Post-Construction. We then compared the average numbers of birds aloft in each height category individually, controlling for any potential

effect of variation in the total survey volume of the radar image between years as well as the number of hours each night that were surveyed. These were run as continuous predictor variables in the analysis.

#### Movement patterns of migrants

#### Golden Eagle Migration

Golden eagles had the highest numbers of individuals detected on migration than any of the raptor species (Table 1), but even within this species, there were significantly greater numbers of golden eagles migrating in the fall season than the spring season. A sharpshinned hawk migration also appears to be associated with the site, but this fall migration appears to occur earlier in the Sept. period, so our observation dates tended to likely catch only the tail end of this migration. The focus of our research fell upon golden eagles due to abundance relative during their this concentrated migration, and further focused on fall migration as the period of most intense movement.

# Pre-construction eagle movement patterns

Johnson et al. (2013) assessed the general movement patterns of birds during the preconstruction periods starting with fall 2008 data (83 detected eagles in 10 day survey period – not shown in Table 1) and fall 2009 and spring 2009/2010 prior to the main construction period on site. She found hourly passage rates during fall migration peaked at midday and increased by 17% with each 1 km/hr increase in wind speed (Fig. 4) and by 11% with each 1°C increase in temperature. The propensity to cross the ridge-tops where turbines would be built differed between age classes, with juvenile eagles almost twice as likely to traverse the ridge-top area as adults or sub-adults. During fall migration, Golden Eagles were more likely to cross ridges at turbine heights (a risk zone that we defined as crosses of the ridge top area within a 100 wide buffer zone centered on the turbine strings, and which also occurred <150m above ground) under head or tail winds (Fig. 5), but decreased with such high-risk crosses increasing temperature. Conversely, during spring migration, eagles were more likely to move within the ridge-top area under eastern These wind conditions are cross winds. typically associated with very low wind speeds, and it appears they may be using the ridge tops to maintain general altitude or seek out thermals for lift. This data set suggested that some weather conditions might result in high-risk crosses, but the total number of such crosses was both small relative to the overall passage rate of eagles through the area and fairly predictable based on prevailing weather conditions.

#### Pre- vs post-construction eagle movement patterns

Johnson et al. (2014) used data from fall 2009 (pre-construction), Fall 2010 (Postconstruction, pre-operational) and Fall 2011 (Post-construction, operational) to compare the responses of migrating eagles to the wind turbines. As with the data above, flight paths of the birds were projected onto the ridges using GIS, and tracks that cross the turbines strings identified and assessed for the heights at which eagles crossed under varying weather conditions.



Figure 4. Average number of Golden Eagles per hour observed during fall 2009 migration separated by wind speed (high  $\ge$  8.5 km/hr; low  $\le$  8.5 km/hr – the ground wind speed associated with turbine cut-in speed). X-axis represents the start of the observation hour. (from Johnston et al. 2013)



Figure 5. Number of Golden Eagles that moved over the ridge-top area under varying categories of wind direction (western cross winds [226 - 315°], head winds [136 - 225°], and tail winds [316 - 45°]) in the fall 2009. Movements over the ridge-top area include all flight altitudes (ALL - n = 81), whereas flights Within Risk Zone are within rotor-swept height (RSH) and  $\leq$  150 m above ground (n = 22). Movements over the risk zone and at winds above turbine cut-in speed ( $\geq$  8.5 km/hr) further identifies conditions under which eagles potentially would have been at risk of being hit by a spinning turbine blade (n = 16). (from Johnston et al. 2013).

#### **Otter et al. • Avian Movement and Wind Farms**

A total of 1134 golden eagles flew within 2km of the study ridge during three fall migration seasons with a greater number counted in post-construction (2010 and 2011) compared to pre-construction (2009; Table 2). Although our sample size for the total number of eagles that passed through the site was higher in each of the post-construction years, the proportion of crosses over the ridge-top area – regardless of flight altitude – did not differ between years (18%; Table 2).

There was a significantly smaller proportion of crosses into the risk zone (within rotorswept height;  $\leq 150$  m agl) in postconstruction years (1%) compared to preconstruction (6%; Table 2). Furthermore, not all of the crosses into the risk zone involved instances of higher-risk flights - where wind speeds were sufficient to spin the turbine blades (turbine cut-in speed;  $\geq 6.8$  km/h ground speed). Here, we observed a smaller proportion of higher-risk crosses into the risk zone in post-construction (<0.01%) compared to pre-construction (5%; Table 2). Golden eagle flight altitude (m agl) above the ridge-top was higher in post-construction compared to pre-construction (Fig. 6). When viewing this relationship while accounting for differences in wind speed between the preand post-construction years, there is an overall shift upwards in flight altitude as wind speed increases, but flight altitude overall is significantly higher at all wind speeds under post-construction years (Fig. 7).

During pre-construction, over fifty percent (n = 31) of all crosses over the ridge-top area occurred under western crosswind conditions, however, only 13% (n = 4) occurred within the risk zone ( $\leq$  150 m agl). By comparison, a third (n = 19) of ridge-top crosses occurred under headwinds, but represented over 42% (n = 8) of all crosses within the risk zone. Of the eagles that crossed into the risk zone under headwinds, all (n = 8) were under higher-risk conditions when the turbines would have been spinning.

Table 2: Percent of all golden eagles observed at the Dokie 1 Wind Energy Project (within 2 km from turbine string) that: crossed the ridge-top area (within 100 m from turbine string); also flew within the risk zone ( $\leq$  150 m above ground); and, also flew within the risk zone when winds were above turbine cut-in speed (higher-risk flight; 6.8 km/h). Data collected on Fall Migration (30 September – 24 October) during Pre- (2009) and Post-construction (2010-2011) years. (from Johnston et al. 2014)

	Pre-		Ро	st-		
	%	n	%	n	X <sup>2</sup>	Ρ
Site (2 km)		327		807	-	-
Ridge-top cross	18	60	18	148	0.01	0.92
Ridge-top cross within risk zone	6	20	1	9	26.45	< 0.01
Higher-risk cross	5	15	0.004	3	25.67	< 0.01



Figure 6. Golden eagle flight altitudes above the ridge-top area during fall migration over one preconstruction (n = 60) and two post-construction (n = 148) seasons. Box represents median, first and third quartiles, and whiskers the maximum and minimum altitudes. Dashed line represents risk zone ( $\leq$  150 m above ground). (from Johnston et al. 2014)



Figure 7. Golden eagle flight altitude above the ridge-top area (m above ground) versus ground-based wind speed (km/h) during pre- (n = 60) and post-construction (n = 148) years. Some data points overlap. Grey box represents higher-risk flight zone (risk zone [ $\leq$  150 m above ground] and above turbine cut-in speed [6.8 km/h]). (from Johnston et al. 2014)

In contrast, during post-construction, flights into the risk zone and of higher-risk under headwinds dropped to 7% (n = 5) and 3% (n =

2), respectively. Despite the high proportion of entries into the risk zone under tailwinds in both pre- (71%) and post-construction (67%),

#### **Otter et al. • Avian Movement and Wind Farms**

the total number of flights under these conditions was very small (n = 7 and 3, respectively) relative to the total number of ridge crosses detected. The proportion of higher-risk crosses under tailwinds, however, was higher pre- (57%) than during postconstruction (0%).

#### Recorded eagle collisions during postconstruction.

Independent carcass searching was conducted throughout the spring and fall migration periods in both post-construction years (spring 2011 through Fall 2012) and spanned early March through late Oct each year (Stantec Consulting Ltd. 2012a, 2012b). This included the entire migration season of the golden eagles, as well as that of other migrating raptors known to use the site. Further, during this period, there were visual observers on site daily during the migration periods. There were no carcasses or witnessed collisions of golden eagles or any other raptors in either year.

#### **Conclusions for Eagle Collision Risk**

The data suggest that there was a limited potential risk to golden eagles of wind-farm particularly construction. under certain condition. For example, there was a number of low flights that crossed the ridge lines in pre-construction periods, particularly in saddles and at the ends of ridgelines (Johnston et al. 2013) and during head wind conditions. Such an example is found at the south end of Johnson Col where there was some overlap with turbines JC1 to JC3.

However, the pre- vs post-construction analysis showed strong evidence that the birds were both detecting and taking aversive action to turbines (Johnston et al. 2014). This was done primarily via minor adjustments to heights at which birds crossed the ridge, as there appeared to be little change in the number of birds utilizing the area or in changes to their migration routes. However, the number of ridge-crosses within the areas of turbine strings at both turbine height and under winds when turbines would be spinning was dramatically reduced in post-construction compared to pre-construction. Further, in two years of carcass searching, there was no evidence of eagle collisions. Thus, the risk to migrating eagles from this installation appears to be negligible.

However, we did find that headwinds continue to account for the main ecological predictor that coincides with high-risk crosses, despite these being relatively few in number. This might indicate a potential means of mitigation should Dokie I Wind Energy Project wish to reduce risk even further. For example, de Lucas et al. (2012) report on programs in Spain where visual observers monitor risksensitive flight patterns of migrating griffon vultures (Gyps fulvus) and use this information to temporarily idle individual turbines where high movement patterns are being observed. Such techniques have led to a 50% reduction in the detected rate of vulture collisions at an estimated loss of less than 0.1% in power generation per year. At Dokie, high risk crosses under headwinds often coincide with the south end of Johnson Col, eg. JC1-JC3. If observers tracking routes through the Dokie I Wind Energy Project found low flights were occurring under headwind conditions, they may be able recommend idling specific high-risk turbines without large impacts on energy generation under such conditions the wind direction runs parallel to the orientation of the turbines, and idling of one turbine in the string is likely to be compensated by increased efficiency of the turbines that had been in its wake.

#### **Nocturnal Migration**

# Passage Rates – Horizontally-tracking radars

We tracked a total of 1 495 296 aerial targets over the five year survey period, with highest numbers of detected targets being consistently recorded in Fall migrations (Table 3). While these numbers are corrected for the discrepancy between auto-tracking and manual-tracking, there is significant variability between years and seasons in the number of nights surveys were conducted, and the total number of hours in which radar data was able to be collected. This was due to mechanical difficulties with equipment, or periods of poor weather (high precipitation) during the survey periods that precluded data Coupled with this are slight collection. differences in the total area being covered by radars, due to slight variation in background clutter between the survey years. As a result of this, we calculated the passage rates on horizontal radars as targets detected/hour/km<sup>2</sup> to standardize between comparison periods. We then used a nested General Linear Model, with hour of the night nested within season, and season (spring/fall) nested within year to compare corrected counts of targets.

There was significant variation in the detected number of targets within each level of the nesting. Passage rate varied across the night within each season ( $F_{17, 607}$ =5.74, P<0.0001), with highest passage rates in the fall occurring between 21:00 and 23:00h, and then showing a steady decline throughout the rest of the night (Fig. 8). In the spring, hourly passage rates were lower overall than fall, but tended to be more consistent through the night (Fig. 8).

Passage rates were consistently lower in the spring than the fall across years ( $F_{3, 607}$ =7.29, P=0.0001 – Fig. 9), and there was also variability in passage rates across years (F<sub>4, 607</sub>=5.01, P=0.0006). Technical difficulties with radar and poor weather in springs 2009 and 2010 resulted in a low number of survey days/hours (Table 3), which may account for the very low target detection rates during these springs. For all other springs, the confidence limits in passage rate overlap substantially, suggesting little variation between the pre and post-construction period.

Fall passage rates were tracked from 2009 through 2012, and these rates were fairly consistent between the pre-construction (2009) and post-construction (2011-2012)periods. However, the lowest detection rates in the fall migration were also recorded in 2010, the period of heaviest construction on the wind installation, despite a similar number of surveyed hours to other fall migrations. While this might reflect a slightly lower number of nights on which the radars were operable in fall 2010, never-the-less if there was displacement of migrants during the construction period, the post-construction analysis suggests that this was temporary.

Table 3- The total numbers of tracked targets by season and year across the survey periods from 2008-2012. Variation in the number of nights surveyed between seasons and years reflected both problems encountered with weather or equipment. Target numbers shown reflect both exclusion of non-avian-like targets through application of filter expressions in radR, and are corrected using the methodology outlined in Fig. 3 (above) and in d'Entremont et al. (submitted).

	2008		2009		2010		2011		2012	
Targets detected	Spring 81 338	Fall -	Spring 6 436	Fall 430 597	Spring 19 138	Fall 104 202	Spring 98 689	Fall 246 284	Spring 109 134	Fall 399 478
Number of Nights Surveyed	16	-	4	12	7	6	9	9	13	11
Date Range over which sample collected	11-31 May	-	12-15 May	26 Aug- 7 Sept	19-26 May	29 Aug- 3 Sept	19-28 May	24 Aug- 2 Sept	18-30 May	19 -29 Aug
Hours Surveyed	75.7	-	21.1	91.6	16.6	50.7	49.0	59.8	77.6	81.9



Figure 8. Variation in the number of targets/hr/km<sup>2</sup> detected in relation to time of night and season. Night hour is an average across the hour noted on the axes. Values represent mean ± 95% Confident Intervals.



Figure 9. Variation in the number of detected targets/hr/km<sup>2</sup> between seasons and across years. 2008 and 2009 represent pre-construction years, 2010 a construction year, and 2011 and 2012 post-construction years. Values are means  $\pm$  95% Confidence Intervals

#### **Otter et al. • Avian Movement and Wind Farms**

# Mortality estimates of tracked migrant cohort

In order to contextualize these results, we compared the number of birds tracked during the two post-construction years with detected mortality from carcasses searches being independently conducted in 2011 and 2012 (Stantec Consulting Ltd 2012a & b, Stantec conducted respectively). daily surveys from 17 Apr-21 June and 4 Aug-20 Oct in 2011, and from 14 Mar-18 Oct in 2012. Every other turbine in the site (n=24) were surveyed once every 2 days. Each turbine pad was systematically searched for collisions, and both searcher efficiency trials and scavenger removal rates were conducted to estimate potential loss of carcasses to these error sources. To be conservative, we included all detected carcasses from these searches one day on either end of the beginning and end of radar tracking surveys. During the entire postconstruction period when radar surveys were conducted, a total of five carcasses were detected in 2011(no collisions occurred during the spring period - 18-29 May, and 3 bats (all silver-haired bats) and 2 birds (both Swainson's thrushes) during the fall migration - 23 Aug- 3 Sept 2011). We calculated the corrected number of carcasses by dividing the number of detected carcasses by the product of the seasonal correction estimates for: proportional area searched: searcher efficiency; and, scavenger impact (Table 2-4 of Stantec Consulting Ltd 2012a). This resulted in an estimated combined total of 11.00 bird/bat mortalities in 2011 during the period associated with track counts. During nightly radar surveys, detected we approximately 344 973 targets in 2011, giving an estimated mortality rate of 0.0032% in 2011.

During the periods of radar surveying in 2012 (plus one day on either season) and 18-30 Aug), there were 2 bird (both white-crowned sparrows) and no bat carcasses discovered in the Spring survey period (17-31 May), and 1 bird (red-breasted nuthatch) plus 7 bat carcasses (three silver-haired bats, two hoary bats, one little brown bat, and one Myotis sp.) during the Fall survey period (18-30 Aug). Applying the seasonal correction factors for 2012 (Table 2-4, Stantec Consulting Ltd 2012b), the estimated total number of carcasses for 2012 was 23.93 collisions during survey periods (birds and bats combined). As 508 612 targets were detected on these same nights, the estimated mortality rate of the cohort in 2012 was 0.0047%. If the two years are combined, the estimated mortality rate of the entire cohort of migrants detected is 0.0041%.

As we are unable to determine the species of targets tracked on radar, we are unable to determine exact mortality rates per species. However, silver-haired bats represented 6 of the 10 bat mortalities detected in the two postconstruction years and may be a species to consider for focal research with new facilities in the region. Further, although the numbers of both were small, there was twice the number of bats detected in collisions as birds. Among the birds detected in collision searches, all were passerines and fairly common species for the region. Mortality risk to populations of these individual species from collisions with the installation would appear to be negligible.

#### Heights of Migrants – Vertical Radar

Vertical radar files were subjected to the same filtering criteria in radR as applied to the horizontal radar files. However, the count numbers for vertical radar are uncorrected, as we have not yet determined if the same correction factors determined for the horizontal radars can be applied to the vertical dataset with the same degree of precision. However, the aim of the current analysis is to compare the relative number of birds in different sections of the vertical airspace above the ridgeline, and the results of the analysis will not differ if using the uncorrected track counts.

The average number of targets detected/hr within each height category (0-300m above ground, 301-600m, 601-900m, and 901-1200m) were summated from the main dataset for each night sampled. We then compared the average numbers of birds aloft in each height category individually, but represented the data in a single graph per season so that relative passage patterns across height categories can be seen (Figure 10).

For passage rates in all height categories, there was no significant effect of the total area of radar sampling or the number of hours per

night in which radar data was collected. There were, however, significant effects of both the Operational Phase (Pre- Construction vs Construction vs Post-Construction) and Season (Spring vs Fall) in targets detect/hr across nights (Table 4). This resulted from number of targets aloft in each height category being greater in the fall migration than the spring, but this is particularly evident in the two lowest height categories (0-300m and 301-600m – Fig. 10). Interestingly, the effect of Operational Phase is that the number of targets detected in almost all height categories in Construction increased and Post-Construction compared to Pre-Construction (Fig. 10). Some of this is likely an artifact of the shift to higher resolution in the radar recording imagery part way through the project (beginning in 2010). However, accounting for this potential artifact, there appears to be no evidence of a reduction in passage rates within each height category between pre- and post-construction.

Table 4. Comparison of the numbers of targets/hr aloft in each height category above the radars. Area sampled and number of hours surveys were conducted did not effect results, but there were significant effects of both Operational Phase (pre-vs construction vs post-construction) and season (Spring vs Fall) in almost all height categories. "Season" in the 901-1200m category had little more explanatory effect than the intercept-only model, and thus is likely not contributing significant additional variation.

	neight category								
	0-300m		301-0	500m	601	-900	901-1200		
	X <sup>2</sup>	Р	X <sup>2</sup>	Р	X <sup>2</sup>	Р	X <sup>2</sup>	Р	
Intercept	0.83	0.36	0.79	0.37	1.44	0.23	4.93	0.026	
Area Sampled	1.38	0.24	1.39	0.24	0.06	0.80	0.50	0.48	
Total Hours Radar Sampled	1.59	0.21	0.42	0.51	0.76	0.38	1.66	0.20	
<b>Operational Phase</b>	14.28	<0.001	19.16	<0.0001	139.70	<0.0001	176.78	<0.0001	
Season	28.36	<0.0001	10.06	0.002	4.79	0.03	4.98	0.026	

**Otter et al. • Avian Movement and Wind Farms** 



Figure 10. The average number of Targets detected / hour on vertically-oriented radars subdivided into four 300m height categories above ground. Data is delineated by both Operational Phase of the installation (Pre-construction vs Construction) and season (Fall vs Spring migration). Passage rates, particulary in the lower height categories are higher in the Fall migration compared to the Spring migration, and were also consistently higher in the Construction and Post-Construction operational Phases within each height category. Values are means ± 95% Confidence Intervals.

The number of birds aloft in the lowest height category (0-300m agl), which corresponds to the locations of the turbines. is much higher in the fall than spring migration season. This also corresponds to slight differences in the number of carcasses detected under turbines during these survey nights - of the 15 total carcasses found under the turbines during post-construction periods when radar surveys were conducted, only 2 (13%) were found in the Spring migration period, whereas 13 (87%) were found in the Fall migration period. Further, all 10 bat carcasses detected during nights we were conducting our radar surveys occurred in the fall migration period, so some of the increase in target detections in the lower height categories during this season may represent increased tracking of bat targets alongside birds. As the fall migration period was also when we encountered the highest number of insect returns on radars (which required filtering of radar imagery), there may also have been increases in hunting/foraging of bats that contributed to additional vertebrate targets in the radar detections. Notably, however, the majority of bat collisions involved known migratory species - silver-haired and hoary bats - rather than Myotis or other resident species.

#### **Cumulative Mortality Modelling**

Overall, the total mortality rates of the tracked migrants reported in this report was exceptionally low, even for species that represent significant concern with wind energy development (raptors and bats). This is also reflected in the detailed assessments of carcass searching provided in the Annual

Monitoring reports by Stantec for the two post-construction years (Stantec Consulting Ltd. 2012a & b). As mentioned previously, an estimated 34.93 total mortalities (birds and bats combined) were reported in postconstruction carcass searches during the same nights in which 853 585 targets were tracked migrating through the region. As these were detected using horizontal radars, they represent all migrants within 1.5km either side of the radar, but at altitudes below 600m (the upper detection limit of the horizontal radar beams). This combined mortality rate at this single installation site is approximately 0.0041% of the tracked targets using the airspace around the facility.

However, Dokie I Wind Energy Project is but one of a number of proposed or constructed installations in the south Peace region of British Columbia. Lee & Hanneman's (2012) assessment of industrial development in the south Peace Region, they report over 250 meteorological towers distributed over more than 50 ridgelines (covering over 340,000 ha) in the region that currently hold wind energy development tenures (Fig. 11). At least three of these tenures have resulted in constructed wind facilities, and several more are currently in development. Many of these, however, are linearly situated on the main access of migratory movement through the region (Fig. 11).



Figure 11. The locations of Meteorological towers and Wind Energy Tenures in the Peace Region of British Columbia (from Kee & Hanneman 2012). Superimposed on this is the primary migratory axis (in red) for birds in the region – both nocturnal and diurnal migrants. This constitutes the confluence of the eastern-most portion of the Pacific flyway and the western-most part of the Continental Flyway.

To determine what potential impact this might have on migrating birds/bats, we modelled a scenario of having 15 wind installations through which our cohort of tracked targets must traverse during migration. We then modelled this under three alternate scenarios.

- 1. The first scenario is that the mortality rate associated with each installation mirrors that reported above for the Dokie I Wind Energy Project (0.007%) and that the cumulative mortality on the cohort of the slightly more than 850,000 targets would be additive (linear) with each additional wind installation that they pass.
- 2. The second scenario is that avoidance of the first installation is energetically costly, requiring birds to alter their routes and pay metabolic costs to avoid collisions. With this scenario, we assume that the ability to successively avoid installations would diminish with each one encountered. To model this, we set an exponential increase in the mortality rates with each farm, starting with a 5% exponential increase and increasing by 5% step increments to a maximum of a 25% exponential increase in mortality.
- 3. The final scenario modelled was one in which the cohort of birds being track learns to recognize and avoid installations with increasing efficiency with each successive site encountered. Under this scenario, the mortality rates are decreasing exponentially with each installation. We ran this scenario with decreases of mortality in 5% increments to a maximum 25% exponential decrease in mortality.

In all scenarios, we estimated the number of cumulative collision fatalities as the original cohort traversed the 15 installation sites. The equation used for these estimates is:

$$M = (C - \sum_{i=1}^{15} m_{1-i}) * r * f^i$$

Where:

- *M*= the estimated cumulative number of fatal collisions across the 15 installations
- *C*= *the size of the initial cohort of targets that were tracked.*
- *m*= sum of mortalities at all installations prior to the current installation being traversed
- r= the overall mortality rates in this case the constant of 0.000041(or 0.0041%)
- f= the increase/decrease function in mortality under the different scenarios, which is raised to the power of the number of installations traversed. This number ranges from 0.75 (25% decrease) to 1.25 (25% increase in mortality). If all installations have exactly the same mortality rates, this function is 1.0.

While the outcome of such an exercise is conjectural, it provides a relative estimate of cumulative mortality from wind turbine collisions under varying scenarios.

#### **Otter et al. • Avian Movement and Wind Farms**

If the mortality rates remain equivalent at each installation traversed, the cumulative number of collisions estimated across 15 wind installations would project to 524, which remains 0.061% mortality from the tracked cohort. Under the tested scenarios of increasing/decreasing mortality rates, the range in estimated collisions was between 112 and 4769 mortalities (best-case to worst-case scenarios tested - Table 5, Fig. 12). Even under the most extreme scenario tested - an exponentially increase of 25% mortality with each new installation - the total number of estimated collisions forecast remained below 0.6% of the tracked cohort. As this represents all collisions of birds and bats combined, this estimate would be lower for any given bird species. Of more concern would be the fact that the collision mortalities involving bats were biased to a particular species (silver-haired bat) and it is impossible from radar imagery to determine the number of tracked targets that represent this one species. While the number of this species affected at the single installation tested remains low (6 of this species detected over two years, and under 15 total expected when corrections applied) and may not constitute a significant risk to the overall population, further research should continue with new installations planned for the region to better assess the cumulative collision risk to nocturnally-migrating/hunting bats.

Table 5. Estimates of number of the original cohort of 853 585 targets tracked in post-construction monitoring at
Dokie I Wind Energy Project traversing a hypothesized 15 wind installations in the south Peace Region of British
Columbia under either equivalent, increasing or decreasing mortality rate scenarios.

	Estimated number of Cumulative Collisions	% of Cohort killed
No Change in Mortality Rates	524	0.061
Increasing Mortality Rates		
5%	789	0.092
10%	1212	0.14
15%	1904	0.22
20%	3008	0.35
25%	4769	0.56
Decreasing Mortality Rates		
5%	358	0.042
10%	253	0.030
15%	186	0.022
20%	142	0.017
25%	112	0.013



Figure 12. Estimates of the cumulative mortality associated with wind turbine collisions of a cohort of 853 585 aerial targets traversing up to 15 wind installations on spring/fall migration. If collision rates remained the same with each installation as those observed at the Dokie I Wind Energy Project (represented as installation 1, the starting point of all lines), the accumulated number of collisions follow the straight black line with closed circles. Under scenarios of increasing mortality risk with each additional installation encountered (lines with open squares), mortality begins to increase significantly at about 7-8 installations, but even under the most extreme scenario tested (25% exponential increase) the total mortality over 15 installations is below 1% of the tracked cohort. Under scenarios where birds learn to avoid installations progressively with each one encountered (lines with open circles), cumulative mortality rates do not climb as steeply. The upper and lower bounds of lines represent 25% increase and 25% decrease, respectively, from initially measured mortality rates. Each line represents either an increase or decrease in mortality rates of 5%.

# Discussion and recommendations

#### Eagles

Despite finding several variables (age, seasonality, wind patterns) during the pre-

construction assessment that predicted increases in the number of high-risk ridgeline crosses, our comparisons with postconstruction behavior indicates that the eagles are making small-scale adjustments to their altitudes as they cross the ridgeline, and thus flying above turbine height. This decreases the number of eagles that appear to be making risky crosses, and strongly suggests the bird are detecting the towers and adjusting their flights to avoid them. This was independently corroborated, as no carcasses of raptors were detected during the two years of postconstruction monitoring by Stantec biologists (Stantec Consulting Ltd. 2012a & b). Collisions may have occurred, but resulted in birds descending in sloped flight to land outside the search detection zones as many collisions among raptors appear to affect wings vs killing the birds immediately – birds crippled in this manner can soar out of the turbine pad range prior to making contact with the ground (Barrios & Rodríguez 2007). This "crippling bias" (Whitfield 2009) can result in under-estimation of collision rates. However, none of the observers witnessed collisions during behavioural observations, despite being present throughout the full days and range of the migration season. Further, it is not unexpected that the birds may be detecting and taking evasive action towards turbines. de Lucas et al. (2007) found that migrating raptors increase flight altitudes when crossing ridgelines with wind turbines, and that the magnitude of these adjustments were higher when turbines were rotating. Similarly collision-risk models comparing preconstruction flight densities versus detected collisions suggest that golden eagles show high collision-avoidance rates at other installations (Whitfield 2009). Barrios & Rodríguez (2007) also found that flight behavior in griffon vultures affected collision risk; straight line flights, which are typical of the migrating eagles we observed, were less likely to result in collisions than circle soaring in and around turbines. Overall, the collision risk associated with golden eagles at this facility seems to be low.

One potential concern is that avoidance behavior can increase the energetic expenditure associated with migration, or that displacement could deprive species of

necessary resources (e.g. foraging sites). We found little evidence of displacement - the flight trajectories and number of birds crossing the ridgelines pre- vs post-construction do not appear to differ. Avoidance behavior appears to be associated with slight adjustments to flight altitude, as seen with migrating raptors in Spain (de Lucas et al. 2007). This could affect energetic costs associated with flight, and this aspect of migratory behavior was something we were unable to directly assess in the current study. However, the adjustments to flight altitudes involved upward shifts of ~200m and the ranges of flight altitudes in the pre- vs post-construction overlapped (Fig. 6). As such, the adjustment did not seem to take birds outside the range of heights recorded in pre-construction monitoring. Anecdotal data recorded on site suggests that flight adjustments did not increases the amount of flapping flight required of the birds. Where this might, however, affect flight energetics is in having to increase altitudes while facing headwind conditions. Under headwinds, eagles tend to decrease their flight altitude (Johnston et al. 2013), and this may take advantage of locally-decreased wind speeds through friction with underlying topography. In the context of the Dokie I Wind Energy Project, such headwinds during fall migration would create winds coming from the south end of Johnson Col, and these would tend to cause the strings of turbines on this ridge to align and be within the turbulence of the turbines closer to the end of the ridge. Under such conditions, idling the turbines (e.g.JC1 & JC2) where most ridge crosses were noted may result in decreased collision risk (de Lucas et al. 2012), but the loss of power generation from these turbines may be compensated partially by those turbines that had been within their wake.

One of the primary questions is why we found little evidence of potential impact to golden eagles on the Dokie I Wind Energy Project, when other facilities worldwide have reported serious impacts to raptor populations (e.g. Smallwood & Thelander 2005; de Lucas et al. 2008; Carrete et al. 2009; Dahl et al. 2012; Ferrer et al. 2012)? Ours, though, is not the only study to suggest that wind facilities have low risk among surveyed raptors (e.g. Villigas-Patraca et al. 2014). There is, however, a pattern that appears to emerge between those facilities in which risk is elevated - in most cases, high impacts on raptors are seen among wind facilities where there are large, resident er breeding (de Lucas et al. 2008; Carrete et al. 2009; Dahl et al. 2012) or wintering (Barrios & Rodríguez 2004; Smallwood & Thelander 2005) populations. In such areas, birds are expected to make repeated flight movement through the wind facility's turbine zones, and this can result in increasing habituation and closer approaches to turbines. Excluding habituation potential, the probabilistic of collisions increases with the number of flights within the rotor-swept zone, as is integrated into the common collision-risk models (e.g. Band model – Band et al. 2007). By comparison, the majority of golden eagles traversing our study site and region are migratory – they spend only the time required to traverse the site at the Dokie I Wind Energy Project during northward and southward migration, with few birds stopping or foraging within the wind installation. During the migration, the birds are typically scanning in the direction of travel, as opposed to hunting raptors which might be focusing their attention towards prey detection. This could result in an increased ability to detect and avoid obstacles within the flight path. Further, single flights through the facility decrease time spent within rotor-swept zones, and thus predict low collision potential (Whitfield 2009). Such flight behavior is known to be correlated with low collision and high avoidance levels (Barrios & Rodríguez 2007), as we saw with the golden eagles in the present study.

This suggests that planning is the most important aspect in siting wind facilities to minimize risks to raptors. Pre-construction

monitoring should not only document the presence of potentially affected raptor species, but also their spatial utilization of the area. Sites that have large resident populations of raptors with repeated flight behavior through the proposed location of turbines will potentially have high collision risk. These might constitute breeding areas, wintering congregation areas, or areas where birds stop on migration for periods of refueling. Surveys of activity not only during migration, but also during the breeding season for raptors (e.g. time coinciding with monitoring of nocturnal migrants) would be useful additions to monitoring plans. This could document the number of breeding raptors hunting within the facility.

As seen in this study, however, areas in which high densities of raptors are found may not necessarily constitute a high collision risk if spatial use of the area by individuals is temporary, such as passage on migration. Within British Columbia, congregation zones of wintering bald eagles on the coasts or along river systems may constitute examples of high potential wind development. risk for However, migratory corridors of golden eagles may be at lower risk than would be presumed by the density of birds in the region. Further work, though, is necessary to determine whether the avoidance behavior and low collision potential at the Dokie I Wind Energy Project is representative of other facilities in the region, and we would strongly encourage a requirement for pre- and post-construction monitoring of raptor flight behavior (in addition to carcass searches) at other facilities being constructed within the region. This data would allow a better estimation of the potential cumulative effect of wind energy development in the Peace Region.

#### **Nocturnal Migration**

The radar surveys for this study demonstrate that there is high migration movement through this region. Largely as a result of the timing of when surveys were conducted, many of the migrants detected were likely passerines, but other nocturnal migrants (waterfowl, migratory bats) were also likely part of the tracked migratory traffic. Passage rates are much higher in the fall than spring surveys, similar to that seen for golden eagles, and this might reflect the movement of both adults and juvenile birds during post-breeding. Further, the increase in bat collisions in the fall may indicate this group is also adding to detected targets on radars. There seemed, however, to be little indication that movement rates, particularly those in the lower altitudes corresponding to the locations of the wind turbines, differed substantially between pre and post-construction surveys. This suggests that birds (and bats) are not being displaced from the facility. Unlike the raptors, we did not see shifts of radar-detected targets into higher vertical height categories during postconstruction, but this may also reflect that the lowest height category (0-300m agl) includes over half its airspace above the reach of the turbines themselves. Preliminary results from night-vision cameras suggest that while there was no difference in birds detected directly beside turbines vs in the airspace half-way between turbines (Walsh 2012), there might be a slight decrease in the number of detected targets within rotor-swept heights in birds moving near the turbines (Walsh et al. in prep). Thus, movement may be being adjusted on a finer scale than measured via radar.

Regardless of whether nocturnal migrants show minor changes in their flight patterns in

relation to construction, the mortality rates of birds and bats at the Dokie I Wind Energy Project appear to be very low in relation to other reported facilities (Barclay et al. 2007; Zimmerling et al. 2013). Even projecting a 25% compounded increase in mortality across wind installations in the region resulted in low estimates of impacts to the cohort of radartracked migrants, and if there is any ability to detect and avoid installations through learning, the forecast cumulative impacts of wind development on nocturnal migrants in the region is minimal. This is perhaps not surprising when recent projections of collision risks to nocturnally-migrating birds from wind development were found to be both low relative to estimated population sizes and compared fatalities from other to anthropogenic sources (Loss et al. 2013; Zimmerling et al. 2013). It is critical, however, that monitoring at each new installation within the region be continued to determine whether mortality risk appears to be either increasing or decreasing with each new installation along the migratory pathway, as this will validate both the direction and magnitude of cumulative effects.

Studies are currently underway to determine the influence of weather patterns on heights of migrants, specifically whether rain events during individual nights result in decreased flight altitude and increased collision risk to migrants (d'Entremont & Otter, in prep). We will also undertake additional studies on hourly passage rates in relation to operational phase of the installation to determine whether subtle differences in spatial patterns of flight differ between pre- and post-construction (d'Entremont & Otter, in prep). Finally, analysis by Marc d'Entremont on the flight patterns of birds under varying experimental lighting conditions will determine whether proposed tower lighting might further enhance detection and avoidance behavior.

Bats have been identified as being among the groups most affected by wind aerial development. While the numbers of bat collisions at Dokie I Wind Energy Project are extremely low by comparison with other installations, caution should be employed in projecting this to other installations in the region without direct post-construction assessment. There is high variability in the number of bat mortalities between installations (Barclay et al. 2007), and this group is also subject to variation between years. Further, the absolute numbers of migratory bats traversing the region are unknown, and methods of detecting differences between migratory bats and migratory birds from radar images are still speculative. This makes estimations of the proportion of the cohort being affected by collisions difficult to accurately assess.

In determining the cumulative effect of expansion of the wind industry in the region, we recommend an adaptive approach of monitoring the mortality rates associated with all wildlife, particularly raptors and bats, in a stepwise approach. With each facility completed, the patterns of mortality (increase/decreasing or stable relative to the Dokie I Wind Energy facility) need to be determined and this information used to set upper acceptable thresholds on the cumulative allowable impacts for the region. In setting these thresholds, sensitivity to the relative impact of mortality from wind development compared to cumulative mortality from alternate energy sources (e.g. effects on passerine populations from global climate change associated with fossil fuel exploitation) need also to be weighed into decisions (Kikuchi 2008).

### **Literature Cited**

- Arnett, E.B., W.K. Brown, W.P. Erickson, J.K. Fieldler, B.L. Hamilton, R.H. Henry, A. Jain,
  G.D. Johnson, J. Kerns, R.R. Koford, C.P. Nicholson, T.J, O'Connell, M.D. Piokowski, and
  R.D. Tankersely Jr. 2008. Patterns of bat fatalities at wind energy facilities in North
  America. *Journal of Wildlife Management* 72: 61-78.
- Baerwald, E.F., G.H. D'Amours, B.J. Klug, and R.M.R. Barclay. 2008. Barotrauma is a significant cause of bat fatalities at wind turbines. *Current Biology* 18: R695-696.
- Band, W., M. Madders and D.P. Whitfield. 2007. Developing field and analytical methods to assess avian collision risk at wind farms. Pp 259-275. in: de Lucas, M., G.F.E. Janss, and M. Ferrer (eds). *Birds and wind farms: risk assessment and mitigation*. Quercus, Madrid.
- Barclay, R.M.R., E.F. Baerwald, and J.C. Gruver. 2007. Variation in bat and bird fatalities at wind energy facilities: assessing the effects of rotor size and tower height. *Canadian Journal of Zoology* 85: 381-387.
- Barrios, L. and A. Rodríguez. 2004. Behavioural and environmental correlates of soaring-bird mortality at on-shore wind turbines. *Journal of Applied Ecology* 41: 72-81.
- Barrios, L. and A. Rodríguez. 2007. Spatiotemporal patterns of bird mortality at two wind farms of sourthern Spain. Pp 229-239. in: de Lucas, M., G.F.E. Janss, and M. Ferrer (eds). *Birds and wind farms: risk assessment and mitigation.* Quercus, Madrid
- Calvert, A. M., C. A. Bishop, R. D. Elliot, E. A. Krebs, T. M. Kydd, C. S. Machtans, and G. J. Robertson. 2013. A synthesis of human-related avian mortality in Canada. *Avian Conservation and Ecology* 8(2): 11.http://dx.doi.org/10.5751/ACE-00581-080211
- Carrete, M. J.A. Sánchez-Zapata, J.R. Benítez, M. Lobón, and J.A. Donázar. 2009. Large scale risk-assessment of wind-farms on population viability of a globally endangered long-lived raptor. *Biological Conservation* 142: 2954-2961.
- Carrete, M. J.A. Sánchez-Zapata, J.R. Benítez, M. Lobón, F. Montoya and J.A. Donázar. 2012. Mortality at wind-farms is positively related to large-scale distribution and aggregation in griffon vultures. *Biological Conservation* 145: 102-108.
- Dahl, E.L., K. Bevanger, T Nygård, E. Røskaft and B.G. Stokke. 2012. Reduced breeding success in white-tailed eagles at Smøla windfarm, western Norway, is caused by mortality and displacement. *Biological Conservation* 145: 79-85.
- d'Entremont, M.V., M.I.. Hartley, and K.A. Otter. Submitted. Analytical protocols for the detection and auto-extraction of aerial vertebrate targets from digital radar signals at a wind energy project. *Avian Conservation and Ecology* (provisionally accepted Feb 2014)

- de Lucas, M., G. Janss, and M. Ferrer. 2007. Wind farm effects on birds in the Strait of Gibraltar. Pp – 219-227. in: de Lucas, M., G.F.E. Janss, and M. Ferrer (eds). *Birds and wind farms: risk assessment and mitigation*. Quercus, Madrid
- de Lucas, M., G.F.E. Janss, D.P. Whitfield, and M. Ferrer. 2008. Collision fatality of raptors in wind farms does not depend on raptor abundance. *Journal of Applied Ecology* 45: 1695-1703.
- de Lucas, M., M. Ferrer, M.J. Bechard, A.R. Muñoz. 2012. Griffon vulture mortality at wind farms in southern Spain: distribution of fatalities and active mitigation measures. *Biological Conservation* 147: 184–189.
- Desholm, M. and J. Kahlert. 2005. Avian collision risk at an offshore wind farm. *Biology Letters*. 1: 296-298.
- Desholm M. A.D. Fox, P.D.L. Beasley and J. Kahlert. 2006. Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review. *Ibis* 148: 76-89.
- Drewitt, A.L. and R.H.W. Langston. 2006. Assessing the impacts of wind farms on birds. *Ibis* 148: 29-42.
- Everaert, J. and E.W.M. Stienen. 2007. Impact of wind turbines on birds in Zeebrugge (Belgium): significant effect on breeding tern colony due to collisions. *Biodiversity and Conservation* 16: 3345-3359.
- Ferrer M., M. de. Lucas, G.F.E. Janss, E. Casado, A.R. Muñoz, M.J. Bechard and C.P. Calabuig. 2012. Weak relationship between risk assessment studies and recorded mortality in wind farms. *Journal of Applied Ecology* 49: 38-46.
- Fox, A.D., M. Desholm, K. Kahlert, T.K. Christensen, and I.K. Petersen. 2006. Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. *Ibis* 148: 129-144.
- GAO 2005. Wind Power: impacts on wildlife and government responsibilities for regulating development and protection wildlife. United States Government Accountability Office report to Congressional Requesters GAO-05-906
- Johnston, N. N., J. E. Bradley, A. C. Pomeroy, and K. A. Otter. 2013. Flight paths of migrating Golden Eagles and the risk associated with wind energy development in the Rocky Mountains. Avian Conservation and Ecology 8(2): 12. <u>http://dx.doi.org/10.5751/ACE-00608-080212</u>.
- Johnston NN, Bradley JE, Otter KA (2014) Increased flight altitudes among migrating golden eagles suggest turbine avoidance at a Rocky Mountain wind installation. *PLoS ONE* 9(3): e93030. doi:10.1371/journal.pone.0093030
- Kikuchi, R. 2008. Adverse impacts of wind power generation on collision behavior of birds and anti-predator behavior of squirrels. *Journal for Nature Conservation* 16: 44-55.

- Kingsley, A., and B. Whittam. 2007. Wind Turbines and birds: a background review for environmental assessment. Environment Canada/Canadian Wildlife Service. Pp. 81.
- Kunz, T.H., E.B. Arnett, B.M. Cooper, W.P.Erickson, A.R. Hoar, G.D. Johnson, R.P. Larkin, M.D. Strickland, R.W. Thresher, and M.D. Tuttle. 2007a. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. *Frontiers in Ecology and the Environment*. 5: 315-324.
- Kunz, T.H., E.B. Arnett, B.M. Cooper, W.P.Erickson, R.P. Larkin, T. Mabee, M.L. Morrison, M.D. Strickland, and J.M. Szewczak. 2007b. 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., L.A. Brennan, M.L. Morrison, K.K. Boydston, B.M. Ballard, R.D. Bryant. 2007. Wind energy development and wildlife conservation: challenges and opportunities. *Journal of Wildlife Management* 71: 2487-2498.
- Lee, P and M. Hanneman. 2012. Atlas of land cover, industrial land uses and industrial-caused land change in the Peace Region of British Columbia. Global Forest Watch Canada report #4 International Year of Sustainable Energy for All. 95 pp.
- Loss, S.R., T. Will and P.P. Marra. 2013. Estimates of bird collision mortality at wind facilities in the contiguous United States. *Biological Conservation* 168: 201-209.
- McIntyre, C. L., D. C. Douglas, and M. W. Collopy. 2008. Movements of Golden Eagles (*Aquila chrysaetos*) from interior Alaska during their first year of independence. *Auk* 125:214-224.
- Stantec Consulting Ltd. 2012a. Dokie Wind Energy Project 2011 Operational Wildlife Monitoring Report. Prepared for: Dokie General Partnership. Burnaby, BC, 87 pp.
- Stantec Consulting Ltd. 2012b. Dokie Wind Energy Project 2012 Operational Wildlife Monitoring Report. Prepared for: Dokie General Partnership. Burnaby, BC, 87 pp.
- Smallwood, K.S., and C.G. Thelander. 2005. Bird mortality at the Altamont Pass wind resource area. Final Report. National Renewable Energy Laboratory, NREL/SR-500-36973. Golden Colorado, USA.
- Taylor, PD, JM Brzustowski, C Matkovich, ML Peckford, D Wilson. 2010. radR: an open-source platform for acquiring and analysing data on biological targets observed by surveillance radar. *BMC Ecology* 10:22; doi:10.1186/1472-6785-10-22
- Thelander, C.G., K.S. Smallwood, and L. Rugge. 2003. Bird risk behaviours and fatalities at the Altamont Pass wind resource area. National Renewable Energy Laboratory Technical Report NREL/SR-500-33829. Golden Colorado, USA.
- Villigas-Patraca, R., S.A. Cabrera-Cruz, and L. Herrera-Alsina. 2014. Soaring migratory birds avoid wind farm in the isthmus of Tehuantepec, southern Mexico. *PLoS ONE* 9(3):e94262.

- Walsh, D.A. 2012. A technique for avian nocturnal migration research: determining flight pattern of local nocturnal migrants around pre-operational wind turbines. BSc. Thesis. University of Northern British Columbia.
- Whitfield, D.P. 2009. Collision avoidance of golden eagles at wind farms under the 'Band' collision risk model. Report to the Scottish Natural Heritage. Natural Research Ltd. UK. Pp. 35.
- Zimmerling, J.R., A.C. Pomeroy, M.V. d'Entremont, and C.M. Francis. 2013. Canadian estimate of bird mortality due to collisions and direct habitat loss associated with wind turbine developments. Avian Conservation and Ecology 8(2): 10. <u>http://dx.doi.org/10.5751/ACE-00609-080210</u>

### Acknowledgements

We would first like to thank Bob Elner, Canadian Wildlife Service, whose visionary approach to regulatory agencies, academics and industry working collaborative to define and address research questions was the impetus for this collaborative research partnership.

We would also like to acknowledge the support in this partnership from Anna Jamieson, Claire Spero and Julia Mancinelli from the Dokie General Partnership over the course of this study, as well as Wendy Easton, Andrew Robinson and Charles Francis from Environment Canada.

Funding for the research was provided from NSERC Canada (Special Research Opportunities, Strategic Projects, and Collaborative Research & Development Grants), Environment Canada, Dokie General Partnership (Alterra Power Corp), EarthFirst Canada and Stantec Consulting. Technical support and collaboration was provided by Russell Technologies Inc, Phil Taylor and John Brzustowski of the radR Project, and Stefanie LaZerte on R programming.

The West Moberly First Nation, Halfway River First Nation, Saulteau First Nations and McLeod Lake Indian Band kindly allowed us to work on their traditional territories during this project.