INTERIM REPORT

Investigating Impacts of Wind Power Development in the M-KMA: A Literature Review on the Development of the Wind Power Industry in BC and Corresponding Effects on Valued Ecosystem Components

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DECEMBER 01, 2010

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Request for Proposal Number: M-K 0111

CITATION: McCann, Rob. 2010. Investigating Impacts of Wind Power Development in the M-KMA: A Literature Review on the Development of the Wind Power Industry in BC and the Corresponding Effects on Valued Ecosystem Components. Wildlife Infometrics Inc. Report No. 362. Wildlife Infometrics Inc., Mackenzie, British Columbia, Canada.

ABSTRACT

Although wind energy represents an alternative and renewable energy resource with few of the greenhouse gas impacts associated with hydro-carbons, the rapid growth in the wind energy industry has been met with controversy and concerns. Impacts to wildlife, wildlife habitat, and societal values associated with both, have recently emerged. In spite of the fact that commercial wind energy generation has existed in North America for thirty years, the significance of many known impacts is still unknown. Much of this uncertainty can be traced to insufficient regulatory oversight, the rapid growth of the industry that has resulted in ever more wind energy facilities and an ever widening geographic footprint, rapidly changing wind turbine technology, and a lack of rigorous research to quantify impacts and place them in a meaningful perspective.

A large volume of literature (both ‘grey’ and scientific) has been generated and yet many wind energy facilities have never been studied, or had results of studies released into the public domain. As wind energy expands its geographical footprint, facilities are being built in new ecological settings, often without appropriate or relevant guidance. Unanticipated impacts have, and are, occurring. Impacts can be categorized into two broad categories: direct impacts (fatalities to wildlife) and indirect impacts (functional and structural changes in ecosystems). Impacts, however, are not simply measured in terms of wildlife and habitat, but also in terms of people’s perceptions, although these may be easier to quantify.

To date, avian and bat species have received most attention in terms of research and literature. This primarily reflects the habitat types and topographic features where energy facilities have been constructed. Simple conclusions as to the significance of direct and indirect impacts on species’ population status, or the efficacy of various mitigating actions are elusive. The M-KMA is faced with a novel situation as high elevation subalpine and alpine ridge lines that provide important seasonal habitat for large mammals such as caribou and grizzly bears are the primary sites proposed for wind energy development. These appear to be the first developments within these habitat types and within a regional context of relatively pristine ecosystems.

ACKNOWLEDGMENTS

Funding to accomplish this work was made available by the Muskwa-Kechika Advisory Committee and was facilitated by contract to the BC Ministry of Agriculture and Lands. Thanks to Don Roberts for his support in making this work happen.

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INTRODUCTION

This project will provide a suitability analysis specific to wind power development in the Muskwa-Kechika Management Area (M-MKA). In this report we present background information on the Wind Power industry and associated impacts to several valued ecosystem components. The M-MKA was established to ensure that wildlife populations and wilderness and cultural values are preserved in perpetuity while allowing for resource extraction and development activities such as oil and gas, forestry, and recreation. Currently there are three investigative use permits (IUP) within the M-MKA boundary and 11 IUPs that occur within a 15 km buffer of the M-MKA boundary. The *Muskwa-Kechika Management Plan Regulation* requires strategic plans for all such activities; there is currently no such plan to guide the development of wind power within the Management Plan Regulations.

The Muskwa-Kechika Advisory Board seeks to address this deficiency through an analysis of wind power development that defines both known and potential impacts to the entrenched M-KMA values of wildlife and wildlife habitat values, and wilderness values including visual impacts. The analysis has three major components: 1) a literature review of research and studies regarding wind power development with an emphasis on relevancy to the M-KMA; 2) spatial modeling and mapping to determine those portions of the M-KMA where wind power development is, or is not, constrained by terrain features, and where wind power development would impinge upon wildlife, wildlife habitat and wilderness values (including visual impacts); and 3) an evaluation of current wind power tenures within the M-KMA to determine their compatibility with the stated M-KMA values and a suitability analysis with respect to known and potential impacts stemming from wind power development.

STUDY AREA

The study area of the MKMA is located in north-eastern BC, its' extent ranging approximately from N56°22' to N59°57' and W122°47' to W128°56'. The MKMA is comprised of four biogeoclimatic zones, Boreal Black and White Spruce (BWBS), Spruce Willow Birch (SWB), Boreal Altai Fescue Alpine (BAFA) and Engelmann Spruce – Subalpine Fir (ESSF) (Figure 1). The BWBS zone forms nearly a quarter of the MKMA, dominating the plateau areas to the north east of the study area and valley bottoms of rugged mountainous terrain. The two main ecosystems found in the BWBS are upland forests and muskeg. Stands of trembling aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), and black spruce (*P. mariana*) can be found in the upland forests, occupying suitable sites dependent on drainage and topography. The muskeg ecosystem supports both black spruce and tamarack (*Larix laricina*) tree species and is primarily a result of a climate which is both long and cold in the winter and warm and short in the summer with the presence of permafrost. Precipitation is relatively low receiving the least amount of snowfall of the four zones found in the MKMA. Long cold winters and short cool summers are characteristic of the SWB zone which generally has a harsh climate. This zone is dominant covering nearly half of the MKMA and occurs between the BWBS and Alpine Tundra zones. Tree species are more limited than the BWBS zone; white spruce, trembling aspen and lodgepole pine can be found at the lower elevations of the SWB

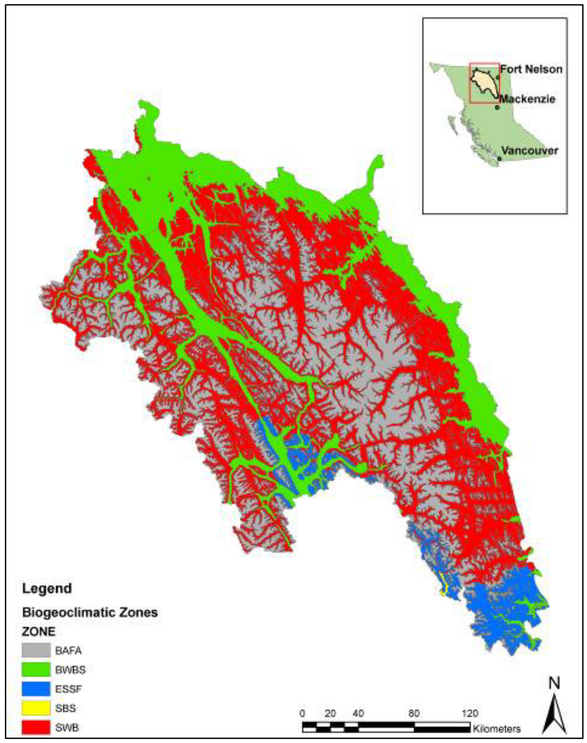

Figure 1. The biogeoclimatic zones represented in the Muskwa-Kechika Management Area in northern British Columbia.

shifting to more dominant stands of subalpine fir (*Abies lasiocarpa*) to deciduous shrubs at higher elevations. Many of these forests are relatively old due to infrequent fires; although, large burns have been introduced to create open grassland areas with occurrences of trembling aspen.

The BAFA zone occurs on a quarter of the MKMA landscape. It occurs in the mountainous high elevations in steep rugged terrain. The growing season is relatively short with temperatures rising above 0°C for 1 to 4 months of the year. Ecosystems are a patchy mosaic near the treeline, a combination of krummholz, alpine tundra and alpine meadows. Distribution of plant and tree species is highly dependent on erosion deposition, drainage, precipitation and aspect. The ESSF zone is limited to the southeastern portion of the MKMA and upper portion of the Fox River drainage. It occurs in mountainous terrain typically at mid slope elevations and high elevation valleys. The climate conditions create long cold winters with deep snowpacks to short cool summers. Engelmann spruce (*P. engelmannii*) and subalpine fir are the main tree species in the ESSF. Pure stands of subalpine fir occur at higher elevations forming patchy tree islands in the subalpine parklands. There is only a trace occurrence of the Sub-Boreal Spruce zone in the lower southeastern portion of the MKMA and hence will not be discussed.

The M-KMA is occupied, or partially occupied, by eight herds of woodland caribou (i.e., the Rabbit, Muskwa, Pink Mountain, Gataga, Frog, Horseranch, Finlay, and Graham herds). These are herds of woodland caribou that are considered by the Council on the Status of Endangered Wildlife in Canada (Thomas and Gray 2002) to be a species-at-risk and, for the most part, are listed as "special management concern"; the Graham herd has been listed as "threatened". Other significant wildlife species include black bears, grizzly bears, wolves, moose, mountain goats, elk, bison, deer, wolverines and Stone sheep.

LITERATURE REVIEW

Wind Power: An Emerging Industry with Emerging Problems

The modern era of wind-sourced energy in North America was fostered by the 1973 oil embargo that prompted US federal tax credits and research and development support for wind turbines across a wide range of capacity. Between 1981 and 1990, approximately 17,000 small and intermediate size turbines (20 – 350 KW) were installed, primarily in California. Poor machine design and the vicissitudes of economics and government policy stifled the wind power industry for much of 1990s until a geographically wider industry re-emergence in 1999[1]. Between 1998 and 2002, wind energy installed capacity in the US increased at a 26% compound growth rate (1,848 MW to 4,685 MW; Sterziner et al. 2003). Installed capacity in the US wind energy sector is expected to further increase from ≈10,000 MW in 2007 (by implication, a 17% compound growth rate between 2002 and 2007) to 50,000 MW in 2020 (NWCC 2007). Estimates for global growth rates in capacity are similar with an expected quadrupling from ≈150 GW in 2009 to ≈600 GW by 2020[2].

From an environmental perspective, the 1980's California boom in wind farms is highlighted by Altamont Pass Wind Resource Area (APWRA) where the world's largest concentration of wind turbines occurs[3]. By 1989, the lethal impact of wind turbines on birds in the APWRA was consistently documented (Thelander et al. 2003). This installed base of approximately 5,400 active turbines (Thelander et al. 2003) lies within a major avian migratory route and the world's largest breeding population of golden eagles (*Aquila chrysaetos canadensis*). Among the earliest commercial wind farms in the United States (US), the smaller capacity turbines require far more machines than would be employed today for the given capacity (≈580 MW). Other turbine design features exasperate the impacts to birds. Low lattice towers (18 – 24m) potentially provide attractive perching sites and allow rotor sweeps (at 60 – 80 rpm) to pass close to the ground where raptors focused on prey collide with the blades. Siting of turbines on ridgelines and along canyons likely contribute to raptor fatality. Over the period between 1998 and 2000, Thelander et al. (2003) estimated an average annual fatality rate of 0.19 birds/turbine/year or about 1,000 mortalities/year of which ≈50% were raptors. Smallwood and Thelander (2004) reported that raptor fatalities may be as high as 0.24 fatalities/turbine/year (≈1300 raptors) with golden eagles, red-tailed hawks (*Buteo jamaicensis*), burrowing owls (*Athene cunicularia*) and American kestrels (*Falco*

[1] http://www.telosnet.com/wind/index.html (accessed October 10, 2010)
[2] http://www.amsc.com/products/applications/windEnergy/index.html (accessed October 10, 2010)
[3] http://www.eoearth.org/article/Altamont_Pass,_California (accessed October 10, 2010)

sparverius) the most common species. High turbine density, poorly planned project and turbine siting, early turbine design features, and additional deficiencies in transmission lines that led to rapture electrocution distinguishes the APWRA as the most lethal wind farm in North America[4].

Presumably, much lower avian mortality rates observed for most wind power facilities developed after the APWRA reflects more attention to project and turbine siting[5]. Certainly, an extensive review of wildlife impacts by wind power facilities[6] conducted by the Windshare Wind Power Cooperative for the Exhibition Place Turbine in Toronto suggests that few projects have significant mortality on birds or bats. A number of reviewed wind power facilities, however, were noted to be in important avian habitats, within known avian migratory pathways or in proximity to bat hibernacula. Technology improvements in turbines rather than improvements in project siting may have contributed most to better environmental performance of wind farms in the years immediately following APWRA.

Of interest is the finding in the Windshare review that as the date of publication (document undated but estimated to circa 2000), there were no published studies of wind turbine impacts on bats and little evidence that bats were of concern. In contrast, the USGAO (2005) noted that research conducted in 2004 and 2005 in the eastern US found large numbers of bat mortalities at some, but not all, wind power facilities: two wind farms were each found to cause ≈2,000 bat mortalities over study periods of six weeks (64 turbine installation) and seven months (44 turbine installation) and a third wind farm of only three turbines had a mortality rate of 21 bats/turbine/year. Variation in the quality and extent of research, coupled with site-specific and species-specific impact regimes (USGAO 2005, NRC 2007), reduces the robustness and utility of many existing estimates of avian and bat mortalities. For large terrestrial fauna, such as ungulates and carnivores, data is generally lacking.

The US experience with wind energy is illuminating. A once wavering interest in renewable energy has evolved into a high-profile strategy to address greenhouse gas emissions and to enhance national energy security. Misperceptions that renewable energy is environmentally friendly however, have led to economic incentives driving the regulatory framework and a dysfunctional linkage between regulations, incentives and environmental impacts (Sutton and Tomich 2005). As noted *supra* and by Kunz et al. (2007a), the rapid build-out in the wind energy sector has resulted in unanticipated environmental consequences. Beyond the necessary political will, fixing the US regulatory framework for the wind energy sector is currently hampered by uncertainties on the part of researchers and managers due to gaps in rigorous research, inadequacies in research protocols, and difficulties in linking pre-construction research results to 1) project siting and development decisions, and 2) the type, duration and intensity of post-construction monitoring (NWCC 2010). As with other industries in their infancy, regulatory agencies lack the expertise to manage environmental and direct or indirect wildlife impacts stemming from wind power developments (USGAO 2005).

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[4] http://www.eoearth.org/article/Altamont_Pass,_California (accessed October 10, 2010)
[5] http://www.eoearth.org/article/Altamont_Pass,_California (accessed October 10, 2010)
[6] http://www.windshare.ca/documents/AppC-WildlifeImpacts.pdf (accessed October 10, 2010)

British Columbia Enters the Wind Power Era

British Columbia (BC) is just entering the wind energy era. The drivers for rapid development are founded in legislation under the Utilities Commission Act for BC to be self-sufficient in electricity by 2016 and commitments to ensure minimally 90% of generated electricity continues to be from clean or renewable sources (ILMB 2010). Additional legislation is aimed at reducing greenhouse gas emissions by 33% by 2020. Parallel to the US experience, BC's energy objectives are being promoted by economic incentives while legislation and policies are still evolving (ILMB 2010). As experienced elsewhere, gaps in relevant legislation and policies represent a real potential for unexpected environmental impacts and unrealized mitigation efforts.

Independent power producers figure prominently in BC's 2007 energy plan and both the number and diversity of power generation applicants has increased significantly (ILMB 2010). Currently in BC there are ≈372 (Table 1) investigative use permits (IUP) for wind energy, 12 applications in the BC environmental assessment process, and nine wind energy projects with approved certificates. One approved project is currently producing power at Bear Mountain (34 turbines, 102 MW) and another wind farm on Dokie Ridge (48 turbines, 144 MW) is scheduled to commence operation early in 2011. A 156 MW expansion (52 turbines, Dokie Expansion Project), now under a separate EAO certificate, is being reviewed by the proponent with development status to be determined[7]. Based on energy purchase agreements with BC Hydro, production lifetime of wind energy projects is minimally 25 years, however, new purchase agreements and re-powering of wind farms (turbine upgrades) such as is currently being done in APWRA potentially extends production lifetimes indefinitely (Pettit 2010).

Table 1. Wind power permits in British Columbia as of Oct 14, 2010.

TNRSTG	TNRSTTS	TNRSBPRPS	Number
Application	Accepted	Investigative and monitoring phase	112
Application	Accepted	Investigative phase	5
Application	Allowed	Investigative and monitoring phase	2
Application	Allowed	Investigative phase	1
Application	Offer Accepted	Investigative phase	1
Application	Offered	Investigative and monitoring phase	25
Application	Offered	Investigative phase	3
Tenure	Disposition in good standing	Investigative and monitoring phase	199
Tenure	Disposition in good standing	Investigative phase	24

Following criteria presented in the BC Hydro Wind Data Study (2009), primary theoretical determinates of location for wind power projects are: 1) within 200 km of existing transmission lines, 2) long-term wind speed average ≥6.0 m/s, and 3) and sufficient constructible area (slope ≤20% and suitable terrain characteristics for construction). For projects situated on ridgelines, the ridge can not be oriented parallel to the wind's predominate direction and the ridge top must have a slope <20% over a width ≈100 m or more. Economies of scale tend to determine the minimum capacity (i.e., a minimum of 30 MW) of projects and hence the minimum number of turbines.

[7] http://www.plutonic.ca/s/DokieExpansion.asp (accessed October 12, 2010)

Spacing between turbines in a row, or between rows are generally expressed as multiples of rotor diameters and vary as a function of installed turbine type. Generally, spacing between turbines in a row is 4 rotor diameters, and spacing between rows is 15 rotor diameters. Using a 3.0 MW contemporary turbine with a ≈90m rotor diameter as an example, a 30 MW single row ridgeline project would minimally extend over ≈3.2 km (the BC Hydro model to identify potential wind energy project areas required a minimum ridgeline of 5 km). Potential project areas identified in the Peace Domain are predominately ridgelines (BC Hydro Wind Data Study 2009) with additional potential ridgeline projects identified in the revamped Northwest Domain (BC Hydro Wind Data Study Update 2009). Holt and Eaton (2008) also noted that wind resources in Peace region were primarily located in elevated areas with favorable exposure and terrain speedup effects. The cost of wind energy in the Peace Domain is expected to relatively low due to high wind speeds and a unidirectional wind regime (Holt and Eaton 2008).

The Current Regulatory Framework

The regulatory framework navigated by the wind energy sector in BC is much more cohesive and mature than the sector's US counterparts faced in the past. Obtaining approval for a wind energy project on Crown land in BC is a complex process requiring many permits and the need to interact with a wide variety of government ministries (ILMB 2010). Project size imparts an important distinction in the review process as projects ≥50 MW are under the auspices of the Environmental Assessment Office (EAO) while smaller projects generally lie within the domain of the Integrated Land Management Bureau (ILMB). Several triggers exist however, that may promote smaller projects into the provincial EAO process (transmission lines of 500 KV or higher and ≥40 km in length on a new right of way) or promote a project of any size into the Canadian Environmental Assessment Agency (CEAA) process (e.g., application for financial support initiatives, occurrence of a species at risk within the entire scope of the proposed project). The compatibility between the ILMB, EAO and CEAA processes and M-KMA wilderness values is unclear. It's not cynical to suggest that wind energy proponents may seek to avoid entering EAO or CEAA processes by limiting the size of a development project, or an a priori splitting of large developments across a complex arrangement of partnerships, subsidiaries and holding companies.

The opportunity for environmental impacts exists before proponents are required to conduct formal environmental assessments by any agency. IUPs are issued by ILMB to prospective developers and allow access to the land and investigation of the wind resource. An IUP does not allow building or improvements although there are provisions for technology that sits on the land and is not permanently attached to the land (e.g., self enclosed monitoring stations or equipment mounted on a private vehicle trailer under 5000 kg GVW; MEMPR 2010). IUPs are utilized for initial investigations to determine the siting of meteorological towers (tubular or lattice towers ≈50 m in height and equipped with instrumentation, cables and anchors). Installation of one or more meteorological towers requires a license of occupation (LO) and often an IUP and LO are applied for concurrently. Meteorological towers, like all structures, are mortality sources for birds (Young et al. 2003) and possibly bats, potentially involve clearing forest, and require periodic access for data collection and maintenance. In remote areas, access is expected to be primarily via helicopter; however, there are provisions for works permits to be issued during the monitoring and investigation phase that allow for roads, airstrips, bridges and trails. Areas with a high density of IUP/LOs may be subject to a high level of access disturbance. In particular, IUP/LOs on ridgelines or elevated sites may result in access disturbance at critical times of use by fauna such as grizzly bear (*Ursus arctos*) denning periods and caribou (*Rangifer tarandus caribou*) on winter ranges. For example, the Dokie Expansion Wind Project will use helicopters to access meteorological tower sites approximately every three months over a for two year period to collect data, conduct maintenance and change batteries[8]. Opportunities to identify access issues, upon application for an IUP/LO, are limited to a land status check to identify conflicts with federal or provincial protected areas or known sensitive areas, notice to the EAO, referrals to appropriate key agencies and groups, and advertisement (MEMPR 2010).

There are few legislative avenues that restrict the density of wind farms in an area exclusive of formal environmental review processes that may identify cumulative impacts. Current legislation stipulates buffers between wind farms based on Wake Effect (removal of wind energy from upwind turbines; ILMB 2010) and do not address issues regarding the density of wind farms with respect to environmental concerns. Piecemeal consideration of cumulative impacts can be expected to result in inappropriate spatial and temporal scales of analysis. The potential failure to adequately address cumulative impacts appears rooted in the 50 MW threshold for reviewable projects and the approach to issuance of IUP/IOs based simply on buffers. Its unclear how, after investments have been made on closely situated IUP/LOs by different proponents, an identified cumulative impact would be resolved. Conflicts between proponents and government may lead to compromises which may not reflect the best interest of ecological resources.

In the US the Bureau of Land Management (BLM 2005) has identified the adverse impacts that may occur over the life of a wind power project, from planning through to decommissioning. Potential impacts include: loss of cultural or paleontological resources; increased access; increased safety and human-health risks; impacts to visual resources; changes in land-use; release of hazardous materials; alteration or degradation of floral communities, wildlife habitat and rare or sensitive habitats; noise; interference with fish and wildlife species; geologic hazards and soil erosion; generation of dust; and the use of water and geologic resources. Broadly, ILMB, EAO, CEAA, the Ministry of Environment, Environmental Stewardship Division recognize a similar suite of management concerns with respect to wind farm projects (Table 2).

Existing policy on noise emitted during turbine operation in particular, appears insufficient (Kikuchi 2008) as it is only in relation to residences or residential zoned land. Complaints about noise levels from operating turbines are limited to owners of nearby residences or residential parcels (MEMPR 2010) and only if noise at the receptor exceeds the maximum acceptable level of 40 dB. Sounds emitted from operating turbines include mechanical sounds (caused by interacting turbine components) and aerodynamic sounds (caused by air flow over the blades; Rogers et al. 2006). Aerodynamic broadband (over a wide frequency range) sound is the largest component of wind turbine noise emissions (Rogers et al. 2006) and increases as wind speed increases. Much of the emitted aerodynamic sound from turbines is masked by the ambient sound of the wind, at least from a human perspective. Sound at frequencies

[8] http://www.arfd.gov.bc.ca/ApplicationPosting/getfile.jsp?PostID=15647&FileID=25162&action=view (accessed October 15, 2010)

Table 2. Primary management considerations recognized by provincial and federal regulatory bodies for wind farm projects.

Primary Management Consideration
Current traditional use of the land or its resources by aboriginal persons
Historic, archaeological, paleontological or architectural significance of the site
Mortality of resident or migrating birds/bats due to rotor/tower strikes
Mortality due to electrocution by transmission lines or due to striking transmission lines
Placement of wind power projects in sensitive ecosystems such as wetlands and alpine
Vegetation clearing during nesting periods of birds
Loss or fragmentation of wildlife habitat, particularly for red/blue or SARA listed species
Disturbance of wildlife due to construction activities
Destruction of identified plant or plant associations (red/blue or SARA listed species)
Increased access to wilderness and related increases in hunting, poaching or disturbance
Increased access to sensitive habitats and erosion or sedimentation due to off-road vehicle use
Destruction of riparian vegetation and fish habitat due to construction of crossings for roads or
Hydrologic regime impacts due to construction of wind projects and roads on sheet bogs
Construction impacts such as erosion, sedimentation or fuel spillage
Visual impacts on parks, protected areas and wilderness vistas.
Metal and acid rock leaching
Air quality
Noise during operation of the wind project

near (low frequency sound, 10 – 200 Hz) or below the threshold of human perception (infrasound, generally <20 Hz) is also emitted by turbines (Rogers et al. 2006). A lack of clarity is evident in the interpretation of infrasound and audible sound (Bellhouse 2004) and frequencies in the range of 2 – 100 Hz are perceptible to humans as a mixture of tactile and auditory sensations (Rogers et al. 2006). Current legislation on audible sound and general conclusions that turbines emit negligible levels of infrasound (Bellhouse 2004) are based solely on human perception – there is no consideration of noise interactions with local ecological processes. Animals have different audible ranges (Hz), can hear lower amplitude sounds (dB), and some mammalian (e.g., McComb et al. 2000) and fish species (Enger et al. 1993) have been shown to use infrasound for communication or otherwise respond to infrasound. Two features of infrasound may be relevant: 1) infrasound propagates farther than higher sound frequencies (Rogers et al. 2006), and 2) the dynamic range of infrasound (from perception threshold to discomfort) is smaller than for sounds at higher Hz (Bellhouse 2004).

Additional issues that require consideration include: 1) potential impacts due to turbine failure (structural failures[9] and fires[10]) that involve introduction of physical or chemical turbine components to the environment and ignition of wildfires; 2) insufficient legal requirements and financial obligations (insurance and security deposits) for project decommission and site reclamation, particularly in insolvency cases; 3) potential for, and government response to a large influx of proponent requests for IUPs stemming

[9] http://www.youtube.com/watch?v=CqEccgR0q-o&feature=related (accessed October 20, 2010)
[10] http://www.youtube.com/watch?v=rkGXoE3RFZ8&feature=related (accessed October 20, 2010)

from activities akin to wildcatting (looking for a resource in areas where it is not known to occur) of the wind resource; and 4) the ability of the various regulatory agencies to identify cumulative impacts of multiple wind power projects over spatial and temporal scales commensurate with ecosystem function.

A Review of Recent Research Results on Wildlife Impacts

Much of the early research into the environmental impacts of wind energy developments is deemed cursory, lacking in rigor, or proponent driven. The section focuses on more recent results from research recognized as rigorous. An additional focus is to identify gaps in research; however, many gaps in research relevant to the M-KMA can not be identified by literature review but only by a lack of literature to review. There appears to be a dearth of research on mammals in general (exclusive of bats) and large mammals in particular, reflecting the ecological differences between most established wind energy projects and those that will eventually be built in northern BC. The intent of this section is not to list vast quantities of fatality statistics per turbine or MW of installed capacity, but rather, on the project-specific features leading to extremes in these metrics.

Wind power facilities clearly kill birds and bats (direct impacts) and result in loss or degradation of habitat or alteration of ecosystem function (indirect impacts) for some species. Even where rigorous research results are available, more profound conclusions are not readily forthcoming. The appropriate choice of spatial and temporal scale for wind power impact analyses is difficult to determine (NRC 2007) and complicates cumulative analyses. Background levels of mortality prior to site construction are rarely known as is the degree to which mortality is additive or compensatory, biased towards certain sex or age components of affected populations, or significant at local or regional population levels. Much research is before/after monitoring without clear justification for the duration of either, and without appropriate controls or replication. A lack of consistency in research protocols (e.g., correction for searcher-efficiency bias and carcass persistence in morality counts, timing and duration of monitoring studies) and metrics by researchers make comparisons between studies difficult (USGAO 2005, NRC 2007). Project-specific differences in factors such as turbine technology, topography, weather, climate, soil types and vegetative cover also confound cross study comparisons and obscure simple conclusions as to the effect of individual factors. The impact of wind power projects vary by region, by species-specific vulnerability and also by project-specific features (USGAO 2005, NRC 2007).

Direct Impacts: Avian Species

Wind power facilities kill birds through collisions with towers or rotating turbines (NRC 2007), meteorological towers or supporting guy lines (Young et al. 2003), and collisions with or electrocution by transmission lines (Stemer 2005). High levels of raptor mortality has been the most noted direct impact of some facilities in California and Europe (Kunz et al. 2007b and references therein) but documented avian species mortality from available studies includes a large array of passerines (nocturnally migrating passerines in particular), waterfowl, owls, galliforms, and shorebirds among others (NRC 2007). Overall, resident and migrating passerines represent approximately three-quarters of recorded fatalities but relationships with characteristics of the wind power facilities are lacking. Data, however suggest that forested ridge top facilities may be more lethal (NRC 2007). Species abundance and behaviour appear to interact and influence risk of collisions with turbines. For example, species that perform aerial courtship displays are frequently reported in fatality statistics while other species such as Corvids that are observed to fly within the rotor-swept area of facilities are rarely reported (NRC 2007).

Features of wind power facilities related to high avian fatality may include turbine design, turbine numbers and density, turbine siting and turbine lighting required for aviation safety. Technological innovation in tower design, although generally considered to mitigate raptor fatalities, can have unexpected consequences. For instance, repowering APWRA with new, taller turbines has resulted in lower overall avian fatalities but increased fatalities of red-tailed hawks that fly at higher altitudes[11] and concerns exist that taller and larger turbines will similarly shift or exasperate fatality to other species elsewhere as turbines extend higher into the air column where nocturnally migrating passerines fly (NRC 2007). Individually, meteorological towers appear to be more lethal to birds than turbines (Young et al. 2003) although they have much lower densities on wind power facilities. The effect of aviation lighting on turbines or lighting of other wind power structures such as substations is equivocal. Although lighting has been demonstrated to attract nocturnally migrating birds and is associated with avian fatalities at tall structures such as communication towers, only one fatality event at a wind power facility has been clearly related to lighting (NRC 2007). It is however, the largest fatality event on record (33 passerine fatalities) and occurred during unusually heavy fog (Kerns and Kerlinger 2004). Some fatalities were attributed to collisions with a sodium vapour lighted substation in addition to collisions with turbines and Kerns and Kerlinger (2004) speculate that the sodium vapour lights rather than the red strobe aviation lights on the turbines attracted the birds to the facility. The NWCC (2010) similarly concludes that aviation lighting on turbines does not influence bird fatalities; however, inclement weather that forces passerines to lower elevations does influence fatalities.

Site characteristics such as proximity to key habitats or migration staging areas, and the surrounding vegetation community and topographic feature upon which the facility is located are all believed to influence avian fatalities (NRC 2007). The preponderance of nocturnally migrating passerines in wind power facility fatality statistics focuses much attention to migration behaviour. Migration patterns appear to be species-specific with species departing from, or going to geographically limited breeding or wintering ranges following restricted or narrow-front flight pathways. Species that have wider geographic breeding or wintering ranges tend to exhibit a broad-front or wide flight pathway (NRC 2007) and represent the majority of nocturnal migrators. The influence of local topography on pathways is equivocal; although variation exists, most species migrate at elevations sufficiently above ground level that response to topography appears negligible. Some evidence however, supports topographic responses by migrating birds to high, rugged mountain ranges. Although evidence is scant, general conclusions are that the majority of nocturnally migrating passerines fly at elevations above the rotor-swept area of turbines but become at risk during inclement weather that forces them closer to ground level or while accessing or departing staging areas proximal to wind power facilities (NRC 2007). Although not situating wind power facilities within migration flyways is desirable, this may be difficult to accomplish for broad-front migrators (Kikuchi 2008). Additionally, pre-construction monitoring may be of too short a duration to determine annual variation, or lack thereof, in migration routes (Kikuchi 2008).

[11] http://www.youtube.com/watch?v=RtgBWNKwBkE (accessed October 20, 2010)

The influence of wind power facilities proximal to key habitats may best be demonstrated by raptors. Ridge lines appear to be migratory pathways for raptors and as with features like canyons, provide favourable uplift thermal drafts and winds for soaring. Where such topographic features coincide with prey abundance, as in the case at APWRA, raptors may be both abundant and at significant risk of collisions with turbines (NRC 2007) placed on ridge tops and along canyons (USGAO 2005). While a large proportion of avian fatalities at wind power facilities are nocturnal migrating passerines, raptors highlight that local resident and breeding species are also at risk (Young et al. 2003).

Power transmission lines built to link wind power facilities to electrical grids also represent mortality sources for avian species. Conservative estimates of avian mortalities due to collisions with power transmission lines total ≥174 million birds (Kuvlesky et al. 2007 and references therein). For transmission lines proximal to wetlands, ducks, geese, cranes and swans are most vulnerable whereas transmission lines in upland habitats kill more raptors and passerines (Kuvlesky et al. 2007 and references therein).

General conclusions, exclusive of raptors, are that current avian mortality levels from wind power facilities are not significant and minimal to other anthropogenic sources of bird mortality (USGAO 2005, NRC 2007), notwithstanding that many facilities have not implemented post-construction monitoring programs or made results publicly available. Little is known however, about migratory flyways, species population levels and interactions between specific species and site-specific factors such as topography, weather, and turbine types (USGAO 2005, NRC 2007). Relatively low abundance coupled with long life spans, low reproductive rates and high trophic level suggest that impacts to raptors may be more detrimental than for other avian species (NRC 2007).

Direct Impacts: Bat Species

The few early studies that documented bat fatalities at wind power facilities likely represent underestimates as documented bat fatalities were by-products of avian mortality studies (USGAO 2005). More recently, wind power facilities have been documented to kill large numbers of bats in the US, Europe and south-western Alberta (Kunz et al. 2007b and references therein). Wind power facilities kill bats through collisions with turbine blades (NRC 2007 Horn et al. 2008) and by barotrauma caused by exposure to rapid air-pressure changes proximal to trailing edges and tips of rotating turbines (Baerwald et al. 2008). Most bat fatalities occur during the bat migratory seasons (approximately May/June and August – October in BC; Brigham 2010) and in particular during autumn migration and during periods of low wind speed (<6 m/s) when flying insect activity is greatest (Kunz et al. 2007b and references therein). Aspects of bat ecology may confound simple conclusions. For example, temperate-zone insectivorous species generally mate in autumn and aspects of mating behaviour may account for increased vulnerability to wind turbines (Cryan and Barclay 2009).

Migratory species that roost in trees and migrate long distances appear to be most vulnerable to fatality at wind power facilities (Kunz et al. 2007b, NRC 2007). Of the bat species confirmed as fatalities at wind power facilities (Kunz et al. 2007b), six occur in

BC[12] (hoary bat [*Lasiurus cinereus*], western red bat [*Lasiurus blossevillii*], silver-haired bat [*Lasionycteris noctivagans*], little brown myotis [*Myotis lucifugus*], northern long-eared myotis [*Myotis septentrionalis*], and big brown bat [*Eptesicus fuscus*]). Of these six species, hoary bats and silver-haired bats are the most common fatalities (Kunz et al. 2007b). As with birds, little is known about migratory flyways, species population levels, bat behaviour and interactions between specific species and site-specific factors such as topography, weather, and turbine types, densities and sitting (USGAO 2005, NRC 2007). Recent research in southern Alberta suggests that hoary bats and silver-haired bats follow select migratory routes at least in autumn (i.e., narrow-front pathways) in response to specific landscape features or vegetation communities (Baerwald and Barclay 2009). Applicability of these findings to other locations is unclear as both species roost in trees and may have avoided open prairie habitats in favour of forested foothills of the Rocky Mountains. Migration routes over extensive forested landscapes habitats may not exhibit similar narrow-front pathways.

Turbines situated on forested ridge tops in the eastern US appear to be more lethal to bats (Kunz et al. 2007b and references therein). Large numbers of fatalities however, have also been reported from wind power facilities in agricultural settings in northern Iowa and south-western Alberta, and from mixed-grass prairie settings in Oklahoma (Kunz et al. 2007 and references therein). A lack of rigorous monitoring for bat fatalities at many wind power facilities (Kunz et al. 2007b) suggests that the site characteristics and seasonal aspects associated with bat fatalities are incomplete. The variety of landscape settings from which large numbers of fatalities have been reported however, suggests a lack of correlation between landscape features and bat fatalities at wind power facilities (Cryan and Barclay 2009). Most bat species that appear as fatalities from wind turbines are also summer residents, likely at risk during summer months, and warrant more rigorous investigation (Kunz et al. 2007b).

Bat collisions with buildings or communication towers appear relatively rare (NYSERDA 2005, NRC 2007, Cryan and Barclay 2009 and references therein) and fatalities of bats at wind power facilities represent an unprecedented anthropogenic mortality factor for bats (Cryan and Barclay 2009). A suite of non-mutually exclusive hypotheses to explain why bats are killed by wind turbines have been postulated by Kunz et al. (2007b; Table 3) and a similar set of hypotheses has been presented by Cryan and Barclay (2009). Available evidence does not support an attraction to wind turbine aviation lights by bats although insects may be attracted to some wind turbine lights (Horn et al. 2008) and evidence is inconclusive as to whether bats do not echolocate during migration (Kunz et al. 2007b) and are at greater risk of collisions.

Horn et al. (2008) used thermal infrared cameras to study bat behaviour and observed bats foraging near operating wind turbines and at heights equal to or above the turbine nacelle (70 m agl). Bats were also observed approaching rotating and stationary turbine blades, and investigating the turbine structures with multiple fly-bys or by landing on stationary blades and monopoles. Investigation of turbines and monopoles may be related to roosting behaviour as tree roosting species prefer taller trees (Cryan and Barclay 2009). Additional observations by Horn et al. (2008) include bats being trapped in blade-tip vortices, and being struck by rotating turbine blades. Collisions with turbine

[12] http://www.geog.ubc.ca/biodiversity/efauna/documents/MammalsofBCChecklist.pdf (accessed October 23, 2010)

Table 3. Explanatory hypotheses for bat fatalities at wind power facilities (adapted from Kunz et al. 2007b).

Hypothesis	Details
Linear Corridor	Wind power facilities situated on forested ridge tops create clearings and linear landscapes (roads, power lines) that attract foraging bats
Roost Attraction	Bats are attracted to wind turbines as potential roosts
Landscape Attraction	Insect prey are attracted to altered landscapes that surround wind turbines
Low Wind Velocity	Fatalities of migrating or feeding bats peak during periods of low wind velocity when flying insects are most active
Heat Attraction	Insect prey are attracted to heat produced by wind turbine nacelles
Acoustic Attraction	Audible and (or) ultrasonic sound produced by wind turbines attract bats
Visual Attraction	Wind turbines are visually attractive to nocturnal insects
Echolocation Failure	Bats are unable to acoustically detect rotating turbine blades or else miscalculate rotor velocity
Electromagnetic Field Disorientation	The complex electromagnetic fields produced by wind turbines cause bats to become disoriented
Decompression	Rapid air-pressure changes cause internal injuries and (or) disorient bats foraging or migrating proximal to wind turbines
Thermal Inversion	Thermal inversions cause dense fog in cool valleys that concentrates bats and insects on ridge tops

blades however, may be implicated in only about one-half of bat fatalities (Baerwald et al. 2008). Internal haemorrhaging consistent with barotrauma was found in 90% of bat fatalities with 57% of bat fatalities only exhibiting internal haemorrhaging, 34% of fatalities exhibiting both internal haemorrhaging and external injuries, and 8% of fatalities with only external injuries (Baerwald et al. 2008). In general, it appears that taller turbines are more lethal to bats (Baerwald and Barclay 2009).

Like raptors, bats have long life-spans and low reproductive rates. Among insectivorous bat species litter sizes average 1.2 offspring with typically only one litter per year for temperate-zone species (Barclay and Harder 2003). Data is lacking as to the proportion of females that produce litters annually (Barclay and Harder 2003). Bat life history parameters may predispose them to higher probabilities for population decline due to estimated cumulative impacts from wind power development (Kunz et al. 2007b). In some regions species of bats are in decline, and increased numbers of turbines may result in population level effects (NRC 2007 and references therein). Trends to larger and taller turbines may also increase impacts to bats that feed or migrate at higher altitudes (Kunz et al. 2007b). Monitoring studies at the Dokie Ridge wind farm in northern BC have confirmed the presence of two species prone to fatality at wind power facilities (big brown bats and silver-haired bats) and documented that bats use high elevation sites during migration (Pomeroy et al. 2008). Hoary, silver-haired and big brown bats have also been documented at the Bear Mountain Wind Park (Palmer and Paterson 2010). To the extent that bats are attracted to turbines, pre-construction monitoring studies may not reveal the full extent of probable impacts to local bat species.

Direct Impacts: Conclusions

Predictions and mitigation of direct impacts for proposed facilities are based on results of post-construction studies at existing facilities. As wind power facilities extend their geographic reach, many projects will be built without the advantage of local research and will rely on research results that may not be compatible with local conditions. For example, most wind power facilities have been constructed in agricultural, grassland and desert landscapes in the west or mid-west Continental US or more recently on forested ridge tops in the east (Kunz et al. 2007b), there appears to be little information available for wind power facilities built on subalpine and alpine ridge tops such as is expected in northern BC. Wind power facilities constructed on topographic features that have limited extent but represent important habitat for some species, such as ridgelines, may have significant impacts on those species (NRC 2007). The rapid development of wind power is likely to result in unanticipated and unprecedented impacts on local or regional wildlife populations as has been recently noted for bats (Kunz et al. 2007b, Horn et al. 2008, Cryan and Barclay 2009).

Indirect Impacts and Effects on Ecosystem Structure

Indirect impacts in the form of habitat loss and alteration, habitat avoidance by, or disturbance to wildlife, associated with wind power facilities vary with the landscape setting within which they are situated. Impacts are less in agricultural settings (NRC 2007) than in forested environments and in all likelihood subalpine and alpine settings. Estimates of facility footprints, the surface area directly disturbed, range from 0.4 ha/turbine to 1.2 ha/turbine (NRC 2007, BLM 2005). Young et al. (2003) reported the total area of permanent ground disturbance (roads, substation, and turbine pads) as 10.8 ha for a 69 (600 KW) turbine project (≈0.2 ha/turbine). The Bear Mountain Wind Park in northern BC, a 34 (3 MW) turbine project, has a footprint of 25 ha (0.7 ha/turbine; Pettit 2010).

Clearings in forest habitat, such as for turbines, result in altered microclimates due to increased exposure to light and wind. Clearings exhibit increased temperature, reduced relative humidity and lower soil moisture (NRC 2007 and references therein). Given that wind power facilities are built in areas of favourable wind resources, forest clearings for roads, transmission lines, turbines and substations may experience elevated levels of wind throw along edges and subsequent alterations to forest structure. Forest edges also create changes in abundance and distribution of wildlife species, and may influence predation, competition between species and brood parasitism in birds (Bosworth 2003). The effect of forest edges can extend from 250 m (Robinson et al. 1995) to 340 m (Wood et al. 2006) into the forest for neotropical migrant bird species, greatly increasing estimates of habitat loss or functional alteration.

Soil density on roadbeds tends to increase and can persist even on closed roads for periods >40 years (NRC 2007). Roads are sources of dust and can alter surface water flow, sediment, foster accumulations of nitrogen-based nutrients and pollutants along road edges, encourage introductions of invasive species, and alter trophic relationships. Roads are also sources of direct impacts (wildlife mortality) through wildlife – vehicle collisions, wildlife disturbance and avoidance, and can cause barrier effects and habitat fragmentation (Forman and Alexander 1998). As with forest edge, effects of roads extend well beyond the actual footprint. For example, caribou exhibit avoidance of habitat within 250 m of roads and within 1 km of well sites (Gustine 2005 and references therein) and grizzly bears have been shown to avoid habitats within 100 m of roads (McLellan and Shackleton 1988), and within 500 m of roads during spring and summer, and even further in autumn (Mattson et al. 1987). Ciarniello et al. (2002) reported grizzly bear avoidance of roads up to 2.5 km.

Access improvements have additional impacts. Road side cuts may increase rodent populations (and attract predators) due to creation of favourable habitat for burrows. The all-season roads required for wind power facilities may also permit predators such as wolves (*Canis lupus*) to access caribou winter ranges[13]. Without proper access management, roads to high-elevation wind power facilities may create opportunities for ATV and snowmobile access into alpine habitats. Human-caused mortality of grizzly bears has repeatedly been identified as a prime determinant of grizzly bear population status (Herrero et al. 2000; McLellan et al. 1999) and is mediated by increased access into once remote areas. Access promotes increased human – bear encounter rates and increased bear mortality rates due to deliberate (shooting) and accidental (vehicle collisions) human actions (McLellan and Shackleton 1988; McLellan 1990). In addition to direct human-caused mortalities of grizzly bears resulting from access developments, indirect mortality may result from habitat displacement, habitat degradation, and reduced reproductive potential (Mace et al. 1999). Similar conclusions have been reached for ungulates (Walter et al. 2006 and references therein).

In North America, avoidance of wind power facilities by birds has been poorly documented. Comparisons between turbine plots and references plots at one facility indicated that birds avoided flying in areas with turbines, and a study of male songbirds concluded that species-specific densities were significantly lower within 180 m of the turbines than they were in similar habitats lacking turbines. Additional research at the same facility concluded that displacement of birds by turbines was primarily within ≤100 m of turbines (NRC 2007 and references therein). Pearce-Higgins et al. (2009) examined the responses of 12 avian species to wind-power infrastructure (turbines, roads and transmission lines) at 12 upland wind power facilities. They found that seven species had significantly lower occurrence frequency close to turbines, avoidance of turbines was more pronounced than for roads, and there was no consistent avoidance of transmission lines). Avoidance of turbines was not absolute with breeding bird densities reduced by 15 – 53% within 500 m of turbines. Both greater prairie chickens (*Tympanuchus cupido*) and greater sage grouse (*Centrocercus urophasianus*) avoid transmission lines by at least 500 m, possibly in response to raptors that use transmission lines as perches (Pruett et al. 2009). In general, prairie chickens and sage grouse avoid disturbed areas (Pruett et al. 2009, NRC 2007) and wind power infrastructure may act as barriers to movement and impinge upon connectivity.

Research on avoidance and other behavioural responses to wind power facilities by terrestrial mammals is even scarcer. Kikuchi (2008) concluded that squirrels living at turbine sites exhibit behavioural differences (increased vigilance) as compared to those at a control site without turbines and that turbine noise may be responsible. Walter et al. (2006) monitored radio-collared elk (*Cervus elaphus*) during construction and operation of a wind power facility in a mixed land-use setting. Using metrics of home range and

13 www.vancouversun.com/technology/Caribou+threatened+wind+farms+expert+says/3008130/story.html (accessed November 25, 2010)

dietary quality they concluded that elk were not adversely affected by wind power development. Walter et al. (2006) suggest that behavioural acclimation by ungulates to anthropogenic disturbances accounts for the lack of habitat displacement and that ungulates will often acclimate to wind power infrastructure once primary disturbance sources such as construction are concluded.

Indirect Impacts and Effects on Ecosystem Structure: Conclusions

In conclusion, wind power developments result in some loss of habitat through direct modification but also additional habitat is lost through wildlife behavioural responses (e.g., avoidance) and effects on ecosystem structure (e.g., forest edge effects). Other impacts accrue however, including diminished habitat connectivity and fragmentation, the effects of which may not be immediately apparent. Some impacts of wind power facilities may be counterintuitive and arise from unanticipated interactions. For example, cattle graze on the Bear Mountain Wind Park and livestock grazing is viewed as a traditional and compatible land use (Pettit 2010); however cattle grazing on the APWRA have reduced grass cover making rodents more visible to raptors and raptors more prone to collisions. Cattle dung also attracts insects which may attract insectivorous birds or bats to the facility[14].

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