The Prediction of Moose-Vehicle Collisions in Mount Revelstoke and Glacier National Parks, Canada

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Abstract: Moose (Alces alces)-vehicle collisions (MVC) can result in large ecological and socio-economic costs. The increasing number of MVC across Canada are resulting in population-level effects for moose, greater numbers of human injury and mortality, and increased costs to motorists and insurance companies. In my thesis I developed a set of predictive models to better understand MVC and the locations where they might occur on the Trans Canada Highway bisecting Mount Revelstoke and Glacier National Parks in British Columbia, Canada.

I used logistic regression and expert-based approaches to develop MVC predictive models. Logistic regression models represented local-scale/field-based hypotheses of driver visibility, moose evidence, highway design, roadside vegetation, and moose habitat, as well as landscape-scale hypotheses based on Geographical Information System (GIS) data. I used the Analytical Hierarchy Process (AHP) to develop the expert-based models. Experts were classified as either local or non-local depending on whether their career-related experience was within the 2 National Parks. Experts weighted variables that were within either habitat or driver models. I used the Receiving Operator Characteristic (ROC) to measure the predictive accuracy of the logistic regression and expert-based models. I used the Kappa Index of Agreement (KIA) to compare maps of predicted MVC susceptibility generated using logistic regression and expert-based models.

The logistic regression model based on GIS data was the most successful predictor of MVC. Among the local-scale logistic regression models, the moose evidence model correctly classified the most MVC. For this model, variables moose tracks and game trails were statistically significant predictors of MVC. Of the expert-based models, habitat-related criteria...
were more effective at predicting MVC than driver-related criteria. Most experts weighted moose habitat as the most important factor influencing MVC. Local experts provided weightings that best represented MVC.

The SRC and KIA suggested that habitat-based expert models were more closely associated with the logistic regression model using GIS data than were driver-based expert models. The logistic regression model was only a slightly better predictor of MVC when compared to the expert-based models. In many cases, empirical data may not be available for constructing logistic regression models, thus expert-based modeling can be used as a substitute for developing effective predictive models. Highway planning to reduce MVC risk within Mount Revelstoke and Glacier National Parks should begin by assessing landscape-scale models using both logistic regression and expert-based modeling. Furthermore, finer-scale models using logistic regression moose evidence and habitat models should be completed at high risk MVC locations previously identified by the landscape-scale analysis.
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**Glossary**

<table>
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<th>Description</th>
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<tbody>
<tr>
<td>AIC</td>
<td>Akaike Information Criterion</td>
</tr>
<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
</tr>
<tr>
<td>AT</td>
<td>Alpine Tundra</td>
</tr>
<tr>
<td>BCMOT</td>
<td>British Columbia Ministry of Transportation</td>
</tr>
<tr>
<td>BCMOF</td>
<td>British Columbia Ministry of Forests and Range</td>
</tr>
<tr>
<td>ELC</td>
<td>Ecological Land Classification</td>
</tr>
<tr>
<td>ESRI</td>
<td>Environmental Systems Research Institute</td>
</tr>
<tr>
<td>ESSF</td>
<td>Englemann Spruce-Subalpine Fir</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>ICBC</td>
<td>Insurance Corporation British Columbia</td>
</tr>
<tr>
<td>ICH</td>
<td>Interior Cedar Hemlock</td>
</tr>
<tr>
<td>KIA</td>
<td>Kappa Index of Agreement</td>
</tr>
<tr>
<td>MVC</td>
<td>Moose-Vehicle Collision</td>
</tr>
<tr>
<td>ROC</td>
<td>Receiver Operating Characteristic</td>
</tr>
<tr>
<td>SRC</td>
<td>Spearman Rank Correlation</td>
</tr>
<tr>
<td>TRIM</td>
<td>Terrain Resource Inventory Management</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Transverse Mercator</td>
</tr>
<tr>
<td>WARS</td>
<td>Wildlife Accident Reporting System</td>
</tr>
<tr>
<td>WVC</td>
<td>Wildlife-Vehicle Collision</td>
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Acknowledgements

The completion of this research is primarily a result of the dedication and enthusiasm of the participating experts. I would like to thank all the experts who committed time and energy to the progression of model development. Mount Revelstoke and Glacier senior park warden John Flaa went above and beyond his call of duty in providing spatial and collision data, not to mention the generous in kind support throughout the field season. Logistical and theoretical support by companions Tony Clevenger, Kari Gunson, and Bryan Chruszcz was influential and greatly appreciated.

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1.0 Chapter I: The Issue of Wildlife-Vehicle Conflicts

1.1 Introduction

This thesis is an investigation of different methods used to determine which variables play a significant role in Moose-Vehicle Collisions (MVC) in Mount Revelstoke and Glacier National Parks. First as an introduction, the issue of Wildlife-Vehicle Collisions (WVC) will be placed into the overall context of the ecological effects resulting from transportation infrastructure. This discussion will be followed by an explanation of the issue of WVC including ecological concerns, traffic safety, and economic considerations. The contributing factors and patterns of WVC will then be detailed including animal abundance, traffic intensity, and landscape patterns. This introductory section will conclude with past modeling approaches in the field of WVC research, the specific thesis objectives, and a description of the study area. In the remainder of the thesis I present three research papers. In the first study, I aim to model MVC and to better understand the underlying processes using a logistic regression modeling approach with both GIS and field data. In the second paper I also aim to model MVC, however, here I use an expert-based modeling approach. In the third chapter, I comprised a study which directly compares each modeling approach and its efficiency in predicting MVC. In the concluding chapter I provide a research summary along with associated management responses.

1.2 Ecological Impacts of Transport Infrastructure

1.2.1 Context of Natural Landscape Processes

Land processes involve flow, movement, and transport through space. Forman (1999) defined horizontal natural processes or ecological flows (e.g., surface water, groundwater, animal foraging, migration, plant dispersal, wind erosion, and deposition) as movements that cross two
or more ecosystems or land uses. Applying the concept of horizontal natural processes to planning, conservation, design and management is logical and has advantages. Rather than the tendency of identifying and arranging landscape objects in geometric patterns to achieve a goal, the application of horizontal natural processes mimics nature in irregular and aggregated patterns (Forman 1999). Landscapes impacted by humans that are shaped and sized to mimic natural forms are more likely to be maintained by further natural process though time, making for a sustainable compilation of habitat mosaics (Marsh 1998, Forman 1999). Roads are one of many entities contributing to a complex human ecological imprint. In considering the impact that road infrastructure has on the environment, effort must first and foremost be focused on the disrupted ecological processes.

The impacts associated with modern highway systems on wildlife are greater than any other period in history (Messmer and West 2000). Transportation infrastructure imposes a wide spectrum of effects on wildlife and the environment in general including contamination (Forman and Alexander 1998), hydrologic disturbance (Beasley and Kneale 2002), acoustic disturbance (Kastner-Klein 1998), habitat alteration, corridor creation (Seabrook and Dettmann 1996, Parendes and Jones 2000), and barrier effects (Askins et al. 1987, Malo et al. 2004) (Table 1.1).
Table 1.1 Summary of the ecological impacts of road infrastructure construction and maintenance

<table>
<thead>
<tr>
<th>Ecological Impact</th>
<th>Effect</th>
<th>Reference</th>
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<tbody>
<tr>
<td><strong>Contamination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Construction activity</td>
<td>- Potential pH change</td>
<td>- McGuire and Morrall 2000</td>
</tr>
<tr>
<td></td>
<td>- Erosion</td>
<td></td>
</tr>
<tr>
<td>- Dust/Particulate matter</td>
<td>- Poor driver visibility and road conditions</td>
<td>- Forman and Alexander 1998</td>
</tr>
<tr>
<td></td>
<td>- Impacts on fish and other aquatic life by increased turbidity, and sedimentation</td>
<td>- Spellerberg 1998; Nixon and Saphore 2003</td>
</tr>
<tr>
<td>- De-icing salt</td>
<td>- Degradation of vegetation, soil and biological health through addition of sodium and chloride to surface and groundwater</td>
<td>- Fraser and Thomas 1982; Underhill and Angold 2000; McGuire and Morrall 2000</td>
</tr>
<tr>
<td></td>
<td>- Changes in ecological community composition</td>
<td>- Forman and Alexander 1998; Seiler 2001</td>
</tr>
<tr>
<td>- Vehicle emissions</td>
<td>- Air pollution</td>
<td>- Forman 1999</td>
</tr>
<tr>
<td><strong>Hydrology Disturbance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Increased water, hydrocarbon and heavy metal run-off</td>
<td>- Alterations in the composition of stream macroinvertebrate communities</td>
<td>- Boxall and Maltby 1997; Beasley and Kneale 2002</td>
</tr>
<tr>
<td>- Streamflow alteration</td>
<td>- Combination of culverts and ditches cause higher discharge therefore increased erosion and sedimentation</td>
<td>- Richardson et al. 1975; Riley et al. 1984; Newcombe and Jensen 1996</td>
</tr>
<tr>
<td><strong>Acoustical Disturbance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Wind</td>
<td>- Increase in pollution dispersal</td>
<td>- Kastner-Klein 1998; Trombulak and Frissell, 2003</td>
</tr>
<tr>
<td>- Noise</td>
<td>- Bird population decrease</td>
<td>- Forman 1999</td>
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Table 1.1 continued....

<table>
<thead>
<tr>
<th>Ecological Impact</th>
<th>Effect</th>
<th>Reference</th>
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<tr>
<td>Habitat alteration and corridor creation</td>
<td>- Linear habitat on the road verge</td>
<td>- Road verge habitat is a positive spin-off from road construction</td>
</tr>
<tr>
<td></td>
<td>- Wildlife corridors along road verges</td>
<td>- Creation of migration routes of native species and dispersal of exotic species.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Underhill and Angold 2000</td>
</tr>
<tr>
<td>Physical Barriers to Wildlife Movement</td>
<td>- Barrier effect</td>
<td>- Habitat fragmentation and barrier to dispersing species</td>
</tr>
<tr>
<td></td>
<td>- Wildlife-vehicle collisions</td>
<td>- Wildlife mortality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Clevenger et al. 2002a; Finder et al. 1999; Seiler 2001; Malo et al. 2004</td>
</tr>
</tbody>
</table>

Transportation infrastructure dissects wildlife habitat, movement corridors and feeding areas. Maintenance and operational activities introduce noise and deleterious pollutants. All of these indirectly affect natural ecological processes (Seiler 2001). The extent of the ecological effect that a certain road imposes varies depending on the environmental characteristics, additional unrelated land uses, and the specific road features. Nevertheless, the ecological effect of any given road and its associated infrastructure stretches over a range of distances.

Forman and Alexander (1998) define the area that encompasses the associated ecological effects as the road-effect zone. The road-effect zone varies depending on the topography, hydrology, wind speed and direction, and biotic factors such as animal movement requirements. The most imminent impact is the possible direct loss of habitat where the road is created. The habitat adjacent to the road that although is not directly lost, may be altered and decreased in
quality (Forman 1999). Seiler (2001) claims that the long-term impact of habitat loss, disturbance, barrier and mortality effects on populations and ecosystems depends on the type of infrastructure, landscape, or species considered. Habitat loss, from road construction, matters at a local scale and becomes more detrimental as road width increases. Also, individual roads and railroads are characteristically part of an overall infrastructure network. Thus, synergetic effects with other infrastructure entities or landscape features may aggravate or weaken the significance of the ecological effect (Seiler 2001).

1.2.2 Direct Wildlife Mortality

The ecological impact of barrier effects includes the issue of collisions between motor vehicles and wildlife, and has been attracting attention for many years. WVC are one of the several ecological issues associated with transportation infrastructure. Mortality within transportation corridors is one of many accidents that wildlife may encounter, including abandonment, drowning, falling, or entanglement (Child 1998). Incidental mortality of wildlife incorporates various accidents that can have impacts on population numbers and management programs (Child 1998).

Traffic causes the death of many animals that try to cross a road or railroad (Putnam 1997, Bashore et al. 1985, Schwabe 2000, Clevenger et al. 2002a). WVC are sometimes considered a severe threat to the population viability of certain species (Thomas 1995, Forman and Alexander 1998, Trombulak and Frissell 1999, Jackson 2000, Rudolph 2000). Vehicle-related mortality can have substantial effects on population demographics. For example, collisions with vehicles are the primary cause of death for moose in Kenai National Wildlife
Refuge in Alaska (Bangs et al. 1989). Mortality is a principal threat to species with slow reproductive rates, specialized habitats or migratory behaviours (Trombulak and Frissell 1999).

Putnam (1997) reported that a high ungulate-vehicle collision rate is not sufficient to threaten population status. Thus, an opposing view is that road mortality does not have as significant of an impact on the population level of wildlife as that caused by the barrier effect (Forman 1999). The barrier effect of transportation routes, however, subdivides populations resulting in potential population decline. In considering the road-effect zone described by Forman (1999), the goal of transportation infrastructure planning should be to maintain natural ecological flows by limiting the barrier effect. Theoretically, this concept appears sound; however, relies on maintaining natural ecological flows. If even a slight barrier effect is prevalent, as appears to be the case with any road, the addition of the road kill effect could, depending on the species, combine to cumulatively impact a given population. Thus in maintaining the natural ecological flow theory of Forman (1999), the road kill effect rarely acts alone in triggering population declines.

The free flow of fauna across a road might function well given that adequate passages are available. Because passages are not always economically feasible, the most advantageous option would be to prevent the necessity for wildlife crossing roads by planning transport infrastructure in areas that avoids habitat and corridor dissection. In reality, the quagmire of wildlife and roads will always be present, implying that mitigation measures will be necessary. Roads and railways represent an inevitable landscape characteristic in the modern world, providing access and benefits to society as a whole. The direct impact of road infrastructure and vehicles must be
viewed in the context of maintaining a balance among the transportation needs of society, economical constraints and particularly the preservation of ecological integrity across the landscape.

1.3 Wildlife-Vehicle Collisions in an Ecological and Socio-economic Context

WVC are a serious socio-economical and ecological problem (Bashore et al. 1985, Child et al. 1991, Del Frate and Spraker 1991, Oosenburg et al. 1991, Romin and Bissonette 1996, Finder et al. 1999). Across rural Canada, the issue of collisions between large animals and motor vehicles poses challenges due to the fact that the land bordering highways is typically wilderness and open range where large animal crossings are common. This issue is, however, not unique to British Columbia nor Canada. Other countries experience a similar problem in preventing and mitigating the occurrence of animal-vehicle conflicts (Moen 1979, Lavsund and Sandegren 1991, Inbar et al. 2002). WVC are a common phenomenon causing injury or death to both animals and humans. The Insurance Corporation of British Columbia (ICBC) reported WVC in British Columbia increased from 7,267 collisions in 1997 to 9,789 in 2001 (L-P Tardif & Associates Inc. 2003). Between 1996 and 2005, ICBC recorded 2,536 bears, 1,768 elk, 73 caribou, 6,039 domestic animals, and over 5,000 unknown animal species as being struck (Road Health-University Wildlife Collision Mitigation Research Team 2006). Nearly 3,000 MVC occur annually in North America (Child 1998) and 200 to 300 moose are killed on major British Columbia highways each year (Child et al. 1991, Sielecki 2004). Approximately 4,800 moose were reported killed on Newfoundland roads between 1988 and 1994 (Joyce and Maloney 2001) and up to 17,000 deer vehicle accidents in Michigan alone in 1978 (Hansen 1983). These figures are conservative and do not take underreporting into consideration or the unknown number of
mortalities on rural roads such as logging and mining roads. If the impacts of trains are included, this number is approximately doubled within British Columbia (Child et al. 1991).

1.3.1 Traffic safety and economical concerns

The financial impact of WVC is a combination of reported accidents, unreported accidents, accident clean-up, lost provincial hunting license revenues, and loss of wildlife value (Sielecki 2004). The average material damage claim following a WVC ranges from approximately $4,000 to $15,000 US dollars per vehicle depending on the species in question (Del Frate and Spraker 1991, Thomas 1995). In British Columbia, the average WVC claim in 2000 was $2,200 and $2,800 in 2001 (L-P Tardif & Associates Inc 2003). Between 1997 and 2002, ICBC paid out over $144.5 million in WVC claims and estimated that this figure only accounted for 75% of the total cost due to underreporting (Sielecki 2004). These figures cover single insurance claims of material damage and injuries only and do not consider externalities of loss such as hunting opportunities, traffic delays, highway contractors, police, ambulances etc. The cost for British Columbia Ministry of Transportation Maintenance Contractors to clean up WVC sites was over $5.6 million from 1997-2002 (Sielecki 2004). If every WVC represented a hunting license, the province of British Columbia lost between $75,000 and $610,000 in 2001 (Sielecki 2004).

Efforts have been made to determine the optimal wildlife density in economical terms. Ritz and Ready (2000) established the total economic benefit of one deer to be $98-$223, while the total economic cost was set at $190. Benefits from a larger deer population include hunting and wildlife viewing values. Costs from a larger deer population include deer-vehicle collisions.
and browsing damage to residential plantings, agricultural crops, and forests. Caution must be used when applying the cost-benefit analysis of Ritz and Ready (2000) due to the exclusion of non-quantifiable factors that include non-consumptive values.

The WVC issue should also be viewed from a human safety perspective. The number of injuries in British Columbia rose from 218 to 386 injuries during the period from 1997 to 2001 (L-P Tardif & Associates Inc. 2003). Human injury results from approximately 14% to 18% of collisions with larger mammals such as moose (Joyce and Mahoney 2001). Pynn and Pynn (2004) stated that WVC are a worldwide issue of importance to health care professionals and that as highway networks expand and traffic volume and speed increase, the incidence of collisions also increases. WVC involving large mammals are almost always fatal to the wildlife species and seldom result in human deaths (Pynn and Pynn 2004). Human injuries can be traumatic, depending on the speed at which the automobile was traveling and the type of animal struck (Danielson and Hubbard 1998). In a direct collision, a large animal is typically struck at the legs, causing its body to roll onto the hood and collapse into the windshield and roof (Pynn and Pynn 2004). Due to the severity of injuries and length of rehabilitation associated with a large animal WVC, psychological effects must also be considered. Up to 25% of severely injured patients experience a significant psychological reaction after trauma (Bowley and Boffard 2002). In 3% to 6% of adults involved in large animal WVC, long-lasting psychological reactions are triggered by memories of the event (Pynn and Pynn 2004). As with ecological damage, the socio-economic costs are often underestimated because the assessment methods are inadequate (Seiler 2005).
1.3.2 Effect of Wildlife-Vehicle Collisions on Populations

What distinguishes species that are vulnerable to WVC to those that are not? What is the threshold for survival and management? How great of a loss should be tolerated ecologically? These thresholds may never be known, especially when integrated, however, they must be considered in regards to incidental mortality, road planning, mitigation, and the setting of harvest goals. Wildlife management programs may never achieve their desired goals because continual losses from WVC may threaten both optimal population levels and socio-economic conditions (Child 1983). Frequently, there is uncertainty in assessing the overall consequence of WVC to populations and management due to underreporting of collisions and additional means of incidental mortality (Sielecki 2004). Decisions should therefore incorporate the precautionary principle stating that where there are threats of serious or irreversible damage: lack of full scientific certainty should not be used as a reason for postponing measures to protect environmental degradation (Mitchell 2002).

In British Columbia, road mortality is incorporated into calculations used in harvest management (Child et al. 1991). At the provincial level, road and rail mortality represents about 9.1% of the provincial annual allowable harvest of moose (Child et al. 1991). No adjustments in harvest are made in the Lower Mainland, Kootenay, Cariboo or Peace regions while adjustments in other British Columbia regions range from 4% to 20% (Child et al. 1991). This immediately raises the question of approximately what percent of annual harvest should be used to compensate for road mortality. An increase in the percentage of road mortality is not completely additive or compensatory so increases can be misleading. Similar to the estimation of a maximum sustainable yield in game or fish, the estimation of an ecologically ‘sustainable’ level...
of road mortality should relate to population growth rather than population size or proportional kill (Seiler 2005). In other words, the evaluation should be within the context of population demography, considering sex ratios and rates of mortality, fecundity, immigration and emigration. In this context, the aim of a management strategy should be to balance the ecological integrity of game populations with the needs of society.

1.4 Contributing Factors and Patterns of WVC

More knowledge of where, when, and why WVC occur is needed before any single factor can be considered critical, warranting management and/or mitigation. Wildlife and transportation managers might ask why a given animal enters the transportation corridor and what the odds are of a successful crossing. Vehicle drivers would be interested in knowing where and when collisions are most likely to occur in order to adapt driving appropriately. Transportation planners, responsible for decreasing WVC, should aim to predict the collisions to better implement mitigation measures and locations for future road construction.

The factors contributing to WVC can be categorized into three general groups: a) the animal (ecology and behaviour), b) traffic (density and velocity), and c) the landscape (Sielecki, 2004). Such factors (Table 1.2) are combined spatially and temporally to create a complex distribution of WVC at any given point along the road. Spatial features that may contribute to the occurrence of WVC include landscape patterns, features adjacent to roads, population characteristics, and road and traffic components (Moen 1979, Forman and Alexander 1998, Finder et al. 1999, Clevenger et al. 2003, Rea 2003, Seiler 2005). The frequency and timing of WVC is dependant on weather and light conditions, seasonal and diurnal traffic volumes, and animal population in regards to numbers, foraging and breeding behaviour (Allen and

1.4.1 Animal Abundance and Traffic Intensity

As a single WVC requires the interaction between an animal and a vehicle, the probability of occurrence should be correlated to density and activity of wildlife and traffic volume (Seiler 2005). In Illinois, traffic volume and deer density were both significant predictors of deer/vehicle accidents at the county level (Finder et al. 1999). Moen (1979) states the two main reasons for increased MVC as being the simultaneous rise in both moose and vehicle numbers, however, he notes additional factors including moose movements, forage behaviour, and temporal concerns may also contribute. In practical terms, harvest statistics can be used to help predict collision numbers on a course scale (Seiler 2001). The use of hunting statistics to measure WVC can be uncertain and estimates must be made at the landscape scale. Other predictors such as pellet counts, and hunter observations apply to population patterns at a fine scale.

Whether movement is impeded by roads or not, roads are present within wildlife home ranges. Seasonal migration can cause concentrated movements to lower-lying roadbed areas of less snow early in the winter and late in the spring (Moen 1979, Andersen et al. 1991, Lavsund and Sandegren 1991, Modaferri 1991, Gundersen 1998). Daily movements to gain shade, rest, food and water result in sporadic road crossings over lengthy stretches of road (Moen 1979). In addition, the sex and age of an animal have been considered as collision factors (Belant 1991, Lintermans and Cunningham 1997).
Table 1.2. Factors lending to WVC (Sielecki 2004)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Example</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wildlife Characteristics</td>
<td>species, population, age, sex, stage of reproduction, nutritional needs, movement behavior, population cycles</td>
<td>Bertwhistle 2003; Premo 2001; Schwabe et al. 2000; McDonald and St. Clair 2004</td>
</tr>
<tr>
<td>2. Wildlife Activities</td>
<td>feeding, breeding, sleeping, migrating, evading predators, chasing prey</td>
<td>Moen 1979; Groot Bruinderink and Hazebroek 1996; Finder et al. 1999; Del Frate and Spraker 1991</td>
</tr>
<tr>
<td>3. Natural Water Sources</td>
<td>intermittent and permanent streams, rivers, slews, lakes, ponds, springs, waterfalls</td>
<td>Trombulak and Frissell 1999; Forman 2000</td>
</tr>
<tr>
<td>4. Man-made Water Sources</td>
<td>settling ponds, surface drainage systems, wells, dugouts</td>
<td>Trombulak and Frissell 1999; Forman 2000; Dodd et al. 2003</td>
</tr>
<tr>
<td>5. Natural Food Sources</td>
<td>natural vegetation, salt licks, fish-bearing waters, prey</td>
<td>Fraser and Thomas 1982</td>
</tr>
<tr>
<td>6. Man-made Food Sources</td>
<td>orchards, gardens, clear cuts, pets, livestock, garbage</td>
<td>Child 1998</td>
</tr>
<tr>
<td>7. Wildlife Shelter</td>
<td>caves, cliffs, forests, culverts, bridges</td>
<td>Thompson and Stewart 1998</td>
</tr>
<tr>
<td>8. Habitat Conditions</td>
<td>seasonal vegetation changes, snow depth, drought, flooding, fire, overgrazing</td>
<td>Andersen et al. 1991; Modaferri 1991; Gundersen et al. 1998</td>
</tr>
<tr>
<td>10. Vehicles</td>
<td>size, design, operating condition, brakes, lights, horns</td>
<td>Gunson et al. 2003</td>
</tr>
<tr>
<td>12. Highway Design</td>
<td>road width, number of lanes, curvilinearity of alignment, right-of-way width, shoulder width, ditch depth, pavement surface, lighting</td>
<td>Thomas 1995; Moen 1979; Damas and Smith 1983; Finder et al. 1999</td>
</tr>
<tr>
<td>14. Roadside Development</td>
<td>natural, urban, suburban, rural</td>
<td>Underhill and Angold 2000; Forman 1999</td>
</tr>
<tr>
<td>15. Accident Mitigation Devices</td>
<td>wildlife signs, fencing, under/overpasses, reflectors</td>
<td>Dodd et al. 2003; Huijser 2003; Knapp 2003; Newhouse 2003; Clevenger et al. 2002a; Putnam 1997; Child et al. 1991; Reed et al. 1982; Del Frate and Spraker 1991; Oosenburg et al. 1991</td>
</tr>
<tr>
<td>16. Topography</td>
<td>elevation, cliffs, slope, undulating terrain</td>
<td>Groot Bruinderink et al. 2003; Finder et al. 1999 ; Clevenger et al. 2002a</td>
</tr>
<tr>
<td>17. Weather</td>
<td>rain, snow, sleet, fog, haze, smoke, wind, cloud cover</td>
<td>Schwabe et al. 2000; Gunson et al. 2003</td>
</tr>
<tr>
<td>18. Time of Day</td>
<td>dawn, day, dusk, night, length of day/night</td>
<td>Allen and McCullough 1976; Schwabe et al. 2000; Gunson et al. 2003</td>
</tr>
<tr>
<td>19. Lunar Cycle</td>
<td>phases of the Moon, intensity of Moonlight</td>
<td>Lintermans and Cunningham 1997</td>
</tr>
</tbody>
</table>
Where vehicle speed and/or traffic density are high, road traffic has been shown to have a severe local effect on WVC (Andersen et al. 1991, Becker and Grauvogel 1991, Oosenbrug et al. 1991, Rosen and Lowe 1994, Belant 1995, Jones 2000). High traffic volumes may repel animals from crossing due to high noise or movement creating a barrier effect (Alexander and Waters 2000, Clevenger et al. 2003). For practical use in road planning, traffic levels above 10,000 vehicles per day have been proposed as a critical level for considering roads as an effective barrier (Seiler 2005). Clevenger et al. (2002a) found that a higher number of WVC occurred on roads with low to medium traffic volumes. Multiple pieces of often highly variable and interrelated data usually need to be considered to properly determine why there is a WVC problem at a particular location (Bashore et al. 1985). Vehicle density and speed are therefore confounded by additional factors responsible for WVC. Examples include population density and dynamics, animal behaviour, land use (habitat destruction), land cover, and temporal factors (Bashore et al. 1985, Groot-Bruinderink and Hazebroek 1996, Dique et al. 2003).

1.4.2 Temporal Factors

Temporal factors including time of day and seasonal patterns add to the complexity of WVC. Most WVC occur during dawn or dusk (Allen and McCullough 1976, Moen 1979, Joyce and Maloney 1998, Schwabe et al. 2000, Inbar et al. 2002, Gunson et al. 2003). In British Columbia, MVC generally occur between 5:00 and 11:00 at night (Road Health-University Wildlife Collision Mitigation Research Team 2006). These hours relate to when both moose and people are active in synchrony. Moose are on the move as they feed, and people are typically commuting to and from work (Thomas et al. 1995). With nearly three-quarters of all moose
accidents occurring during hours of darkness, there is a strong indication that visibility is a key factor in MVC (Thomas et al. 1995).

Seasonal variation also plays a role in WVC (Thomas et al. 1995, Child et al. 1991, Del Frate and Spraker 1991, Modaferri 1991). For example, Figure 1.2 shows that MVC in Mount Revelstoke and Glacier National Parks peak between October and January. This trend is generally consistent within British Columbia (Thomas et al. 1995, Child et al. 1991, Del Frate and Spraker 1991, Modaferri 1991, Road Health-University Wildlife Collision Mitigation Research Team. 2006). Belant (1991) contrasted this seasonal trend, reporting MVC frequencies highest from June to September in Minnesota, USA. Lavsund and Sandegren (1991) reported southern Sweden MVC peak in early summer and autumn, while MVC in northern Sweden peak in December and January after snow accumulations had initiated migration to low-land ranges where major roads are common.

Figure 1.1. Moose-vehicle collisions in Mount Revelstoke and Glacier National Parks collected from 1968-2004.
1.4.3 Landscape Factors

Roads (and railways) fragment wildlife habitat resulting in animals being exposed to an elevated risk of mortality. Landscape patterns are a central consideration in the occurrence of WVC (Lavsund and Sandegren 1991, Schwartz and Bartley 1991, Groot Bruinderink et al. 2003, Finder et al. 1999, Clevenger et al. 2003). Finder et al. (1999) found that topographic features at high deer-vehicle collision sites influenced local deer abundance, deer movement patterns, and visibility conditions. Finder et al. (1999) also showed that with more diverse landscapes and shorter distances between nearby forest patches, the probability of a road segment having been a high deer-vehicle collision site was increased. In particular, riparian corridors influenced deer movement patterns, and woods or gullies immediately adjacent to the road may have obstructed the visibility of motorists and/or deer, consequently providing little time for a driver to avoid a collision (Finder et al. 1999). The condition and location of habitat types in relation to roads directly influence WVC (Andersen et al. 1991, Modaferri 1991, Gundersen et al. 1998). Finder et al. (1999) found that the most important predictor of high deer/vehicle accident sites was distance to forest cover, suggesting that woody cover may hide deer from the view of motorists, consequently providing little time for a driver to avoid a collision. Most MVC in Alaska occur at distinct locations which intersect migration corridors and prime habitat areas, particularly lowland marshes and tundra at elevations at or below 200 feet above mean sea level (Thomas et al. 1995).

Roadside brushing likely augments the risk of collision by maintaining early seral vegetation (Child et al. 1991, Rea 2003). Ideal moose habitat for both movement and forage has an opening width of less than 100m, natural water sources and salt licks, approximately 50m to
forest cover and snow interception (Child 1991). Transportation corridors simulate these habitat characteristics with the brushing, plowing and adjacency to forest cover. An increase of 100 m in distance to the nearest forest can reduce collision risks by 15% (Seiler 2005). Transportation corridor use by ungulates is a localized feature that, in addition to other landscape features and patterns, influences the frequency of WVC (Underhill and Angold 2000, Child 1998, Forman 1999).

In addition to the browse characteristics in the transportation corridor, forage quality on a landscape scale must be considered (Seiler 2005). Land-use practices, in particular forestry, dictate the type and quality of ungulate browse (Child 1998). MVC have been found to occur close to forest and wetland while deer-vehicle collisions have been found close to rural (agricultural) habitats (Seiler 2005). Wetland and associated spruce forest are recognized as key moose winter habitats, along with burns and cutovers during peak shrub production years (average 15 – 20 years) (Perry 1999). The spatial distribution of moose can generally be explained by a combination of food palatability and availability (Serrouyal and D’Eon 2002). Overall, the influence of habitat on the occurrence of WVC depends on the composition of the landscape and the position of the road relative to specific habitat elements (Seiler 2005). Where the habitat is homogeneous, WVC will be more randomly dispersed (Allen and McCullough 1976, Bashore et al. 1985). Collision risks will be locally increased and more clustered where habitat is patchy and includes linear landscape features such as riparian corridors (Gundersen et al. 1998, Finder et al. 1999, Clevenger et al. 2003).
1.5 Modeling WVC – Past Approaches

Seiler (2005) noted how new highway planning policies require improved knowledge of the spatial distribution of collisions. Tools for accurately predicting WVC locations can be important for their prevention. Researchers have successfully used a number of techniques and data sources to predict WVC. Past WVC modeling attempts are generally grouped as empirical and expert-based.

Empirical WVC modeling has been successfully attempted with various species of large animals (Rost and Bailey 1979, Finder et al. 1999, Seiler 2005, Malo et al. 2004, Gunson et al. 2006, LeBlanc and Martel 2006). Models using landscape-scale parameters can be a powerful first step in assessing contributing variables within the process of explaining where MVC occur (Gunson et al. 2006). WVC models, however, should be used at both the landscape and local-scales during the process of road design and implementation of mitigation measures (Malo et al. 2004, Gunson et al. 2006).

Expert-based models constructed from either expert opinion or peer-reviewed literature can be a vital step in identifying high risk WVC areas (Marcot 1986), with the results complementing empirical models (Clevenger et al. 2002). Expert-based techniques are relatively inexpensive (Clevenger and Chruzcz. 2004). Expert-based modeling is also an attractive highway planning tool where data necessary for empirical models are lacking (Clevenger et al. 2002b). The use of expert-based GIS models to study human-related effects on wildlife is not uncommon. As examples, Clevenger and Chruzcz (2004) evaluated linkage zones for wildlife crossing structures using expert and literature-based methods of least-cost path movements.
Ruediger and Lloyd (2003) and Road Health-University Wildlife Collision Mitigation Research Team (2006) used a GIS-based approach to identify WVC hotspots by means of heads-up expert consensus.

1.6 Research Objectives

The purpose of this research was to predict the spatial occurrence of MVC along the Trans Canada highway through Mount Revelstoke and Glacier National Parks; to use different methods and techniques such as GIS to aid in the modeling process; and to determine the significant factors related to MVC occurrence. In the first paper presented in the thesis, I used logistic regression to model MVC using both GIS and field data. In the second paper, I used an expert-based approach to model MVC using GIS landscape-scale factors. I compared each regression and expert modeling approach in its efficiency in predicting MVC in the third paper.

1.7 Study Area

The study area was limited to the Trans Canada Highway #1 within the boundaries of Glacier and Mount Revelstoke National Parks, in south-eastern British Columbia, Canada (Figure 1.3). The segment of highway was established in 1962. Speed limits vary between 70 km/h and 90 km/h with two lane traffic and intermittent three or four-lane passing sections. Rugged, steep terrain and frequent snow avalanches have resulted in limited options for transportation routes (Woods 1996). The operation of this segment of the Trans Canada Highway therefore faces numerous challenges including steep grades, extreme weather, rock instability and collisions with wildlife (Woods 1996). Parks Canada is responsible for the planning, construction, and operation of the highway within the boundaries of the National
Parks. Additional infrastructure existing within the parks includes a rail line operated by Canadian Pacific Railway (CPR), power line, hotel, service station, and Parks Canada compounds.

Figure 1.2. The study area of the Trans Canada Highway dissecting Glacier and Mount Revelstoke National Parks representing where MVC collision data were collected from 1968-2004.

In the past four decades, traffic volume has undergone a four fold increase on the Trans Canada Highway through Rogers Pass, Glacier National Park. Such increases stress the need for improved understanding of factors related to MVC (Figure 1.4). Traffic volume has increased over the past decade from approximately 1,335,000 to over 1,640,000 vehicles between 1962 and 2001. The Trans Canada Highway is a major transportation route connecting the commercial centres of Vancouver and Calgary while providing a primary route for vacationers from eastern British Columbia to Alberta.
Figure 1.3. Vehicle traffic through Mount Revelstoke and Glacier National Parks (1962-2001).

MVC rates along this stretch of highway range from approximately 0.016 to 0.045 per kilometre per year (Sielecki 2004) for a total of 0.5 to 3 MVC per year within the parks. This MVC rate is relatively similar to areas outside of the park boundary; however, the spatial coordinate reporting procedure within the park is more accurate for modeling purposes. The park areas are of high concern due to both the Trans Canada Highway and wildlife having limited movement options through narrow and high-mountain passes. In addition, Parks Canada has a management objective to reduce the environmental impact of the transportation corridor, particularly on wildlife, vegetation and aquatic ecosystems within the 2 National Parks.
Glacier and Mount Revelstoke National Parks encompass 3 biogeoclimatic zones, the Interior Cedar Hemlock (ICH), Englemann Spruce-Subalpine Fir (ESSF), and the Alpine Tundra Zone (AT). The ICH is comprised primarily of old-growth cedar (*Thuja plicata*) and mountain hemlock (*Tsuga mertensiana*). In the ESSF, the lower subalpine forests are dominated by Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*) and mountain hemlock. Mean annual precipitation is 700-3000 mm, most of which (70-80%) falls as snow (BCMOF 1991). A total of 239 wildlife species has been recorded in the two parks including four amphibian species, three reptiles, 178 birds and 54 mammals (Achuff et al. 1984).
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2.0 Chapter II: A Spatial Analysis of Moose-Vehicle Collisions (MVC) in Mount Revelstoke and Glacier National Parks using Logistic Regression

Abstract: Moose (Alces alces)-vehicle collisions (MVC) are an ecological and socio-economical issue. In this paper, I predicted the spatial location MVC on the Trans Canada Highway dissecting Mount Revelstoke and Glacier National Parks. I also determined which model was the most effective MVC predictor and identified the related factors. I identified 6 subsets of logistic regression models and used Akaike’s Information Criteria (AIC) to determine the most parsimonious model within each subset. Models represented local-scale/field-based hypotheses of driver visibility, moose evidence, highway design, roadside vegetation, and moose habitat, as well as landscape-scale hypotheses based on Geographical Information System (GIS) data. In addition to this study being the first to examine collisions within these 2 parks, each of these 6 models is unique in predicting MVC. I used the Receiving Operator Characteristic (ROC) to measure the predictive accuracy of the 6 subsets. Using the landscape-scale model, I created a MVC probability map along the highway, providing a powerful and relatively efficient and inexpensive planning tool. Among the local-scale models, the moose evidence model correctly classified the most MVC. Highway planning to reduce MVC risk within Mount Revelstoke and Glacier National Parks should begin by assessing landscape-scale models. Further local-scale analyses using moose evidence and habitat models should be completed at high risk MVC locations previously identified by the landscape-scale analysis. If highway planning is not an option in decreasing MVC, the research suggested mitigation measures including a public awareness program and speed reduction.
2.1 Introduction

Moose-vehicle collisions (MVC) are on the rise across Canada and have significant implications for the conservation and management of moose and socio-economic well being (L-P Tardiff and Associates 2003). The number of WVC the Insurance Corporation of British Columbia (ICBC) reported in British Columbia increased from 7,267 collisions in 1997 to 9,789 in 2001, while the number of injured motorists rose from 218 to 386 (L-P Tardif & Associates Inc. 2003). Government and private industry are now beginning to appreciate the ecological and socioeconomic costs resulting from MVC. Between 1997 and 2002, ICBC spent over $118 million on WVC accident claims (L-P Tardif & Associates Inc. 2003).

There is a lack of published information on the influence of many hypothesised environmental factors on MVC. For example, Seiler, (2005) stated that a more detailed knowledge of preferred moose forage (Ball & Dahlgren 2002, Seiler 2005), embankment of the road (Clevenger et al. 2003), and driver visibility (Bashore et al. 1985) would increase the predictive power of past modeling attempts. Furthermore, techniques for accurately predicting MVC risk are important for the prevention and mitigation of collisions, but have not been extensively tested. Logistic regression is a common and effective approach for predicting the distribution of wildlife (Pearce and Ferrier 2000, Nielsen et al. 2005). Thus, my research was designed to assess and compare the effectiveness of logistic regression as a technique for modeling MVC risk using field and GIS data (Finder et al. 1999, Malo et al. 2004, Seiler 2005, Gunson et al. 2006).
I parameterised logistic regression models of MVC using collision and field data from Mount Revelstoke and Glacier National Parks, Canada. The field-based local-scale models included highway design, moose evidence, roadside vegetation management, moose habitat, and driver visibility. The landscape-scale model used variables taken from a GIS and was inclusive of both moose habitat and driver visibility. I compared the predictive performance of the most parsimonious models and made recommendations to improve highway planning.

2.2 Methods

2.2.1 Data Collection

MVC data were contributed by John Flaa at Mount Revelstoke and Glacier National Parks. The reported location of each MVC was recorded by park wardens by either marking the collision on a map or when possible, by traveling to the site and recording the collision location using a Global Positioning System (GPS) unit. The UTM co-ordinates were recorded in a database along with date of kill, hour of kill and information regarding the number and species of wildlife. MVC records date back to 1968. GPS units were used as the primary reporting method for MVC data locations. The UTM coordinates for each MVC were plotted onto the highway layer within the study area using ArcGIS (ESRI 2005).

The study encompassed a spatial analysis of 55 MVC locations along with 60 randomly generated reference points so that logistic regression could be used to contrast highway points with and without MVC (Figure 2.1). Reference points were created by randomly generating numbers which represented distances along the highway. Road distances started at 0 km from the southern entrance of Mount Revelstoke National Park and extended to the Northern entrance.
of Glacier National Park. Random reference points that were within a snow shed were not included.

Figure 2.1. MVC and random reference locations within Mount Revelstoke and Glacier National Parks. MVC locations were recorded from 1968 to 2004.

Changes in land cover due to natural or human disturbance over time were assessed using Parks Canada forest stand origin data. This assessment explored the assumption that correlations could be studied between independent variable data collected in one season with MVC data spanning nearly four decades. Both coniferous and deciduous cover has regenerated since the right of way was cleared for highway construction in 1962. This effect on the assumption does not warrant concern as the first recorded collision was 6 years after highway construction. Since highway construction, there have not been significant alterations of the
highway with the exception of routine roadside brushing. No significant natural disturbances have occurred within the 500m highway buffer area since highway construction (John Flaa, pers comm.).

2.2.2 Landscape-scale variable analysis (GIS)

I used a GIS to measure 15 landscape-scale variables (500-m radius centred on each MVC or random location) (Table 2.1). All continuous variables were averaged within the 500-m radius buffer centered on each collision and random point. A 500-m buffer around each location represented the road-effect zone (Forman and Alexander, 1998). The road-effect zone is the area that encompasses the majority of ecological effects resulting from road construction and use and is typically the focus of planning and mitigation (Forman, 1999). A minimum of 500-m was kept between random reference points upon creation in order to ensure independence. The 500-m radii represented the area over which collision attributes were sampled using a GIS at the landscape-scale.

I used British Columbia Provincial Government Terrain Resource Information Management (TRIM) spatial data in a GIS to represent highway segments, elevation, slope, and aspect. All TRIM data had a scale of 1:20,000 with a resolution of 25-m x 25-m cell size. Topographical criteria were included due to the inherent nature of moose migration from hills to valleys during the winter (Hundertmark 1997, Gundersen et al. 1998). Thus, I included measures of slope and aspect in an effort to gain insight into the effects of moose movement on MVC.
Table 2.1. Landscape-scale variables measured at each MVC site and reference point to model the factors that possibly influence MVC locations within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DEFINITION</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT (GIS)</td>
<td>Mean aspect within 500m buffer</td>
<td>degrees</td>
</tr>
<tr>
<td>BUILT (GIS)</td>
<td>Distance to the nearest human development</td>
<td>m</td>
</tr>
<tr>
<td>CROSSROAD</td>
<td>Distance to nearest crossroad (maximum 500m)</td>
<td>m</td>
</tr>
<tr>
<td>ELEVATION (GIS)</td>
<td>Elevation above sea level generated using a digital elevation model</td>
<td>m</td>
</tr>
<tr>
<td>FOREST EDGE</td>
<td>Distance to nearest forest edge perpendicular to road (maximum 500m)</td>
<td>m</td>
</tr>
<tr>
<td>HIKING (GIS)</td>
<td>Distance to the nearest hiking trail</td>
<td>m</td>
</tr>
<tr>
<td>HIGH USE HABITAT (GIS)</td>
<td>Area of high moose habitat within 500m buffer as per Parks Canada data</td>
<td>m²</td>
</tr>
<tr>
<td>LAND COVER (GIS)</td>
<td>Dominant land cover type within 500m buffer</td>
<td>Shrub/Coniferous/Mixed</td>
</tr>
<tr>
<td>LINES (GIS)</td>
<td>Distance to the nearest communication line</td>
<td>m</td>
</tr>
<tr>
<td>RAIL (GIS)</td>
<td>Distance to the nearest railway line</td>
<td>m</td>
</tr>
<tr>
<td>RISK SIGN (GIS)</td>
<td>Distance to nearest wildlife-risk sign</td>
<td>m</td>
</tr>
<tr>
<td>SLOPE (GIS)</td>
<td>Mean slope within 500m buffer</td>
<td>degrees</td>
</tr>
<tr>
<td>WATER (GIS)</td>
<td>Distance to the nearest waterbody boundary</td>
<td>m</td>
</tr>
<tr>
<td>WATER INT</td>
<td>Distance to nearest water intersection with the road (maximum 500m)</td>
<td>m</td>
</tr>
<tr>
<td>WETLAND (GIS)</td>
<td>Distance to the nearest wetland boundary</td>
<td>m</td>
</tr>
</tbody>
</table>

I measured the distance to water bodies and wetland due to the fact that moose seek aquatic habitats for drinking water, insect relief, aquatic forage and thermoregulation (Peek 1998). I extracted the distance to water and wetland criteria from BC TRIM data. I measured the presence/absence of high-use habitat at each collision and reference point to determine the relationship of MVC with critical habitat range. I determined the dominant land cover type within a 500m buffer to further assess habitat-related attributes and potential effects on driver
visibility. Habitat classification and land cover data within Mount Revelstoke and Glacier National Parks were based on Parks Canada Ecological Land Classification (ELC) at a scale of 1:50,000 (Achuff et al. 1984).

I used GIS to record the distance from each MVC to rail lines, power lines, hiking trails and built areas. The distance to rail and power lines was based on Parks Canada spatial data while the distance to built areas was extracted from British Columbia TRIM data. Rail lines are plowed in the winter providing a potential movement corridor. In addition, the vegetation clearance within rail line and power line corridors creates the potential for the presence of early seral forage used as forage by moose. I examined the distance to built areas to see if human development affects the occurrence of MVC by means of habitat alteration, human activity, and potential predator avoidance (Malo et al. 2004, Seiler 2005). I included hiking trails in the models to examine the potential for increased moose movement, predation and effect of human use on moose distribution.

I used a GPS in the field to measure the distance of each MVC location from the nearest wildlife risk sign and highway curvature. I used the distance to wildlife risk sign criteria to assess the role of driver awareness on MVC. I analyzed the distance to highway curvature to assess driver visibility at a landscape-scale.

2.2.3 Local-scale variable analysis

From June to August 2005, I collected data for local-scale analyses. I used a GPS to locate each MVC and random reference site in the field and then I recorded 29 local-scale
variables (Table 2.2). Variables ranged from habitat related to driver and highway attributes, each contributing to one of the 5 local-scale model subsets.

2.2.3.1 Habitat

At each site, I measured habitat characteristics using a variety of methods. These data served as proxy measures of forage quantity and quality and thus potential attractants of moose to highway corridors. I placed 25-m transects perpendicular to the highway and measured plant species presence and age at 5-m intervals within 4-m$^2$ quadrats. I assessed shrub ages to determine the most recent year of roadside clearing. The age of the oldest shrub within the 25m transect was used as an indicator of time since the roadside was cleared. I also recorded evidence of browsing, moose tracks, and pellets within each quadrat.

Table 2.2. Local-scale variables measured at each site and reference point to model the factors that possibly influence moose-vehicle collision locations.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DEFINITION</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANG 5M</td>
<td>Mean distance at which an observer standing 5 m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway</td>
<td>m</td>
</tr>
<tr>
<td>ANG 10M</td>
<td>Mean distance at which an observer standing 10 m from the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway</td>
<td>m</td>
</tr>
<tr>
<td>BROWSE</td>
<td>Presence of browse within 100m transect</td>
<td>P/A</td>
</tr>
<tr>
<td>BROWSE (ROADSIDE)</td>
<td>Presence of browse within 25m transect</td>
<td>P/A</td>
</tr>
<tr>
<td>CORRIDOR WIDTH</td>
<td>Width of highway corridor clearance including pavement</td>
<td>m</td>
</tr>
<tr>
<td>DIST COVER</td>
<td>Mean distance to vegetative cover (trees and shrubs $&gt;$1 m high) taken from both sides of the road</td>
<td>m</td>
</tr>
<tr>
<td>DITCH</td>
<td>Presence of ditch adjacent highway</td>
<td>P/A</td>
</tr>
<tr>
<td>ECOTONE</td>
<td>Presence of an ecotone</td>
<td>P/A</td>
</tr>
</tbody>
</table>

Table 2.2 continued...
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DEFINITION</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAME TRAIL</td>
<td>Absent/Low/High</td>
<td>A/L/H</td>
</tr>
<tr>
<td>HABITAT CLASS</td>
<td>Within a 100m radius: Percent cover type being Mixed Forest (MF)/Coniferous Forest(CF)/Wetland(W)/Shrub(S)</td>
<td>MF/CF/W/S</td>
</tr>
<tr>
<td>INLINE</td>
<td>Mean distance at which an observer standing at the pavement edge could no longer see passing vehicles taken from each direction on both sides of the highway</td>
<td>m</td>
</tr>
<tr>
<td>JERSEY BARRIER</td>
<td>Presence of jersey barrier</td>
<td>P/A</td>
</tr>
<tr>
<td>MEDIAN</td>
<td>Presence of median</td>
<td>P/A</td>
</tr>
<tr>
<td>PASSING LANE</td>
<td>Presence of a passing lane</td>
<td>P/A</td>
</tr>
<tr>
<td>PELLETS (ROADSIDE)</td>
<td>Presence of pellets within 100m transect</td>
<td>P/A</td>
</tr>
<tr>
<td>ROADSIDE AGE CLASS</td>
<td>Age of oldest shrub within 25m transect</td>
<td>(1-3 yrs) (4-6 yrs) (7-10 yrs)</td>
</tr>
<tr>
<td>ROADSIDE VEGETATION</td>
<td>Type of vegetation species within 25m transect</td>
<td>P/A</td>
</tr>
<tr>
<td>SLOPE (0-5M)</td>
<td>Mean slope of the land 0-5 m perpendicular to the pavement edge taken from both sides of the road</td>
<td>degrees</td>
</tr>
<tr>
<td>SLOPE (5-10M)</td>
<td>Mean slope of the land 5-10 m perpendicular to the pavement edge taken from both sides of the road</td>
<td>degrees</td>
</tr>
<tr>
<td>SLOPE (10-30M)</td>
<td>Mean slope of the land 10-30 m perpendicular to the pavement edge taken from both sides of the road</td>
<td>degrees</td>
</tr>
<tr>
<td>SPEED</td>
<td>Mean recorded speed of passing vehicle</td>
<td>km/h</td>
</tr>
<tr>
<td>TOPO</td>
<td>Terrain slope category</td>
<td></td>
</tr>
<tr>
<td>TRACKS (ROADSIDE)</td>
<td>Presence of moose tracks within 25m transect</td>
<td>P/A</td>
</tr>
</tbody>
</table>

Note: The levels used in distinguishing the qualitative variables were presence-absence (P/A), continuous-discontinuous-absent (C/D/A) and those presented in the corresponding definitions.

Some roadside vegetation species were grouped into families due to their low occurrence. Western mountain ash (*Sorbus scopulina*) and Saskatoon berry (*Amelanchier alnifolia*) were grouped into the rose family. Narrow-leaved hawkweed (*Hieracium*
umbellatum), common dandelion (Taraxacum officinale), pearly everlasting (Anaphalis margaritacea), yarrow (Achillea millefolium), and oxeye daisy (Leucanthemum vulgare) were classified under the sunflower family. Species that were rarely present in the study area (1-3 occurrences) and could not be grouped into a family were excluded from modeling. The remainder of roadside vegetation was modeled at the species level (Table 2.3).

Table 2.3. Roadside vegetation species present within quadrats and included in modeling.

<table>
<thead>
<tr>
<th>Species</th>
<th>Modeling Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Horsetail (Equisetum arvense)</td>
<td>HORSETAIL</td>
</tr>
<tr>
<td>Grass</td>
<td>GRASS</td>
</tr>
<tr>
<td>Willow (Salix sp.)</td>
<td>WILLOW</td>
</tr>
<tr>
<td>Red-Osier Dogwood (Cornus stolonifera)</td>
<td>DOGWOOD</td>
</tr>
<tr>
<td>Sitka Alder (Alnus crispa)</td>
<td>ALDER</td>
</tr>
<tr>
<td>Western Red Cedar (Thuja plicata)</td>
<td>CEDAR</td>
</tr>
<tr>
<td>Spruce (Picea sp)</td>
<td>SPRUCE</td>
</tr>
<tr>
<td>Thimbleberry (Rubus parviflorus)</td>
<td>THIMBLEBERRY</td>
</tr>
<tr>
<td>Common Red Paintbrush (Castilleja miniata)</td>
<td>PAINTBRUSH</td>
</tr>
<tr>
<td>Black Twinberry (Lonicera involucrata)</td>
<td>TWINBERRY</td>
</tr>
<tr>
<td>Spreading Dogbane (Apocynum androsaemifolium)</td>
<td>DOGBANE</td>
</tr>
<tr>
<td>Lupine (Lupinus sp.)</td>
<td>LUPINE</td>
</tr>
<tr>
<td>Aspen (Populus tremuloides)</td>
<td>ASPEN</td>
</tr>
</tbody>
</table>

I placed a 100-m transect perpendicular to each roadside shoulder to quantify land cover and assess the roadway for presence of moose. I defined land cover as Mixed Forest (MF), Coniferous Forest (CF), Wetland (W), or Shrub (S). During June to August 2005, I recorded the dominant land cover class at 10-m intervals along each transect. Evidence of moose included wildlife trails, pellets, tracks or browse. If the highway bisected two habitat types, I noted this ecotone. I used ecotone as a variable to investigate any habitat edge effect that could potentially be correlated with MVC. I measured the distance to the nearest forest edge perpendicular to the road up to a maximum buffer zone radius of 500m. I also measured the distance to crossroads and water bodies intersecting the road in the same manner. I tested the distance to crossroads to determine whether intersections with potential movement routes influence collision occurrence.
2.2.3.2 Human and wildlife movement

I recorded a number of highway attributes that might influence the movement of wildlife and the ability of drivers to avoid a MVC. I used an inclinometer to measure the slope immediate to the roadbed (0-5 m), the verge (5-10m) and the adjacent land (10-30m). I also identified each site as occurring within one of 6 local topographic classes identified by Gunson et al. (2006) (Figure 2.2). The slope and topographic measurements tested whether embankments had positive or negative relationships with moose-vehicle collisions.

2.2.3.3 Driver visibility

I measured driver visibility as the shortest distance to the point at which a car becomes out of sight of an observer from three different locations adjacent to the highway. I measured field visibility variables as the extent to which a motorist could see moose on the right-of-way. Since I could not determine from what side or which direction a vehicle struck an animal, I took four visibility measurements at each site: 2 facing each direction, on each side of the highway. One in-line (from road edge) and 2 angular measurements were taken (5 metres and 10 metres from the road edge). Recognising that trucks were more visible at greater distances than cars or motorcycles from an observer perspective, I always measured visibility distances using trucks. I measured the distance to vegetative cover (trees and shrubs >1 m high) on both sides of the road to determine driver visibility. I used the average of the two roadside distances as the finalised visibility reading. The corridor width was the total area cleared for the highway including a combination of roadside clearance on both sides of the highway and the highway pavement width.
Figure 2.2. Topographical Slope Classes assessed at each MVC and random reference location. The thick lines represent the highway and the thin lines represent the adjacent land slope. 1A, 1B, 1C, 2A, 2C, 6A, and 6B were excluded from model development due to their infrequent occurrence (Gunson et al. 2006).

2.2.3.4 Highway influence

I recorded the presence/absence of roadside ditches because they might influence visibility and animal movement. I tested the presence/absence of jersey barriers, passing lanes, and medians to explore additional barrier effects resulting from highway design and construction. I recorded the average speed limit using a radar gun at each MVC and random reference site. Highway speed was calculated as the mean of 20 vehicles (10 vehicles going in
each direction). I recorded actual vehicle speed as opposed to speed limit due to the inherent nature of vehicles surpassing posted limits. I did not include traffic volume in model development due to the absence of variability within the study area. I measured all distances using a range finder (Bushnell Yardage Pro 1000).

2.2.4 Data Analysis

Due to the binary nature of the dependent variable (0=reference, 1=collision), and the inclusion of categorical independent variables, I analyzed the data using bivariate logistic regression.

Using landscape-scale GIS data, I developed the logistic regression model with the structure:

\[
Y = \frac{\exp (\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}{1 + \exp (\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}
\]

where \( Y \) is the predicted probability of a MVC and \( \beta_i \) are coefficients based on environmental variables \( x_i \) (Manly et al. 1993). I created the predictive MVC probability surface using 25-m \( \times \) 25-m pixel resolution.

I grouped the variables into 6 different logistic regression model subsets and used Akaike’s Information Criteria (AIC) to determine the most parsimonious model within each subset. The use of model selection criteria enabled inference to be drawn from several models simultaneously, so that a ‘best set’ of similarly supported models could be chosen (Johnson and Omland 2004). I identified subsets of models that contained related sets of variables so that unique phenomena explaining MVC could be more easily isolated, understood, and adapted to mitigation strategies. I used five subsets to model local-scale/field-based hypotheses and one
subset to examine landscape-scale hypotheses using Geographical Information System (GIS) data. The first local-scale subset consisted of parameters that affected the driver visibility of moose. The second subset included the variables that indicated the evidence of moose in the terrain perpendicular to the highway. I assessed highway design in the third subset. In the fourth subset, I examined roadside vegetation species and age in order to relate MVC to roadside management practices in the parks. In the fifth local-scale subset, I tested moose habitat features and influences. I completed a final AIC comparison among the best AIC local-scale models previously identified from each subset in order to identify the most parsimonious model overall. This round of AIC did not include the landscape-scale GIS models in its comparison due to the difference in scale relative to the 5 local-scale models.

In addition to the 6 models which explored variables grouped into common hypothesized subsets, I developed 2 combination models to help further reveal the MVC phenomenon. I recognise that these interaction models were not initial hypotheses, but arose as exploratory analyses of results from the 6 model subsets. Variables chosen for interactions included those that previously showed significance in the original models (Hosmer and Lemeshow 2000).

To reduce multicollinearity between the modelled variables (Zar 1998), screening was completed prior to model development using a Pearson correlation matrix which compared each variable combination, and removed those that were highly correlated ($r > 0.75$) (Seiler 2005). In the GIS model subset, I omitted the distance to communication lines from further analysis because it was highly correlated (Pearson correlation coefficient of 0.89) with the distance to railway and showed a lower correlation than with MVC points (Pearson Correlation Coefficient 0.55).
of 0.45 as opposed to 0.49). In the Driver Visibility model subset, I eliminated angular visibility at 5m as it was highly correlated with inline visibility. In addition, inline is also taken from the road edge closer to where a collision occurs. Also in the Driver Visibility model subset and the Highway Design model subset, slope (5-10m) was highly correlated with slope (0-5m). To capture a greater range of slope measurements, I eliminated slope (5-10m) as it is intermediate to the other two other slope measurements (0-5m and 10-30m).

I used odds ratios to calculate the contribution that a unit increase in the independent variable made to the probability of an MVC (Tabachnick and Fidell 1996). I used Wald statistics to test the significance of the individual independent variables. I used the sign of the coefficient to determine the direction of influence of the independent variables on the collision probability.

Each topographic and distance variable was modelled as a simple linear and then a quadratic term. I used the quadratic form for further model comparisons if the more complex variant had an AIC score of < 2 points relative to the simple linear form. For the GIS variables, I included quadratic terms in further modeling for the three topographic variables of elevation, slope and aspect. For the driver visibility variables, I included the quadratic terms for inline visibility and angular visibility at 10m for further modeling.

I used the change in deviance to assess the model fit and the Cook's distance to examine high-leverage points which may have been influential to the analysis (Menard 2001). I investigated the three points with the highest leverage to determine the location in the parks, and the corresponding change in coefficient when excluded in the analysis. After both statistical and
biological consideration, the points remained in the model because 95% of the cases were within +/- 2 (Menard 2001).

Auto-correlation had to be corrected, because the significance and corresponding inferences of the explanatory variables were important (Neilsen et al. 2002). Auto-correlation is the lack of independence between pairs of observations at given distances in space or time (Diniz-Filho et al. 2003). Autocorrelation was assessed (PASSaGE) by calculating the Moran’s I using the un-standardized model residuals and distance between points. The Moran’s I autocorrelation structure was not limited to one specific area, instead showing a general trend of positive autocorrelation in the first 7 km and negative autocorrelation for another 15 km. This autocorrelation pattern was representative for each of the six model subsets. I estimated robust standard errors using the Huber/White sandwich estimator in the program STATA (StataCorp 2002) to correct for autocorrelation (Huber 1967; White 1980). The Huber/White sandwich estimator is robust to clustering (Bifulco and Ladd 2006) and decreased the potential for type I errors by correcting the standard errors to generate more conservative significance levels (Lennon 2000).

2.2.5 Model Validation

I used the Receiver Operating Characteristic (ROC) to determine classification accuracy of the final predictive model. I chose ROC as the validation method to avoid testing arbitrary probability threshold values. An advantage of the ROC approach over traditional classification tables is its ability to evaluate the proportion of correctly and incorrectly classified predictions over a continuous range of threshold probability cut-off levels (Pearce and Ferrier, 2000). ROC validation was developed using independent data not included during model
creation. I excluded twenty percent of the total data points for model validation. To represent the variance associated with the process of choosing validation data, I repeated the ROC procedure 5 times. For each iteration, I used a different set of randomly selected collision and reference points. I generated a final ROC value using the average of the 5 rounds of validation. I followed this validation procedure for each of the 6 different models.

2.3 Results

2.3.1 AIC Model Comparison

2.3.1.1 Driver visibility model subset

Of the ten Driver Visibility candidate models, the Vehicular/Human Influenced hypothesis provided support as the most parsimonious with an AICw of 0.436 (Table 2.4). This final model included the variables of recorded vehicle speed, corridor width, and presence/absence of passing lanes. Adding variables of roadside slope or visibility distance to this model did not contribute to the AICw (AICw = 0.283 and 0.224 respectively). The AICw for the additional hypotheses were approximately zero. Speed was essential in explaining MVC in the Driver Visibility model, exerting a positive influence on the odds of MVC (Table 2.5). Corridor width displayed a significant effect in the Vehicular/Human Influenced model. MVC were more likely with increasing corridor widths.
Table 2.4. Results of driver visibility AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Hypothesis/Model</th>
<th>Variables</th>
<th>K</th>
<th>-2LL</th>
<th>AIC</th>
<th>AICw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicular/Human Influenced</td>
<td>SPEED + PASSING LANE + CORRIDORWIDTH</td>
<td>4</td>
<td>132.7</td>
<td>140.71</td>
<td>0.436</td>
</tr>
<tr>
<td></td>
<td>SLOPE(0-5M) + SLOPE(10-30M) + PASSING LANE + SPEED + CORRIDORWIDTH</td>
<td>6</td>
<td>129.53</td>
<td>141.53</td>
<td>0.283</td>
</tr>
<tr>
<td></td>
<td>INLINE + INLINE² + ANG10 + ANG10² + PASSING LANE + SPEED + CORRIDORWIDTH</td>
<td>8</td>
<td>125.93</td>
<td>141.93</td>
<td>0.224</td>
</tr>
<tr>
<td></td>
<td>SPEED + INLINE + INLINE² + ANG10 + ANG10² + DISTCOVER</td>
<td>7</td>
<td>132.80</td>
<td>146.80</td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td>SLOPE(0-5M) + INLINE + INLINE²</td>
<td>4</td>
<td>148.25</td>
<td>156.25</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>SLOPE(10-30M) + ANG10 + ANG10²</td>
<td>4</td>
<td>147.10</td>
<td>155.10</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>INLINE + INLINE² + ANG10 + ANG10²</td>
<td>5</td>
<td>146.75</td>
<td>156.75</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>SLOPE(0-5M) + SLOPE(10-30M) + DISTCOVER</td>
<td>3</td>
<td>154.45</td>
<td>160.45</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>SLOPE(0-5M) + SLOPE(10-30M) + DISTCOVER</td>
<td>3</td>
<td>153.33</td>
<td>161.33</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>SLOPE(0-5M) + SLOPE(10-30M) + INLINE² + INLINE³ + ANG10 + ANG10²</td>
<td>7</td>
<td>142.22</td>
<td>156.22</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Shaded row represents the final model to be used.

Table 2.5. Results of logistic regression analysis for the most parsimonious AIC driver visibility model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>S.E. (Robust)</th>
<th>$W$</th>
<th>$P$ (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPEED*</td>
<td>0.155</td>
<td>0.046</td>
<td>10.05</td>
<td>0.001</td>
</tr>
<tr>
<td>CORRIDOR WIDTH*</td>
<td>0.046</td>
<td>0.02</td>
<td>7.255</td>
<td>0.028</td>
</tr>
<tr>
<td>PASSING</td>
<td>-0.127</td>
<td>0.49</td>
<td>0.070</td>
<td>0.801</td>
</tr>
<tr>
<td>Constant</td>
<td>-16.968</td>
<td>4.70</td>
<td>12.09</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*P<0.05

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2.3.1.2 GIS model subset

The Topographic Influence and Water Body hypothesis was selected as the final model of the nine candidate models within the GIS subset (AICw = 0.537) (Table 2.6) and the subsequent MVC probability layer is presented in Figure 2.3. Within this model, topographic variables included slope, aspect, and elevation while water bodies included lakes, rivers, and wetlands. The Topographic Influences and Wetland hypothesis resulted in the next highest AICw (AICw = 0.299). This model differed from the best in that it did not include aspect, rivers, and lakes. When slope was examined as an individual variable within the GIS model, a similar influence was found with MVC being correlated to flat slopes (Table 2.7). Additional topographic variables which were significantly correlated to MVC in the GIS/Driver Visibility model, but not the GIS model alone included elevation and aspect. The distance to wetland had the most influence in the GIS model, ahead of slope, with MVC occurring significantly closer to wetland. Quadratic terms of slope, aspect, and elevation were included. MVC were more probable at 0-10° slope, north-easterly to southerly aspects, and low to mid elevations. The GIS model produced the highest ROC score at 96%.
Table 2.6. Results of GIS AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Hypothesis/Model</th>
<th>Variables</th>
<th>K</th>
<th>-2LL</th>
<th>AIC</th>
<th>AICw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographic Influences and Water Bodies</td>
<td>ELEVATION + ELEVATION$^2$ + SLOPE + SLOPE$^2$ + ASPECT + ASPECT$^2$ + WETLAND + WATER</td>
<td>9</td>
<td>44.075</td>
<td>62.08</td>
<td>0.537</td>
</tr>
<tr>
<td></td>
<td>WETLAND + ELEVATION + ELEVATION$^2$ + SLOPE + SLOPE$^2$</td>
<td>6</td>
<td>51.345</td>
<td>63.35</td>
<td>0.299</td>
</tr>
<tr>
<td>Topographic Influences and Wetland</td>
<td>ELEVATION + ELEVATION$^2$ + SLOPE + SLOPE$^2$ + ASPECT + ASPECT$^2$ + HIKING + RAIL</td>
<td>9</td>
<td>46.515</td>
<td>64.52</td>
<td>0.159</td>
</tr>
<tr>
<td>Topographic Influences and Moose Movement</td>
<td>HABITAT + WETLAND + WATER + LANDCOVER</td>
<td>5</td>
<td>61.475</td>
<td>71.48</td>
<td>0.005</td>
</tr>
<tr>
<td>Moose Habitat</td>
<td>BUILT + HIKING + RAIL</td>
<td>4</td>
<td>101.558</td>
<td>109.56</td>
<td>0</td>
</tr>
<tr>
<td>Human Built</td>
<td>RISK + CURVE + SLOPE + SLOPE$^2$ + ASPECT + ASPECT$^2$ + LANDCOVER</td>
<td>8</td>
<td>65.429</td>
<td>79.43</td>
<td>0</td>
</tr>
<tr>
<td>Driver-Related Attributes</td>
<td>ELEVATION + ELEVATION$^2$ + SLOPE + SLOPE$^2$ + ASPECT + ASPECT$^2$</td>
<td>7</td>
<td>68.169</td>
<td>82.17</td>
<td>0</td>
</tr>
<tr>
<td>Topographic Influences</td>
<td>HIKING + RAIL + SLOPE + SLOPE$^2$</td>
<td>5</td>
<td>85.96</td>
<td>95.96</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Shaded row represents the final model to be used.

Table 2.7. Results of logistic regression analysis for the most parsimonious AIC GIS model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>S.E. (Robust)</th>
<th>W</th>
<th>P (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WETLAND*</td>
<td>-0.002</td>
<td>0.0004</td>
<td>9.798</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SLOPE*</td>
<td>-1.049</td>
<td>0.296</td>
<td>7.440</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SLOPE$^2$</td>
<td>0.017</td>
<td>0.006</td>
<td>4.962</td>
<td>0.003</td>
</tr>
<tr>
<td>ASPECT$^2$</td>
<td>3.0 x 10$^{-4}$</td>
<td>1.0 x 10$^{-4}$</td>
<td>4.305</td>
<td>0.041</td>
</tr>
<tr>
<td>ELEV$^2$</td>
<td>-4.0 x 10$^{-5}$</td>
<td>2.0 x 10$^{-6}$</td>
<td>3.309</td>
<td>0.058</td>
</tr>
<tr>
<td>ASPECT</td>
<td>-0.085</td>
<td>0.0479</td>
<td>2.664</td>
<td>0.076</td>
</tr>
<tr>
<td>ELEV</td>
<td>0.055</td>
<td>0.0343</td>
<td>2.475</td>
<td>0.112</td>
</tr>
<tr>
<td>WATER</td>
<td>0.001</td>
<td>0.003</td>
<td>0.135</td>
<td>0.707</td>
</tr>
<tr>
<td>Constant</td>
<td>0.958</td>
<td>16.38</td>
<td>0.004</td>
<td>0.953</td>
</tr>
</tbody>
</table>

*P<0.05

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Figure 2.3. Probability surface showing the likelihood of MVC for Mount Revelstoke and Glacier National Parks using the GIS logistic regression model.

2.3.1.3 Roadside vegetation model subset

Of the Roadside Vegetation Models, the Forage Species hypothesis had the greatest AICw, although, the weight was only 0.504 suggesting uncertainty in model selection. Variables included in this model were selected to approximate moose browse as reported in the literature. Neither shrub age nor non-forage species were effective in explaining the distribution of MVC (AICw = 0.174 and AICw = 0.041, respectively; Table 2.8). Within the Roadside Vegetation
model, the presence of grasses was positively correlated to MVC sites, while the presence of alder significantly decreased the likelihood of a kill (Table 2.9).

Table 2.8. Results of Roadside Vegetation AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Hypothesis/Model</th>
<th>Variables</th>
<th>K</th>
<th>-2LL</th>
<th>AIC</th>
<th>AICw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage Species</td>
<td>WILLOW + DOGWOOD + ALDER + CEDAR + ASPEN + HORSETAIL + GRASS + SPRUCE + ROSE</td>
<td>10</td>
<td>139.088</td>
<td>159.09</td>
<td>0.504</td>
</tr>
<tr>
<td>Forage Species and Shrub Age</td>
<td>ROADSIDE AGECLASS + WILLOW + DOGWOOD + ALDER + CEDAR + ASPEN + HORSETAIL + GRASS + SPRUCE + ROSE</td>
<td>11</td>
<td>138.477</td>
<td>160.48</td>
<td>0.246</td>
</tr>
<tr>
<td>Shrub Age</td>
<td>ROADSIDE AGECLASS</td>
<td>2</td>
<td>157.4</td>
<td>161.42</td>
<td>0.174</td>
</tr>
<tr>
<td>Non-Forage Species</td>
<td>TWINBERRY + DOGBANE + LUPIEN SP. + WHITEBOGORCHID + PAINTBRUSH + SUNFLOWER</td>
<td>7</td>
<td>150.207</td>
<td>164.21</td>
<td>0.041</td>
</tr>
<tr>
<td>None-Forage Species and Shrub Age</td>
<td>ROADSIDE AGECLASS + TWINBERRY + DOGBANE + LUPIEN SP. + PAINTBRUSH + WHITEBOGORCHID + SUNFLOWER</td>
<td>8</td>
<td>148.996</td>
<td>165.00</td>
<td>0.033</td>
</tr>
<tr>
<td>Trees/ Shrubs</td>
<td>WILLOW + DOGWOOD + CEDAR + TWINBERRY + ALDER + ASPEN + DOGBANE + SPRUCE + ROSE</td>
<td>10</td>
<td>148.822</td>
<td>168.82</td>
<td>0.004</td>
</tr>
<tr>
<td>Trees/ Shrubs and Shrub Age</td>
<td>ROADSIDE AGECLASS + WILLOW + DOGWOOD + CEDAR + TWINBERRY + ALDER + ASPEN + DOGBANE + SPRUCE + ROSE</td>
<td>11</td>
<td>147.527</td>
<td>169.53</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Note: Shaded row represents the final model to be used.
Table 2.9. Results of logistic regression analysis for the most parsimonious AIC Roadside Vegetation model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>( \beta )</th>
<th>S.E. (Robust)</th>
<th>( W )</th>
<th>( P ) (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRASS*</td>
<td>1.080</td>
<td>0.515</td>
<td>5.194</td>
<td>0.036</td>
</tr>
<tr>
<td>ALDER</td>
<td>-0.976</td>
<td>0.52</td>
<td>4.050</td>
<td>0.061</td>
</tr>
<tr>
<td>SPRUCE</td>
<td>1.153</td>
<td>0.626</td>
<td>3.704</td>
<td>0.065</td>
</tr>
<tr>
<td>HORSETAIL</td>
<td>-0.884</td>
<td>0.469</td>
<td>3.617</td>
<td>0.059</td>
</tr>
<tr>
<td>DOGWOOD</td>
<td>0.757</td>
<td>0.62</td>
<td>1.672</td>
<td>0.222</td>
</tr>
<tr>
<td>WILLOW</td>
<td>0.734</td>
<td>0.607</td>
<td>1.405</td>
<td>0.227</td>
</tr>
<tr>
<td>ROSE</td>
<td>-0.312</td>
<td>0.543</td>
<td>0.414</td>
<td>0.565</td>
</tr>
<tr>
<td>CEDAR</td>
<td>-0.560</td>
<td>1.027</td>
<td>0.367</td>
<td>0.585</td>
</tr>
<tr>
<td>ASPEN</td>
<td>-0.137</td>
<td>0.484</td>
<td>0.077</td>
<td>0.778</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.913</td>
<td>0.618</td>
<td>2.260</td>
<td>0.139</td>
</tr>
</tbody>
</table>

\( *P<0.05 \)

2.3.1.4 Moose habitat model subset

The Land Cover Type model was the most parsimonious of the Moose Habitat candidate models (AIC\( w = 0.479 \)) (Table 2.10). The addition of the distance to water intersection variable to this land cover model decreased the AIC\( w \) (AIC\( w = 0.441 \)), however, the small differences in AIC\( w \) suggest uncertainty in model selection. The remainder of the candidate hypotheses all had AIC\( w \) under 0.01. Coniferous forest exerted a significant positive influence on the odds of a MVC within the Moose Habitat model (Table 2.11).
Table 2.10. Results of Moose Habitat AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Hypothesis/Model</th>
<th>Variables</th>
<th>K</th>
<th>-2LL</th>
<th>AIC</th>
<th>AICw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Cover Type</td>
<td>CF + MF + WETLAND + SHRUB</td>
<td>5</td>
<td>141.532</td>
<td>151.53</td>
<td>0.479</td>
</tr>
<tr>
<td>Proximity to Aquatic Habitat and Land Cover Type</td>
<td>MF + CF + SHRUB + WETLAND + WATERINT</td>
<td>6</td>
<td>139.676</td>
<td>151.68</td>
<td>0.441</td>
</tr>
<tr>
<td>Full Model</td>
<td>ECOTONE + FORESTEDGE + WATERINT + CF + MF + WETLAND + SHRUB</td>
<td>8</td>
<td>137.6</td>
<td>155.62</td>
<td>0.059</td>
</tr>
<tr>
<td>Proximity to Aquatic Habitat and Shrub</td>
<td>WATERINT + WETLAND + SHRUB</td>
<td>4</td>
<td>151.304</td>
<td>159.30</td>
<td>0.010</td>
</tr>
<tr>
<td>Forest Type and Edge Habitat</td>
<td>FORESTEDGE + CF + MF + ECOTONE</td>
<td>5</td>
<td>147.892</td>
<td>159.89</td>
<td>0.007</td>
</tr>
<tr>
<td>Proximity to Aquatic Habitat</td>
<td>WATERINT + WETLAND</td>
<td>3</td>
<td>155.242</td>
<td>161.24</td>
<td>0.004</td>
</tr>
<tr>
<td>Edge Habitat</td>
<td>ECOTONE + FORESTEDGE</td>
<td>3</td>
<td>158.946</td>
<td>166.95</td>
<td>0</td>
</tr>
<tr>
<td>Proximity to Aquatic Habitat and Edge Habitat</td>
<td>WATERINT + WETLAND + FORESTEDGE + ECOTONE</td>
<td>5</td>
<td>154.87</td>
<td>166.87</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Shaded row represents the final model to be used.

Table 2.11. Results of logistic regression analysis for the most parsimonious AIC Moose Habitat model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>S.E. (Robust)</th>
<th>$W$</th>
<th>$P$ (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONIFEROUS FOREST*</td>
<td>0.038</td>
<td>0.0126</td>
<td>8.683</td>
<td>0.002</td>
</tr>
<tr>
<td>SHRUB</td>
<td>-0.042</td>
<td>0.021</td>
<td>3.418</td>
<td>0.050</td>
</tr>
<tr>
<td>WETLAND</td>
<td>0.038</td>
<td>0.028</td>
<td>2.713</td>
<td>0.179</td>
</tr>
<tr>
<td>MIXED FOREST</td>
<td>0.003</td>
<td>0.013</td>
<td>0.050</td>
<td>0.804</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.971</td>
<td>0.809</td>
<td>1.217</td>
<td>0.230</td>
</tr>
</tbody>
</table>

* $P<0.05$

2.3.1.5 Moose evidence model subset

The AICw was 0.529 for the Trails and Transect Evidence model, providing support as the most parsimonious of the Moose Evidence candidate models (Table 2.12). This model
included moose evidence within the 100m transect as well as the presence/absence of game trails. The candidate models with only trails (AICw = 0) or only evidence indicators of tracks, browse, and pellets (AICw = 0.048) performed poorly on their own. The inclusion of roadside tracks, browse, and pellets did not help to explain MVC occurrence (AICw = 0.315) nor were the roadside variables effective predictors on their own (AICw = 0). Evidence of moose was positively correlated with MVC sites with the presence of tracks being the most important, followed by presence of pellets, and presence of game trails (Table 2.13). This most parsimonious AIC moose evidence model including both trails and transect evidence indicators correctly classified 86% of MVC using ROC.

Table 2.12. Results of Moose Evidence AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Hypothesis/Model</th>
<th>Variables</th>
<th>K</th>
<th>-2LL</th>
<th>AIC</th>
<th>AICw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trails and Transect Evidence</td>
<td>TRAIL + TRACKS + BROWSE + PELLETS</td>
<td>5</td>
<td>94.432</td>
<td>104.43</td>
<td>0.529</td>
</tr>
<tr>
<td>Full Model</td>
<td>TRAIL + TRACKS + BROWSE + PELLETS + TRACKSROAD + BROWSEROAD</td>
<td>7</td>
<td>91.4</td>
<td>105.42</td>
<td>0.315</td>
</tr>
<tr>
<td>Roadside Evidence and Transect Evidence</td>
<td>BROWSE + TRACKS + PELLETS + TRACKSROAD + BROWSEROAD</td>
<td>6</td>
<td>95.729</td>
<td>107.73</td>
<td>0.101</td>
</tr>
<tr>
<td>Transect Evidence</td>
<td>BROWSE + TRACKS + PELLETS</td>
<td>4</td>
<td>101.262</td>
<td>109.26</td>
<td>0.048</td>
</tr>
<tr>
<td>Moose Tracks</td>
<td>TRACKS + TRACKSROAD</td>
<td>3</td>
<td>106.924</td>
<td>112.92</td>
<td>0.008</td>
</tr>
<tr>
<td>Trails</td>
<td>TRAIL</td>
<td>2</td>
<td>127.0</td>
<td>130.99</td>
<td>0</td>
</tr>
<tr>
<td>Browse Presence</td>
<td>BROWSE + BROWSEROAD</td>
<td>3</td>
<td>141.641</td>
<td>147.64</td>
<td>0</td>
</tr>
<tr>
<td>Roadside Evidence</td>
<td>TRACKSROAD + BROWSEROAD</td>
<td>3</td>
<td>145.696</td>
<td>151.70</td>
<td>0</td>
</tr>
<tr>
<td>Trails and Roadside Evidence</td>
<td>TRACKSROAD + BROWSEROAD + TRAIL</td>
<td>4</td>
<td>121.153</td>
<td>129.15</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Shaded row represents the final model to be used.
2.13. Results of logistic regression analysis for the most parsimonious AIC Moose Evidence model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>β</th>
<th>S.E. (Robust)</th>
<th>W</th>
<th>P (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRACKS*</td>
<td>1.887</td>
<td>0.603</td>
<td>10.62</td>
<td>0.002</td>
</tr>
<tr>
<td>PELLETS</td>
<td>2.467</td>
<td>1.619</td>
<td>5.527</td>
<td>0.128</td>
</tr>
<tr>
<td>TRAIL</td>
<td></td>
<td></td>
<td>6.719</td>
<td></td>
</tr>
<tr>
<td>TRAIL(HIGH)*</td>
<td>1.616</td>
<td>1.333</td>
<td>2.040</td>
<td>0.018</td>
</tr>
<tr>
<td>TRAIL(LOW)</td>
<td>0.210</td>
<td>0.595</td>
<td>0.035</td>
<td>0.875</td>
</tr>
<tr>
<td>BROWSE</td>
<td>0.959</td>
<td>0.594</td>
<td>1.952</td>
<td>0.106</td>
</tr>
<tr>
<td>Constant</td>
<td>-2.927</td>
<td>0.496</td>
<td>4.911</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*P<0.05

2.3.1.6 Highway design model subset

The comparison of the nine Highway Design candidate models resulted in the Highway Corridor Engineering hypothesis as being the most parsimonious (AICw = 0.579) (Table 2.14). The full model, which included the additional variable of distance to crossroad, was no more parsimonious (AICw = 0.215). The hypothesis that variables associated with moose movement resulted in a model with a lower AICw (AICw = 0.144). The additional highway design hypotheses modeling more individual variable groupings were all under AICw of 0.1. Corridor width displayed a significant effect in both the Driver Visibility and the Highway Design models (Table 2.15). In each model, MVC were more likely with increasing corridor widths. The Highway Design model showed the poorest performance among the model subsets with a 46.2% ROC score.
Table 2.14. Results of Highway Design AIC candidate model selection within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Hypothesis/Model</th>
<th>Variables</th>
<th>K</th>
<th>-2LL</th>
<th>AIC</th>
<th>AICw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway Corridor Engineering</td>
<td>TOPO + SLOPE(0-5M) + SLOPE(10-30M) + MEDIAN + JERSEY + PASSING LANE + CORRIDORWIDTH + DITCH</td>
<td>9</td>
<td>130.893</td>
<td>148.89</td>
<td>0.579</td>
</tr>
<tr>
<td>Full Model</td>
<td>TOPO + DITCH + SLOPE(0-5M) + SLOPE(10-30M) + MEDIAN + JERSEY + PASSING LANE + CROSSROAD + CORRIDORWIDTH</td>
<td>10</td>
<td>130.8</td>
<td>150.84</td>
<td>0.215</td>
</tr>
<tr>
<td>Moose Movement</td>
<td>TOPO + SLOPE(0-5M) + SLOPE(10-30M) + CROSSROAD + JERSEY + CORRIDORWIDTH + DITCH</td>
<td>8</td>
<td>135.71</td>
<td>151.71</td>
<td>0.144</td>
</tr>
<tr>
<td>Highway Features</td>
<td>MEDIAN + JERSEY + PASSING LANE + CORRIDORWIDTH</td>
<td>4</td>
<td>144.156</td>
<td>154.16</td>
<td>0.044</td>
</tr>
<tr>
<td>Topographic Class</td>
<td>TOPO</td>
<td>2</td>
<td>152.561</td>
<td>156.56</td>
<td>0.014</td>
</tr>
<tr>
<td>Slope</td>
<td>TOPO + DITCH + SLOPE(0-5M) + SLOPE(10-30M)</td>
<td>5</td>
<td>149.5</td>
<td>159.48</td>
<td>0.003</td>
</tr>
<tr>
<td>Median Presence</td>
<td>MEDIAN</td>
<td>2</td>
<td>158.055</td>
<td>162.05</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Note: Shaded row represents the final model to be used.
Table 2.15. Results of logistic regression analysis for the most parsimonious AIC Moose Habitat model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>S.E. (Robust)</th>
<th>$W$</th>
<th>$P$ (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CORRIDOR WIDTH*</td>
<td>0.063</td>
<td>0.028</td>
<td>10.04</td>
<td>0.027</td>
</tr>
<tr>
<td>PASSING LANE</td>
<td>0.749</td>
<td>0.494</td>
<td>2.074</td>
<td>0.129</td>
</tr>
<tr>
<td>SLOPE (0-5M)</td>
<td>-0.029</td>
<td>0.019</td>
<td>1.851</td>
<td>0.134</td>
</tr>
<tr>
<td>MEDIAN</td>
<td>-1.156</td>
<td>1.018</td>
<td>1.503</td>
<td>0.256</td>
</tr>
<tr>
<td>DITCH</td>
<td>-0.289</td>
<td>0.527</td>
<td>0.336</td>
<td>0.584</td>
</tr>
<tr>
<td>JERSEY BARRIER</td>
<td>0.199</td>
<td>0.468</td>
<td>0.143</td>
<td>0.671</td>
</tr>
<tr>
<td>SLOPE (10-30M)</td>
<td>0.001</td>
<td>0.01</td>
<td>0.006</td>
<td>0.927</td>
</tr>
<tr>
<td>TOPO</td>
<td></td>
<td></td>
<td>8.868</td>
<td></td>
</tr>
<tr>
<td>TOPO(2B)</td>
<td>0.574</td>
<td>1.236</td>
<td>0.51</td>
<td>0.642</td>
</tr>
<tr>
<td>TOPO(3A)</td>
<td>-1.353</td>
<td>0.867</td>
<td>-1.59</td>
<td>0.119</td>
</tr>
<tr>
<td>TOPO(3B)</td>
<td>-1.571</td>
<td>0.897</td>
<td>-1.70</td>
<td>0.080</td>
</tr>
<tr>
<td>TOPO(3C)</td>
<td>0.913</td>
<td>1.308</td>
<td>0.81</td>
<td>0.485</td>
</tr>
<tr>
<td>TOPO(4)</td>
<td>0.347</td>
<td>0.911</td>
<td>0.41</td>
<td>0.704</td>
</tr>
<tr>
<td>TOPO(5A)</td>
<td>-0.422</td>
<td>0.890</td>
<td>-0.44</td>
<td>0.635</td>
</tr>
<tr>
<td>TOPO(5B)</td>
<td>-0.412</td>
<td>0.978</td>
<td>-0.44</td>
<td>0.674</td>
</tr>
<tr>
<td>TOPO(6C)</td>
<td>-1.212</td>
<td>1.178</td>
<td>-1.03</td>
<td>0.303</td>
</tr>
<tr>
<td>Constant</td>
<td>-2.237</td>
<td>1.369</td>
<td>-1.94</td>
<td>0.102</td>
</tr>
</tbody>
</table>

* $P<0.05$

2.3.1.7 Interaction models

The first model combined GIS and driver visibility models to explore both human/animal effects and the 2 scales at once (Table 2.16). Slope-speed, slope-corridor width, wetland-speed and wetland-corridor width were included as interactions. In the GIS/Driver Visibility interaction model, MVC were more likely to occur in flat areas with greater speeds. When GIS was combined with Driver Visibility, the interaction model had a smaller prediction accuracy than GIS alone, yet still impressive, correctly classifying 92.4% of points correctly. The second combination model included variables from the moose habitat and driver visibility models. Interaction terms consisted of coniferous forest with both speed and highway corridor width (Table 2.17). None of the variables were statistically significant in the Moose Habitat/Driver Visibility interaction model. When Driver Visibility was combined with moose habitat, the
interaction model had a higher ROC score than the Driver Visibility model alone, yet was still poor; only correctly classified 65.7% of the points.

Table 2.16. Results of logistic regression analysis for the most parsimonious AIC GIS/Driver Visibility interaction model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>S.E. (Robust)</th>
<th>$W$</th>
<th>$P$ (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOPE x SPEED*</td>
<td>-0.017</td>
<td>0.007</td>
<td>6.208</td>
<td>0.015</td>
</tr>
<tr>
<td>ASPECT*</td>
<td>-0.129</td>
<td>0.053</td>
<td>3.920</td>
<td>0.015</td>
</tr>
<tr>
<td>ASPECT$^2*$</td>
<td>4.36 x $10^{-4}$</td>
<td>1.7 x $10^{-4}$</td>
<td>5.343</td>
<td>0.008</td>
</tr>
<tr>
<td>ELEV</td>
<td>0.138</td>
<td>0.077</td>
<td>5.073</td>
<td>0.015</td>
</tr>
<tr>
<td>ELEV$^2$</td>
<td>-9 x $10^{-5}$</td>
<td>5.0 x $10^{-5}$</td>
<td>5.513</td>
<td>0.050</td>
</tr>
<tr>
<td>SLOPE$^2$</td>
<td>0.023</td>
<td>0.012</td>
<td>4.098</td>
<td>0.015</td>
</tr>
<tr>
<td>SLOPE x WIDTH</td>
<td>0.008</td>
<td>0.004</td>
<td>3.537</td>
<td>0.053</td>
</tr>
<tr>
<td>WETLAND x SPEED*</td>
<td>-2.0 x $10^{-5}$</td>
<td>7.8 x $10^{-6}$</td>
<td>2.825</td>
<td>0.026</td>
</tr>
<tr>
<td>WETLAND x WIDTH</td>
<td>1.0 x $10^{-5}$</td>
<td>9.3 x $10^{-6}$</td>
<td>0.381</td>
<td>0.326</td>
</tr>
<tr>
<td>WATER</td>
<td>-0.002</td>
<td>0.003</td>
<td>0.127</td>
<td>0.611</td>
</tr>
<tr>
<td>PASSING</td>
<td>-0.047</td>
<td>0.961</td>
<td>0.002</td>
<td>0.961</td>
</tr>
<tr>
<td>Constant</td>
<td>-27.371</td>
<td>29.065</td>
<td>1.856</td>
<td>0.345</td>
</tr>
</tbody>
</table>

* $P<0.05$

Table 2.17. Results of logistic regression analysis for the most parsimonious AIC moose habitat/driver visibility interaction model predicting MVC in Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>S.E. (Robust)</th>
<th>$W$</th>
<th>$P$ (Robust)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WETLAND</td>
<td>0.044</td>
<td>0.028</td>
<td>3.395</td>
<td>0.124</td>
</tr>
<tr>
<td>SHRUB</td>
<td>-0.036</td>
<td>0.022</td>
<td>2.333</td>
<td>0.102</td>
</tr>
<tr>
<td>CONIFEROUS FOREST x WIDTH</td>
<td>0.001</td>
<td>3.0 x $10^{-4}$</td>
<td>2.215</td>
<td>0.117</td>
</tr>
<tr>
<td>PASSING</td>
<td>-0.511</td>
<td>0.438</td>
<td>1.327</td>
<td>0.243</td>
</tr>
<tr>
<td>CONIFEROUS FOREST x SPEED</td>
<td>2.0 x $10^{-4}$</td>
<td>2.0 x $10^{-4}$</td>
<td>0.879</td>
<td>0.307</td>
</tr>
<tr>
<td>MIXED FOREST</td>
<td>0.009</td>
<td>0.014</td>
<td>0.345</td>
<td>0.520</td>
</tr>
<tr>
<td>Constant</td>
<td>-1.254</td>
<td>0.90</td>
<td>1.573</td>
<td>0.050</td>
</tr>
</tbody>
</table>

* $P<0.05$
2.3.2 ROC Validation

Swets (1988) identifies 70 – 90% discrimination ability as reasonable and rates higher than 90% as very good discrimination because the sensitivity rate is high relative to the false positive rate. Using this 70% as a minimum threshold, the acceptable models after ROC validation in descending order include GIS, GIS + Driver Visibility, Moose Evidence, and Moose Habitat. Highway Design, Roadside Vegetation, Driver Visibility and the Moose Habitat/Driver Visibility models were below the 70% threshold (Table 2.18). The final AIC test among the best local-scale model from each of the 5 subsets strongly supported the Moose Evidence model as the most parsimonious (AICw = 1.0), adding further support to its ROC score of 86% as the strongest field-based MVC predictive model.

Table 2.18. Model ROC Validation results on the best AIC model from each subset.

<table>
<thead>
<tr>
<th>Model</th>
<th>ROC</th>
<th>S.E.</th>
<th>AICw</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIS</td>
<td>96%</td>
<td>0.035</td>
<td>n/a</td>
</tr>
<tr>
<td>GIS + Driver Visibility</td>
<td>92.4%</td>
<td>0.061</td>
<td>n/a</td>
</tr>
<tr>
<td>Moose Evidence</td>
<td>86%</td>
<td>0.076</td>
<td>1.0</td>
</tr>
<tr>
<td>Moose Habitat</td>
<td>70.2%</td>
<td>0.115</td>
<td>0</td>
</tr>
<tr>
<td>Moose Habitat + Driver Visibility</td>
<td>65.7%</td>
<td>0.117</td>
<td>0</td>
</tr>
<tr>
<td>Driver Visibility</td>
<td>63%</td>
<td>0.12</td>
<td>0</td>
</tr>
<tr>
<td>Roadside Vegetation</td>
<td>59.2%</td>
<td>0.123</td>
<td>0</td>
</tr>
<tr>
<td>Highway Design</td>
<td>46.2%</td>
<td>0.126</td>
<td>0</td>
</tr>
</tbody>
</table>

n/a: GIS model not tested using AIC among other models due to difference in scale.

2.4 Discussion

2.4.1 Model Performance

Although ROC scores for the GIS, GIS and Driver Visibility Interaction, Moose Evidence and Moose Habitat models exhibited reasonably high discrimination, results should be interpreted with caution. As the study area is within a National Park, the land processes outside
park boundaries, such as forestry, may have exerted a greater influence on areas close to the park entrance over those near the centre of the park. As the study area is situated within both a high mountain pass and a protected area, the transportation challenges and ecological processes are unique. The model results should therefore not be directly extrapolated to other areas. If the models were to be used elsewhere, the structure could be kept intact with site-specific variables appropriately adapted to the location and species.

Additional caution should be used when interpreting these models as not all of the collisions which have occurred in the past were reported. The total number of collisions involving motor vehicles and large animals in Canada has generally been underestimated by 20 to 30% (Damas and Smith 1982). Examples of these reporting discrepancies include the unknown taking of carcasses before highway contractors are alerted, carcasses falling out of sight, or animals moving away to die at unknown locations. In addition, drivers may report the collision to another jurisdiction or fail to report a minor collision, instead paying for the damages privately (Sielecki 2004).

The varying degrees of unexplained variation present among the models can be attributed to a complex array of other potential factors. The models were developed using the data and techniques available and were not inclusive of all possible variables. Examples include traffic volume or moose density measures previously shown to have successfully explained WVC (Bashore et al. 1985; Finder et al. 1999; Clevenger et al. 2003; Malo et al. 2004). Notwithstanding the inclusion of additional variables, unexplained variation may be due to one simple, but determining factor such as weather, driver alertness or moose behaviour. There is a possibility that the inclusion of Mount Revelstoke MVC in the overall model affected prediction
accuracy due to the 16 km distance gap between parks. The two parks do, however, share ecosystem characteristics and are managed under one division of Parks Canada.

### 2.4.2 Interpretation of Contributing Factors

Speed was found to have a significant relationship with MVC in the Driver Visibility model. Higher speeds leading to a greater chance in MVC is a logical finding and provides support to the literature, although Seiler (2005) and Malo et al. (2004) modelled speed limit as opposed to actual radar speed. The width of the road was significantly correlated to MVC in both the Driver Visibility model and the Highway Design model, although these 2 models were poor predictors overall. MVC sites were found at highway locations with greater corridor width than reference sites. Clevenger and Waltho (1999) found that wildlife use of highway passages was positively correlated with road width. Any chance for improved visibility resulting from greater vegetation clearance may have been masked as the bulk of accidents in the 2 parks occurred at night. A similar trend could explain the low correlation of MVC with distance to road curve, inline visibility, and angular visibility. Gunson et al. (2006) accredited the lack of WVC explanation at curved highway sections to a decrease in vehicle speed. Furthermore, roadside brushing likely augments the risk of collision by maintaining early seral vegetation which attracts wildlife to the highway (Child et al. 1991, Rea 2003). Other studies have provided support for animals preferring to cross highways or railways that are closer to vegetation cover (Jaren et al. 1991, Clevenger et al. 2003, Seiler 2005, Malo et al. 2004). The combination of increased visibility and increased moose attraction may have led to the poor predictive abilities of the Driver Visibility and Highway Design models.
The positive correlation between a wider highway corridor width and MVC may simply be a function of the highway being reduced to narrow widths along steeper sections. Both corridor width and speed no longer showed significance when combined with coniferous forest. This interaction finding complements Seiler, (2005) where the distance between forest cover and the road was significantly correlated to MVC; however, if vehicle speed was increased, the effect of forest proximity was less important. Coniferous forest as a single variable in the Habitat model was, however, significant. Coniferous forest has been found to be an important habitat type, with moose use ranging from 31- 49% use per season in central British Columbia (Perry 1999). Mixed forest was not, however, found to be a significant contributor to the Habitat model. Perry (1999) found mixed coniferous/deciduous forest to be a slightly less important moose habitat, being selected 26-41% per season. In addition, moose avoid wolves by spacing out and escaping into patches of conifers (Kunkel and Pletscher 2000).

The largest influence on MVC in the GIS model was the slope variable, which was negatively correlated to the probability of a MVC. A relatively flat slope has been related to MVC in previous studies (Gunson et al. 2006, LeBlanc and Martel 2006). Clevenger et al. (2003) found that mammals were more likely to cross when the highway was level with the adjacent terrain. Where the two national parks are within the Selkirk Mountain range, this effect may be magnified due to the narrow valley corridors and limited gentle sloping landscapes. Snow accumulation is less in the valley bottoms, providing important ungulate habitat in the late autumn, winter and early spring (Woods 1996). The rugged mountain terrain forces both wildlife and human movement through the valley passes (Woods 1996). The majority of MVC within Mount Revelstoke and Glacier National Parks occurred in winter months providing support for this theory. The distance to wetland variable showed a significant correlation to
MVC within the GIS model whereas the distance to water did not. Moose seek aquatic habitats for drinking water, insect relief, aquatic forage and thermoregulation (Peek 1998).

The poor predictive ability of the Roadside Vegetation model may be attributed to a relatively homogeneous highway corridor throughout the 2 parks. Moose are browsing specialists with 90% of average diets being shrubs and trees throughout winter when the majority of MVC occurred (Perry 1999). Many of the preferred shrub species for moose were relatively common at both MVC and random reference locations. The presence of grass was the only significant variable within the Roadside Vegetation model and this may have been due to the overall scarcity of grasses in the steeper, higher elevation reference point locations. Shrub age most likely did not contribute to the AICv in Roadside Vegetation candidate models due to the majority of roadside shrubs being toward the 4 to 6-year-old range throughout the entire park.

Moose tracks and high-use game trails along a 100-m transect were correlated to MVC. Roadside moose evidence along only a 25-m transect was not included in this final model as its AICv was not improved after inclusion in the full model or on its own. Roadside evidence may not have improved the model due to the presence of roadside browsing at the majority of both MVC locations (89%) and reference points (75%).

2.4.3 Scale-dependent factors

Similar to Gunson et al. (2006), models at the landscape-scale can be a powerful first step in assessing contributing variables within the process of explaining where MVC occur. This landscape-scale/GIS approach shows promise due to its relatively efficient and inexpensive operation. The field-based models may have shown less predictive ability than the landscape-
scale model, but were nevertheless important for examining local-scale processes and revealing factors important at both scales of analysis. For this reason, I created the GIS and Driver Visibility interaction model; although, the ROC score for this interaction model was no higher than that of the GIS model on its own.

Although the Moose Habitat and Moose Evidence models suggested that habitat was a strong predictor of MVC, the distance to high-use habitat and land cover variables in the GIS model subset were not present in the AIC best GIS model. The explanation for this difference in predictability between the different models seems to be a scale-dependant issue where local effects within 100m such as forest type and moose evidence are more proficient in their prediction of MVC when using direct habitat variables. Often, availability of habitats is defined by multiple scales; however, the actual use of the habitat is restricted to one scale (Johnson et al. 2002). In addition, the landscape-scale area identified as high-use habitat or land-cover type might not have been selected for by moose and if so it may be so only at certain times of the year, thus introducing a temporal aspect to the model. Joyce and Maloney (2004) suggest that MVC occur in areas of low and high moose density. My models were created using variables stemming from an anthropogenic perspective, however, human impressions on where moose should live do not ultimately determine where a moose will be. High-quality habitat might be vacant or only occupied by a certain sex and this can counter model suggestions, being explained only by a concept called “Umwelt” (Von Uexkull, 1921, 1937). Predictions from an anthropogenic perspective are thus complex as the Umwelt concept states that animals have programmed neurohormonal cues in how the environment is interpreted which can be species, gender, social or season dependant (Bubenik 1998).
An opposite scale-related phenomenon may have occurred within my Highway Design model where the poor predictive ability may be attributed to the local-scale variables being overshadowed by landscape-scale factors. The topographic class variable examined using a 100-m transect may not have been large enough to exhibit the influence on moose movement, instead requiring the use of landscape-scale topographic factors as seen in the GIS model. Linear landscape elements such as riparian corridors, ditches, steep slopes and ridges may funnel animals alongside or across the roadway and thereby increase the risk of collisions (Seiler 2005, Malo et al. 2004). The importance of highway corridor width decreased when combined with landscape-scale factors of slope and wetland in the GIS/Driver Visibility interaction model. The speed and slope interaction variable did, however, show significance when the models with two different scales were combined, suggesting MVC are correlated to locations with higher vehicle speeds and lower slope values.

2.4.4 Management Implications

GIS is a powerful tool in the initial identification of high-risk areas for highway planning with field work only being required where local-scale mitigation measures are needed. If the need for local-scale analysis is required, Moose Evidence and Habitat should be modelled due to their reasonably high predictive abilities. Attention should be focused on highway segments close to wetland, at flat slopes, adjacent wider highway corridors, presence of coniferous forest, moose evidence and at higher vehicle speeds.

Improved road planning is the primary practice that should be regarded as the means to reduce the ecological effects that transport infrastructure impose. This study has helped reveal some of the underlying processes that contribute to MVC within the parks. The Trans Canada
Highway in Mount Revelstoke and Glacier National Parks, is a well established transportation route and mitigation measures will be necessary if road alteration or new construction occurs. Although improved highway planning is the ideal outcome based on predictive model results, mitigation decisions can also be facilitated. An effective and acceptable countermeasure should reduce animal-vehicle interactions while still allowing for necessary animal behaviour and movements (Bashore et al. 1985). Suggested measures include reductions in vehicle speed, a fencing/underpass combination, and public awareness. Reduction in vehicle speed may be difficult to implement in practice due to a requirement of additional enforcement, which can be costly. A fencing and wildlife underpass combination could be effective along the highway adjacent the Beaver River, however, would require pre-monitoring of crossing frequencies. Whenever possible, these mitigation techniques should be coupled with a public awareness program such as the Wildlife Collision Prevention Program in British Columbia. Complete reliance should not be put into educational programs to enhance public awareness about WVC as their success has not yet proven effective (Romin & Bissonette 1996), however these programs can be a starting point.

The models presented here may provide useful tools for road planners, but effective mitigation of MVC will require a more concrete approach that includes consideration of the landscape outside of park boundaries and more in depth knowledge of the local moose populations. An example of further work would be to investigate actual moose movement in the study area using telemetry data to map key crossing points. The data in combination with the collision points and modeling could provide invaluable information helping to explain the process of MVC in the national parks.
2.5 References


3.0 Chapter III: Using an Expert-Based Approach to Predict Moose-Vehicle Collisions in Mount Revelstoke and Glacier National Parks

Abstract: A Moose (*Alces alces*) - vehicle collision (MVC) is an ecological, economical, and social issue affecting both the animal(s) and human(s) involved. In order to better understand and mitigate MVC, experts contributed to the development of models by weighting the relative importance of landscape-scale explanatory criteria. The predictions made by local experts with site-specific knowledge of the area where the MVC occurred were compared to the non-local experts to assess the importance of different criteria contributing to MVC. To assess predictive abilities of the model hypotheses, I grouped criteria into either habitat-based models or driver-based models, resulting in two distinct map sets. I developed the expert-based models using the Analytical Hierarchy Process (AHP) and I used a structured survey approach where experts could assess criteria relevancy, weight the criteria, and review the weights for consistency. I used the Receiver Operating Characteristic (ROC) to validate the resulting models and Kappa index of agreement to compare them. Moose habitat classification was the highest weighted habitat-related criteria by local and non-local experts. The mean weights of distance to built area, distance to power line, aspect, slope, and distance to rail line were all notably low for both local and non local experts. Among driver-related criteria, the speed limit was weighted as the most important factor influencing MVC. Overall, habitat-based models were more proficient than driver-based models in predicting MVC within Mount Revelstoke and Glacier National Parks. The ability of local and non-local expert models to predict MVC was similar with local experts slightly outperforming non-local experts using habitat-related criteria. Given the similarity in
results, there is little evidence to suggest that one expert group should be favoured over the other. However, considering that habitat related criteria are more powerful for predicting MVC, and habitat can vary considerably across the landscape, I suggest that local experts should be used when possible.

3.1 Introduction

Wildlife-Vehicle Collisions (WVC) are common phenomena in many parts of Canada, causing injury or death to both animals and humans. The number of WVC the Insurance Corporation of British Columbia (ICBC) reported in British Columbia increased from 7,267 collisions in 1997 to 9,789 in 2001, while the number of injured motorists rose from 218 to 386 (L-P Tardif & Associates Inc. 2003). Between 1996 and 2005, 54,842 deer, 7,056 moose, 2,536 bears, 1,768 elk, 73 caribou, 3,277 other wildlife species and 6,039 domestic animals and over 2,000 unknown animal species were involved in collisions with motor vehicles (Road Health-University Wildlife Collision Mitigation Research Team 2006). WVC can have a significant impact on species conservation, wildlife management, traffic safety, as well as from an economic point of view. Between 1997 and 2002, ICBC spent over $118 million on WVC accident claims (L-P Tardif & Associates Inc. 2003). Human injury resulted from 14% to 18% of collisions with larger mammals like moose *Alces alces* in Newfoundland (Joyce & Mahoney 2001). Nearly 3,000 Moose-Vehicle Collisions (MVC) occur annually in North America (Child 1998) and 200 to 300 moose are killed on major British Columbia highways each year (Child et al. 1991, Sielecki 2000).
Tools for accurately predicting MVC locations can be important for the prevention and mitigation of future MVC. Researchers have used a number of techniques and data sources to predict MVC (Clevenger et al. 2002, Seiler 2005, Malo et al. 2004). Of these, expert-based techniques are relatively inexpensive and designed for contemporary model building purposes (Clevenger and Chruszcz 2004). GIS-based approaches have been used to identify WVC hotspots, albeit by means of heads-up expert consensus as opposed to weighting criteria using AHP (Ruediger and Lloyd 2003, Lloyd and Casey 2005, Road Health-University Wildlife Collision Mitigation Research Team 2006). Expert-based modeling is also an attractive highway planning tool where full data sets necessary for empirical models are lacking (Clevenger et al. 2002). Here I used MVC data to assess the effectiveness of expert-based modeling of MVC locations in Mount Revelstoke and Glacier National Parks, Canada.

In this chapter, I addressed 5 objectives that allowed me to assess the effectiveness of expert-based models for identifying and understanding MVC. First, I tested the predictive success of expert-based models for predicting the location of MVCs in Mount Revelstoke and Glacier National Parks. I defined success as the percentage of correctly classified MVC locations. Second, I documented the criteria experts identified as important for predicting MVC occurrence. Experts weighted criteria using a quantitative method that compared the relative importance of each criterion for identifying MVC locations. Within the third objective, I compared the relative predictive performance of expert models based on habitat criteria to models developed using driver-related criteria. My goal was to identify the suite of model variables that best predicted
MVC. Fourth, I compared the relative abilities of local and non-local experts to predict locations where MVC occurred and I documented the range of variability in opinion among experts. This chapter will allow for a comparison of MVC predictive methods as well as recommendations for reducing MVC.

3.2 Methods

3.2.1 Expert-Based Approach using the Analytical Hierarchy Process

Standard scoring and comparative weighting of criteria were applied to predict where MVC will occur. The criteria included biological and driver-related factors which were weighted by experts in terms of their relation to the spatial distribution of MVC. Criteria were weighted using a decision making tool developed by Saaty (1977) known as the Analytical Hierarchy Process (AHP) which was comprised of pair-wise comparisons. The “pair-wise comparison” refers to the relative importance of one criterion in comparison to another, providing a weighting from 0 to 1 for each. For this study, the final weightings for all the criteria were combined to predict where high MVC risk highway sections occur in a quantitative manner.

I developed a total of 10 MVC predictive maps. Two maps were created using habitat-related criteria and two using driver-related criteria, each created by local experts and non-local experts. The local and non-local expert groups were then combined to make two more maps, one overall habitat-based and one overall driver-based map. I made this distinction between local and non-local in order to investigate potential variability of geographic location and local knowledge of the study area.
3.2.2 The Structured Survey Approach

A structured survey was used to generate the expert opinions necessary to construct the AHP. Experts were contacted and asked to make pair wise judgements on the importance of criteria hypothesised as important for predicting the location of MVC. The structured survey approach provides a framework for individuals with diverse backgrounds and in remote locations to work on the same problem. Key features of the structured survey technique include anonymous responses, feedback and information, independence, and participant equality (Stone Fish and Osborn 1992). The structured survey approach can support a group of decision makers in synergy with anonymity (Gavish & Gerdes 1998) and mediation (Clawson et al. 1993). Anonymity was provided for the survey participants to enhance the quality of the decision outcomes, and to reduce ramifications from external influences such as politics. I obtained approval from the UNBC ethics committee.

The effectiveness of producing results using the structured survey process has been studied in comparison to traditional group techniques (Dalkey 1969, Helmer 1994). When real data were lacking, and the best available information was based on expert opinion, the structured survey has been shown to be superior to group discussions, and other face-to-face interactions (Pill 1971, Riggs 1983). However, the method has both advantages and disadvantages in comparison to an in-person meeting (Table 3.1).
Table 3.1. Advantages and disadvantages of structured surveys in comparison to face to face meetings (adapted from Sherry 2002).

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Cost effective, time efficient</td>
<td>- Limits experts ability to seek clarification and elaboration from other experts</td>
</tr>
<tr>
<td>- Freedom to participate when and where they want to</td>
<td>- No opportunity to share ideas in an interactive manner</td>
</tr>
<tr>
<td>- Prevents conflict and confrontation</td>
<td>- In-depth conversation and issue debating is limited</td>
</tr>
<tr>
<td>- Anonymous participation avoiding group conformity and dominance by some members</td>
<td></td>
</tr>
<tr>
<td>- Makes use of expertise which is often an untapped resource</td>
<td></td>
</tr>
<tr>
<td>- Reveals level of precision within group</td>
<td></td>
</tr>
</tbody>
</table>

The structured survey is similar to the Delphi method (*sensu* Dietz 1987) in that both methods retain the anonymity of participants, allow for mediation, and are cost effective. The two approaches do, however, differ in one main feature. In the structured survey, experts are consulted in one stage comprised of various iterations, whereas the Delphi process involves iterative stages that stimulate discussion in a conventional group setting with the aim of reaching group consensus on an issue (Dietz 1987). I intended to independently assess differences in opinions, thus not requiring collaboration or consensus. The weighting of criteria does not change after the expert has worked through the AHP process.
3.2.3 Structured Survey Process Components

The five-step process for completing the structured survey was: 1) selection of the criteria for predicting MVC; 2) selection of experts; 3) final weighting of criteria by experts; 4) combining and evaluating the criteria weights; and 5) the creation of the MVC predictive maps and investigating the variation in weighting. These components allowed experts to participate in an asynchronous fashion (Sherry 2002). Each one of these stages is explained below.

3.2.3.1 Criteria Selection and GIS Manipulation

In general, criteria were pre-selected for model inclusion due to their potential to affect the process of an MVC event. A review of MVC literature was used to determine the criteria to be weighted (Clevenger et al. 2002, Sielecki 2004, Seiler 2005). These criteria were selected based on their availability and compatibility for use in Geographical Information Systems (GIS). Ten habitat-related criteria (Table 3.2) and three driver-related criteria (Table 3.3) were included in the analysis.
Table 3.2. Habitat-related GIS criteria weighted in the expert-based model predicting the spatial occurrence of MVC in Mount Revelstoke and Glacier National Parks, BC, Canada.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>Landscape elevation that would increase the risk of MVC throughout the majority of the year</td>
<td>Low (&lt;1500m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate (1500m-2000m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (&gt;2000m)</td>
</tr>
<tr>
<td>Slope</td>
<td>Slope most likely for a moose to cross a highway</td>
<td>Low (&lt;20°)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate (20°-30°)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (&gt;30°)</td>
</tr>
<tr>
<td>Aspect</td>
<td>Aspect which increases the risk of MVC distribution throughout the year</td>
<td>Flat (aspect = 0°)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>North (aspect = 315°-45°)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>South (aspect =135°-225°)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>East (aspect = 45°-135°)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>West (aspect = 225°-315°)</td>
</tr>
<tr>
<td>Land Cover</td>
<td>Land cover type that increases the risk of MVC based on potential for increased habitat suitability</td>
<td>Coniferous Forest</td>
</tr>
<tr>
<td>Type</td>
<td></td>
<td>Mixed Forest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shrub</td>
</tr>
<tr>
<td>Moose Habitat</td>
<td>The importance of moose habitat classification in relation to moose-vehicle collisions. (based on Parks Canada Ecological Classification)</td>
<td>Not Present</td>
</tr>
<tr>
<td>Classification</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Distance to</td>
<td>Distance to water body most likely to increase the risk of MVC</td>
<td>Low (&lt;500m)</td>
</tr>
<tr>
<td>Water Body</td>
<td></td>
<td>Moderate (500m-1km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (&gt;1km)</td>
</tr>
<tr>
<td>Distance to</td>
<td>Distance to wetland most likely to increase the risk of MVC</td>
<td>Low (&lt;500m)</td>
</tr>
<tr>
<td>Wetland</td>
<td></td>
<td>Moderate (500m-1km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (&gt;1km)</td>
</tr>
<tr>
<td>Distance to</td>
<td>Distance to rail line most likely to increase the risk of MVC</td>
<td>Low (&lt;1km)</td>
</tr>
<tr>
<td>Rail Line</td>
<td></td>
<td>Moderate (1-2km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (&gt;2km)</td>
</tr>
<tr>
<td>Distance to</td>
<td>Distance to power line corridor most likely to increase the risk of MVC</td>
<td>Low (&lt;1km)</td>
</tr>
<tr>
<td>Power Line</td>
<td></td>
<td>Moderate (1-2km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (&gt;2km)</td>
</tr>
<tr>
<td>Distance to</td>
<td>Distance to human development most likely to increase the risk of MVC (building or disturbed land)</td>
<td>Low (&lt;1 km)</td>
</tr>
<tr>
<td>Built Area</td>
<td></td>
<td>Moderate (1-2km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High (&gt;2km)</td>
</tr>
</tbody>
</table>
Table 3.3. Driver-related criteria weighted in the expert-based model predicting the spatial occurrence of MVC in Mount Revelstoke and Glacier National Parks, BC, Canada.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Wildlife-Risk Sign</td>
<td>Distance to wildlife-risk sign most likely to increase the risk of MVC</td>
<td>• Low (&lt;1km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Moderate (1-2km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High (&gt;2km)</td>
</tr>
<tr>
<td>Distance to Highway Curvevature</td>
<td>Distance to a highway curve most likely to increase the risk of MVC</td>
<td>• Low (&lt;1km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Moderate (1-2km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High (&gt;2km)</td>
</tr>
<tr>
<td>Posted Speed Limit</td>
<td>Speed limit most likely for to increase the risk of MVC</td>
<td>• 70km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 90km/h</td>
</tr>
</tbody>
</table>

I included topographical criteria of slope, aspect, and elevation due to the inherent nature of moose migration from hills to valleys during the winter (Hundertmark 1997, Gundersen et al. 1998). I included the distance to water bodies (Table 3.2) and wetland (Table 3.2) due to the fact that moose seek aquatic habitats for drinking water, insect relief, aquatic forage and thermoregulation (Peek 1998).

Habitat classification and land cover data within Mount Revelstoke and Glacier National Parks were based on Parks Canada Ecological Land Classification (ELC) at a scale of 1:50,000 (Achuff et al. 1984). Moose habitat classification was based upon Parks Canada inventories (Table 3.2). Land cover classification (Table 3.2) divided vegetation cover into three classes of shrub, open forest and closed forest.

I used GIS tools to measure the distance from each MVC to rail lines (Table 3.2), power lines (Table 3.2), and built areas (Table 3.2). Rail lines and power lines both provide potential moose movement corridors and create the potential for the presence of...
early seral forage (Child et al. 1991). Moose populations are adapted to exploit early seral habitats created through disturbance (Perry 1999). I examined the distance to built areas to see if human development affects the occurrence of MVC by means of habitat alteration, human activity, and potential predator avoidance (Malo et al. 2004, Seiler 2005).

As a component of survey preparation, I used a GPS in the field to measure the distance of each MVC location from the nearest wildlife risk sign (Table 3.3) and GIS to determine the distance to highway curvature (Table 3.3) and posted speed limit (Table 3.3). I used the distance to wildlife risk sign criterion to assess the role of driver awareness for a potential MVC. I analyzed the distance to highway curvature to assess driver visibility at a landscape-scale. Speed is a known determining factor for vehicle accidents in general (Seiler 2005). I used British Columbia Provincial Government Terrain Resource Information Management (TRIM) spatial data in GIS to represent highway curvatures, elevation, slope, aspect, water bodies, and wetlands (Table 3.2). TRIM data were based on a scale of 1:20,000 with a resolution of 25-m x 25-m cell size.

Before expert review, I separated criteria with continuous data into categories based on equal linear distances determined by buffered zones from a given criteria perceived to be related to MVC. For example, I grouped distances to wetland into three categories of low, medium, and high. I created this placement to avoid subjectivity in the creation of the initial categories. The process began with a feedback component where experts reviewed the proposed criteria categories to be modeled and made suggestions for
more relevant classifications. Based on expert suggestions, I modified scales within the rail, risk, built, wetland, water, power line, and curve criteria. Experts also had the option to add new categories to a criterion; however, none of the respondents elected to exercise this option.

3.2.3.2 Expert Selection

I decided to include five local experts and five non-local experts based on expert availability and what defines an expert (Table 3.4) (refer to appendix for in depth summary of each expert). The definition of an expert is a prerequisite because this knowledge is the foundation of this research. There are a wide variety of subjective recommendations on how to define an expert (Hoffman et al. 1991 Shanteau 1992). There is no formula, however, for objective selection of experts, with criteria depending on the research objectives and context (Sherry 2002). Needham and deLoe (1990), however, suggested 2 criteria for expert selection as being representative of regional and sectoral experience in addition to exhibiting authority or expertise measured by profession or training. Ziglio (1996) defined expertise as knowledge and practical engagement of the issue at hand, willingness to contribute, and dedication to the exercise.

Career-based knowledge of moose movements, habitat requirements, and MVC was the primary criterion for inclusion on the list of potential local and non-local experts. Both local and non-local experts were selected based on recommendations from initial expert candidates. This snowballing method (Patton 2002, Neuman 2004) was used to generate a list of recognized experts with detailed knowledge of MVC and day-to-day
career-related experience concerning MVC. Because there is no objective rule for defining an expert, Shanteau (1987) has stated that the best technique is to let those in a discipline select the experts.

Local experts included Mount Revelstoke and Glacier National Park wardens, wildlife biologists, government conservation officers, and other consultants involved with MVC hotspots throughout their careers. I ensured that each local expert had detailed, site-specific knowledge about the location of MVC within the study area. Non-local experts included moose biologists and government conservation officers from various locations within British Columbia, Quebec, and Newfoundland.

<table>
<thead>
<tr>
<th>Career Type</th>
<th>Years Experience</th>
<th>Years Experience Locally</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park Biologist</td>
<td>31</td>
<td>31</td>
<td>Mount Revelstoke and Glacier</td>
</tr>
<tr>
<td>Park Research Associate</td>
<td>16</td>
<td>16</td>
<td>Mount Revelstoke and Glacier</td>
</tr>
<tr>
<td>Wildlife Biologist</td>
<td>14</td>
<td>14</td>
<td>Columbia Basin</td>
</tr>
<tr>
<td>Conservation Officer</td>
<td>13</td>
<td>13</td>
<td>Nelson &amp; Revelstoke</td>
</tr>
<tr>
<td>Park Warden</td>
<td>26</td>
<td>18</td>
<td>Mount Revelstoke and Glacier</td>
</tr>
<tr>
<td>Wildlife Biologist</td>
<td>14</td>
<td>0</td>
<td>Northern BC</td>
</tr>
<tr>
<td>Conservation Officer</td>
<td>17</td>
<td>0</td>
<td>Northern BC</td>
</tr>
<tr>
<td>Wildlife Biologist</td>
<td>14</td>
<td>0</td>
<td>Newfoundland</td>
</tr>
<tr>
<td>Wildlife Biologist</td>
<td>20</td>
<td>0</td>
<td>Northern BC</td>
</tr>
<tr>
<td>Wildlife Biologist</td>
<td>20</td>
<td>0</td>
<td>Quebec</td>
</tr>
</tbody>
</table>

Experts were not provided with detailed information on MVC spatial locations because one of the goals of the process was to assess the MVC predictive capability of experts using their personal recollection and previous experience in the field. The only
background information provided was the link to the Parks Canada website, primarily to ensure non-local experts had a basic understanding of the study area. The literature was not meant to be referenced as a source for decision support because this was meant to be a low cost and time efficient alternative to empirical-based field work.

3.2.3.3 Final expert weighting of criteria

The AHP procedure had to be standardized so that interpretation was the same and weightings were consistent for each expert (Bijl 1996). The decision making process could have been impaired if experts had different perspectives on how the task should be accomplished (Bijl 1996). Before the process began, experts were provided with a detailed summary of the objectives, the AHP procedure, and examples of how weighting should be carried out. Because communication was carried out via email and telephone to individual experts, careful explanation had to be made to ensure an equal understanding of the process.

Following the standardization process, the actual weighting involved the distribution and completion of the structured survey. Experts were asked to conduct pairwise comparisons describing the relative importance of each criterion of the pair in terms of explaining the location of MVC. Experts used Saaty’s continuous rating scale to weight two criteria components. First, experts weighted the relative importance of each category within a single criterion (Table 3.6). Second, experts compared each criterion among one another to assess relative importance. These two steps were completed for both the habitat-related criteria and driver-related criteria. The importance of each
A criterion relative to another was evaluated on a nine-point continuous scale, ranging from 1/9 (extremely less important) to 9 (extremely more important), with 1 in between the two being equally important (Table 3.5, Saaty 1977).

Table 3.5. Continuous rating scale of Saaty (1977, 1986).

<table>
<thead>
<tr>
<th>1/9</th>
<th>1/7</th>
<th>1/5</th>
<th>1/3</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely</td>
<td>Very</td>
<td>Strongly</td>
<td>Moderately</td>
<td>Equal</td>
<td>Moderately</td>
<td>Strongly</td>
<td>Very</td>
<td>Extremely</td>
</tr>
<tr>
<td>Strongly</td>
<td>More Important</td>
<td>Less Important</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The numbers in the scale represented the relative importance of each category and criteria. The numbers did not have any units as they are based on a relative scale. Although any ratio scale can be used in this method; the choice of the 1 to 9 scale recommended by Saaty (1980) is recommended for use in the AHP due to the experimental evidence of having successfully captured user preferences (Harker and Vargas 1987). An example of how a comparison was carried out for categories within a single criterion is provided in Table 3.6. The importance of Shrub cover type in the row relative to Open Forest cover type in the column = 5 (the row variable is strongly more important than the column variable).
Table 3.6. Pair wise comparison matrix method for assessing the relative importance of the categories within the criterion of Land Cover Type to MVC risk in the Glacier and Mount Revelstoke study area.

<table>
<thead>
<tr>
<th></th>
<th>Closed Forest</th>
<th>Open Forest</th>
<th>Shrub</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed Forest</td>
<td>1</td>
<td>1/3</td>
<td>3</td>
</tr>
<tr>
<td>Open Forest</td>
<td>1/3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Shrub</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

3.2.3.4 Calculating and evaluating the criteria weights

All pair wise comparisons were assessed using the ‘WEIGHT’ module in the Idrisi geographic analysis software (Eastman 2006). The ‘WEIGHT’ module calculated the criteria weights by determining the principal eigenvector (sensu Saaty 1980) based on the expert’s pair wise comparison matrix.

The final component involved a review of the weights for consistency. Inconsistencies arose when the relative importance of one criterion did not correspond logically to the importance of another. Weightings were assessed for consistency upon the completion of expert weighting and experts were then notified to adjust the weights. The most inconsistent comparison was identified based on a deviation number calculated in Idrisi (Eastman 2006) to provide the expert with guidance on where to begin the re-weighting. Saaty (1977) indicated that matrices with consistency ratio ratings greater than 0.1 should be re-evaluated. Re-evaluations were therefore required if the consistency ratio exceeded 0.1. Corrections were made where necessary and final weights were created.

3.2.3.5 Creation of MVC predictive maps and variation in weighting
All MVC susceptibility maps were created using a 500-m radius buffer along the highway. A 500-m buffer was used to represent the road-effect zone (Forman and Alexander, 1998). The road-effect zone is the area that encompasses the majority of ecological effects resulting from highway construction and use and is typically the focus of planning and mitigation (Forman, 1999).

The overlay of criteria layers to produce final MVC susceptibility maps consisted of two steps. Prior to the expert weighting of criteria, each category within a criterion served as a nominal data base layer with an equal value and equal influence on the occurrence of MVC. The first step was the multiplication of this base layer by the corresponding category weights within each criterion. The second step involved the multiplication of each categorical map layer by its corresponding weight among criteria. Each of these final criteria layers were then overlaid to produce the final layer for each map type ranging from low (0) to high (1) MVC susceptibility.

\[
\text{MVC Susceptibility} = \sum (\text{Wwithin} \cdot \text{Wamong})
\]

Where \( W_{\text{within}} \) = within criteria weight
Where \( W_{\text{among}} \) = among criteria weight

In addition to testing the differences between local and non-local expert weighting, I assessed the variability in the range of predictions based on a comparison between the mean minimum and maximum recorded weights from all experts. To test this range of weighting, I created the final four predictive maps. I completed two maps for both the mean minimum and maximum criteria weights, each using one for habitat-
related criteria and one for driver-related criteria. I calculated the MVC susceptibility of
the mean minimum and mean maximum weights using the formula $P(x) = \frac{x}{\sum x_r}$. I also
included confidence intervals around each mean to assess the variability within and
among criteria weights.

### 3.2.4 Model Validation

I validated all models using the Receiver Operating Characteristic (ROC) (Swets
1988) and compared them using the Kappa Index of Agreement (Cohen 1960). I used
ROC to determine the degree of correct classification of a MVC data point. ROC was
chosen as the validation method to avoid testing arbitrary MVC susceptibility threshold
values. An advantage of the ROC approach over traditional classification tables is the
ability to evaluate the proportion of correctly and incorrectly classified predictions over a
continuous range of threshold MVC susceptibility cut-off levels (Pearce and Ferrier
2000). Validation was completed by placing the MVC data points over the expert model
MVC susceptibility surfaces in Idrisi (Eastman 2006). This validation procedure was
followed for each model. Swets (1988) identified a 70 – 90% discrimination ability as
reasonable and rates higher than 90% as very good discrimination because the sensitivity
rate is high relative to the false positive rate.

I used the Kappa Index of Agreement (KIA) to compare the distribution of cells
across the MVC susceptibility surfaces (Cohen 1960, Congalton et al. 1983, Rosenfield
and Fitzpatrick-Lins 1986). Categories are typically distributed by chance due to a lack
of precision and the KIA coefficient has often been used to accommodate for these
effects of chance agreement (Rosenfield & Fitzpatrick-Lins 1986, Congalton 1991, Pontius 2000, Foody 2002). Some contest that the KIA should be adopted as a standard measure of classification precision (Smits et al. 1999). KIA can range from 0 (no spatial agreement) to 1.0 (full spatial agreement). KIA greater than 0.75 signify excellent agreement (Fleiss, 1981).

3.3 Results

Although all local and non-local expert confidence intervals overlapped for habitat-related criteria, wide intervals suggested variation within groups (Figure 3.1). Low and medium categories for the elevation criterion displayed wide confidence intervals for both local and non-local experts. A similar trend was present for the slope criterion. Confidence intervals for flat aspects were extremely wide for non-local groups while local experts were more in agreement. The shrub category received the highest weight within the land cover type criterion. The weightings of the distance to power line and built area criteria both led to disagreement in the low and high categories, however for different expert groups. The remainder of habitat-related criteria showed relatively similar weightings and variation among expert types.
Figure 3.1. Mean categorical weights within habitat-related criteria as defined by local and non-local experts (95% Confidence intervals included). The weightings were based on (a) elevation, (b) slope, (c) distance to water body, (d) land cover type, (e) moose habitat classification, and (f) aspect, all within Mount Revelstoke and Glacier National Parks, Canada.
Figure 3.1. continued. Mean categorical weights within habitat-related criteria as defined by local and non-local experts (95% Confidence intervals included). The weightings were based on (g) distance to wetland, (h) distance to rail line, (i) distance to power line, and (j) distance to built area all within Mount Revelstoke and Glacier National Parks, Canada.

The largest disagreement between expert groups when weighting the categories of driver-related criteria occurred with the distance to highway curvature criterion (Figure 3.2). Local experts weighted highway curvatures more heavily as places for MVC compared to straight stretches. In comparison, non-local experts stressed that intermediate distances to highway curvatures were an important influence on MVC. Confidence intervals were relatively wide for the low and medium categories of the distance to highway curvature criterion. Experts strongly agreed that MVC were more likely in zones of higher speed limits (Figure 3.2). Posted speed limit showed extremely high levels of agreement within expert groups.
Figure 3.2. Mean categorical weights within driver-related criteria as defined by local and non-local experts (95% Confidence intervals included). The weightings were based on (a) distance to highway curvature, (b) distance to wildlife-risk sign, and (c) posted speed limit.

Moose habitat classification was the highest weighted habitat-related criterion by all experts combined (Figure 3.3). Distance to wetland was the second highest weighted criterion based on opinions from all experts combined as well as from local experts alone. Non-local experts however, placed more emphasis on both land cover type and the distance to water bodies than on distance to wetland. The mean weights of distance to built area, distance to power line, aspect, slope, and distance to rail line were all notably low regardless of expert group.
Figure 3.3. Mean weights among habitat-related criteria as defined by local and non-local experts all within Mount Revelstoke and Glacier National Parks, Canada (95% Confidence intervals included).

As a whole, experts weighted speed limit as the most important factor influencing MVC among the three driver-related criteria (Figure 3.4). Local experts alone, however, weighted speed limit as the least important. The distance to highway curvature was the highest weighted driver-related criterion based on local experts alone and the second most important based on all experts combined. The weight of distance to wildlife-risk sign was the overall lowest weighted driver-related criterion.
Figure 3.4. Mean weights among driver-related criteria as defined by local and non-local experts (95% Confidence intervals included).

The minimum and maximum weights among habitat-related criteria were extracted from the raw weights of all experts (Table 3.7). Moose habitat classification received the greatest maximum weight at 0.30. The distance to power line criterion was weighted the lowest of the minimum weights at 0.012. As a general trend, the criteria, with the greatest weights, could be clustered into a maximum weight group of approximately 0.2. The opposite trend was observed for a group with minimum weights rarely exceeding 0.03. The greatest differentiation between minimum and maximum weights was found in distance to wetland with a range of 0.239. The narrowest range was observed with distance to power line at 0.073.
Table 3.7. Minimum and maximum weights among habitat-related criteria from all experts (note: normalized weight columns sum to one and were used for mapping purposes).

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Minimum Weight</th>
<th>Normalized Minimum Weight</th>
<th>Maximum Weight</th>
<th>Normalized Maximum Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moose Habitat Classification</td>
<td>0.135</td>
<td>0.345</td>
<td>0.300</td>
<td>0.148</td>
</tr>
<tr>
<td>Distance to Wetland</td>
<td>0.037</td>
<td>0.095</td>
<td>0.276</td>
<td>0.137</td>
</tr>
<tr>
<td>Land Cover Type</td>
<td>0.077</td>
<td>0.197</td>
<td>0.235</td>
<td>0.116</td>
</tr>
<tr>
<td>Distance to Water Body</td>
<td>0.029</td>
<td>0.075</td>
<td>0.253</td>
<td>0.125</td>
</tr>
<tr>
<td>Distance to Rail Line</td>
<td>0.021</td>
<td>0.053</td>
<td>0.227</td>
<td>0.112</td>
</tr>
<tr>
<td>Elevation</td>
<td>0.015</td>
<td>0.039</td>
<td>0.212</td>
<td>0.105</td>
</tr>
<tr>
<td>Aspect</td>
<td>0.023</td>
<td>0.059</td>
<td>0.164</td>
<td>0.081</td>
</tr>
<tr>
<td>Slope</td>
<td>0.023</td>
<td>0.059</td>
<td>0.138</td>
<td>0.068</td>
</tr>
<tr>
<td>Distance to Built Area</td>
<td>0.019</td>
<td>0.049</td>
<td>0.134</td>
<td>0.066</td>
</tr>
<tr>
<td>Distance to Power Line</td>
<td>0.012</td>
<td>0.031</td>
<td>0.085</td>
<td>0.042</td>
</tr>
</tbody>
</table>

Among driver-related criteria, speed limit received both the highest minimum and maximum weight while distance to wildlife risk sign received the lowest (Table 3.8). Distance to highway curvature displayed the greatest differentiation between minimum and maximum weights with a range of 0.661. Distance to wildlife risk sign showed the narrowest range at 0.582.
Table 3.8. Minimum and maximum weights among driver-related criteria using all experts (note: normalized weight columns sum to one and were used for mapping purposes).

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Minimum Weight</th>
<th>Normalized Minimum Weight</th>
<th>Maximum Weight</th>
<th>Normalized Maximum Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Limit</td>
<td>0.105</td>
<td>0.455</td>
<td>0.751</td>
<td>0.355</td>
</tr>
<tr>
<td>Distance to Highway</td>
<td>0.070</td>
<td>0.306</td>
<td>0.731</td>
<td>0.345</td>
</tr>
<tr>
<td>Curvature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to Wildlife</td>
<td>0.055</td>
<td>0.239</td>
<td>0.637</td>
<td>0.301</td>
</tr>
<tr>
<td>Risk Sign</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The KIA results permitted a spatial evaluation of the final MVC susceptibility maps. Using habitat-related criteria, the KIA between local and non-local maps was 0.428 (Figure 3.5). This score suggested low to moderate variation between local and non-local experts.

The KIA comparing local and non-local expert driver-related criteria MVC susceptibility maps was 0.288 (Figure 3.6). The largest difference between the two maps was found in the increased ability of the local expert map to differentiate high and low MVC areas.
Figure 3.5. Expert opinion MVC susceptibility maps using habitat-related criteria (a) local experts, (b) non-local experts, and (c) all experts. The inset map illustrates the location of the study area in south-eastern British Columbia, Canada.
I observed an apparent difference between the MVC susceptibility maps for habitat and driver-related criteria; using all expert weights, the KIA was 0.01, indicating extremely poor spatial agreement (Figure 3.5 and Figure 3.6). The relationship only slightly improved when isolated to local expert weights, also with a low KIA of 0.02. The KIA between non-local expert MVC susceptibility maps of habitat and driver-related criteria displayed the lowest agreement at 0.01.

Reasonable agreement was attained between MVC susceptibility maps based on minimum and maximum weights for both driver and habitat-related criteria (Figure 3.7). The KIA between minimum and maximum driver-related criteria MVC susceptibility maps was 0.68. Minimum and maximum habitat-related criteria maps displayed a lower KIA of 0.40.

Using ROC for validation purposes with a 70% minimum threshold, all expert models were reasonable at discriminating MVC locations from random reference sites (Table 3.9). Overall, habitat-based expert models were more proficient than driver-based models in predicting MVC. The MVC predictive ability of local and non-local expert MVC models was similar with local experts outperforming non-local experts using habitat-related criteria while non-local experts were more accurate using driver-related criteria. Maximum weighted models outperformed minimum weighted models in all cases.
Figure 3.6. Expert opinion MVC susceptibility maps using driver-related criteria. The MVC distribution map (a) local experts, (b) non-local experts, and (c) all experts. The inset map illustrates the location of the study area in south-eastern British Columbia, Canada.
Figure 3.7. MVC susceptibility maps using the lowest and highest expert weights attained. The MVC susceptibility map (a) minimum weighted, and (b) maximum weighted were constructed using driver-related criteria while maps (c) minimum weighted, and (d) maximum weighted, were based on habitat-related criteria. The inset map illustrates the location of the study area in south-eastern British Columbia, Canada.
Table 3.9. ROC Validation results of expert MVC predictive models in Mount Revelstoke and Glacier National Parks, Canada.

<table>
<thead>
<tr>
<th>Model Scenario</th>
<th>Criteria</th>
<th>ROC Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local experts</td>
<td>habitat criteria</td>
<td>82.9%</td>
</tr>
<tr>
<td>Maximum weights</td>
<td>habitat criteria</td>
<td>82.3%</td>
</tr>
<tr>
<td>All experts</td>
<td>habitat criteria</td>
<td>81.9%</td>
</tr>
<tr>
<td>Minimum weights</td>
<td>habitat criteria</td>
<td>80.8%</td>
</tr>
<tr>
<td>Non-local experts</td>
<td>habitat criteria</td>
<td>80.4%</td>
</tr>
<tr>
<td>Non-local experts</td>
<td>driver criteria</td>
<td>79%</td>
</tr>
<tr>
<td>Maximum weights</td>
<td>driver criteria</td>
<td>79%</td>
</tr>
<tr>
<td>All experts</td>
<td>driver criteria</td>
<td>77.7%</td>
</tr>
<tr>
<td>Local experts</td>
<td>driver criteria</td>
<td>76.7%</td>
</tr>
<tr>
<td>Minimum weights</td>
<td>driver criteria</td>
<td>76.5%</td>
</tr>
</tbody>
</table>

3.4 Discussion

Expert-based approaches have proven to be a valuable resource both in impact and scope for the monitoring and management of natural resources (Marcot 1986, McNay 1987, Bowman and Robitaille 2005). The use of expert-based models has been increasingly widespread due to the further availability and refinement of GIS-based software and data. Land cover maps and habitat suitability data are becoming more common. The expert-based approach using GIS is also becoming more inexpensive and easier to use (Clevenger et al. 2002). AHP has been applied in a broad range of environmental impact assessments, land use planning, and natural resource studies (Banai-Kashani 1989, Jankowski and Richard 1994, Xiang and Whitley 1994, and
Bantayan and Bishop (1998). AHP requires little training and ensures consistency in developing relative weights for models and is available in Idrisi (Eastman 2006).

3.4.1 Model Performance

The expert-based models were validated using independent data in the form of past MVC locations. ROC values for all model scenarios were above the 70% threshold indicating reasonably high discrimination between where MVC were and were not. The ROC results, however, should be interpreted with caution as the validation data were represented as precise MVC locations in the statistical procedure even though the presence of reporting errors was unavoidable. In addition, the data were analyzed using GIS where spatial error in cell inclusion or exclusion is inevitable and may have affected the results.

I am unaware of other assessments comparing local to non-local knowledge when predicting MVC or habitat suitability in general. The understanding of whether local knowledge of a given study area provides superior results has ramifications on how stringent expert selection must be and whether non-local experts can successfully be used in larger-scale predictions. The highest predictive ability using habitat-related criteria was achieved by local experts (ROC = 82.9%), however, predictions by non-local experts were nearly as good (ROC = 80.4%). This slight advantage in predictive success by local experts may have been due to background knowledge of the biophysical attributes and history of the study area, recollection of where MVC have occurred in the past, or simply to chance alone. Given the results where habitat-based models outperformed driver-
based models, local experts should be used when possible. This declaration should be coupled with the practical realization that non-local experts could still be used with confidence when local knowledge is not readily available. One factor that must be acknowledged in this study was that the non-local experts involved may have had some knowledge of the study area as three of them have worked within BC while the other two were within Quebec and Newfoundland. None of the models should be directly extrapolated to other areas. If the models were to be used elsewhere, the structure could be kept intact with site-specific variables appropriately adapted to the location and species. If these amendments were made, expert opinion could be confidently used as a basis for mapping MVC susceptibility areas throughout British Columbia and potentially Canada.

3.4.2 Variation

The variation in predictive ability of the models was moderate to high despite cases of low KIA or differences in minimum and maximum weights. An investigation into the variability of predictions, in this case expert weights, is required in assessing model performance (Johnson et al. 2004; Johnson and Gillingham 2005). The KIA displayed similarities between the maps based on local and non-local weights, however, slight differences hinted at site-specific knowledge having an effect on model outcomes.

3.4.2.1 Variation of habitat-related weights

Kappa analysis suggested low to moderate variation between the habitat-related criteria models of local and non-local experts (KIA 0.428). This reasonable agreement is
visually apparent because the local and non-local maps appear similar on a broad level (Figure 3.2). ROC validation supported this minor difference with values being 2.5% different (Local 82.9%, Non-local 80.4%).

Although the majority of confidence intervals for category weights within criteria overlapped; cases existed where they were broad in range suggesting disagreement within a given expert group. Often wider confidence intervals were coupled with notable differences in mean weights between local and non-local expert groups. An example was where the mean weights within the distance to built area criterion showed vast differences between expert groups, with local experts in more agreement with one another. Habitat alteration, human activity, or potential predator avoidance have been documented as reasoning for a relationship between built areas and MVC risk (Malo et al. 2004, Seiler 2005). This variation between the two expert groups, combined with a higher ROC value for local experts using habitat-related criteria, suggests that site-specific knowledge was effective for certain criteria. In this study, the variation was apparent with the anthropogenic-related criteria of distances to power lines, rail lines and built areas.

The weighting among habitat-related criteria showed minimal variation when local and non-local expert opinion were compared as all confidence intervals overlapped. As reported in the literature, moose require openings and wetlands to forage for a wide variety of herbaceous and woody plants (Davidson and Dawson, 1990), yet, local experts weighted the distance to wetland criteria higher than their non-local counterparts. The
distance to wetland criterion also displayed the greatest differentiation between minimum and maximum raw weights (0.239) suggesting disagreement between experts. The narrowest range between minimum and maximum weights was observed with the distance to power line criterion at 0.073 and can be attributed to all experts agreeing on the low relative importance to MVC despite providing an immediate food source for ungulates by facilitating both site access and early seral forage (Yoakum et al. 1980, Hengeveld 1998).

3.4.2.2 Variation of driver-related weights

The local expert driver-based map differentiated high and low MVC susceptibility areas to a greater degree than that of non-local experts. This specificity difference was primarily due to the proportion of low MVC susceptibility cells being more evident in the local expert map in the same places medium susceptibility cells were present in the non-local expert map (Figure 3.1). In other words, local experts were in overall greater agreement using driver-related criteria. Differences in ROC performance was small when comparing the local and non-local expert maps with a difference of only 2.3% (Non-local ROC = 79%; Local ROC = 76.7).

The categories within driver-related criteria were weighted similarly between local and non-local experts. An observable difference was where local experts placed more weight on shorter distances to highway curvatures than did non-local experts (local mean = 0.65; non-local mean = 0.30). In addition, local experts placed more emphasis on highway curvature than did non-local experts when comparing among criteria (local
mean = 0.649; non-local mean = 0.298). These weight differences in the highway curvature criterion seemingly contributed to the slight differences in the driver-based model performance. The reasoning for the difference in opinions on the effect of highway curvature, let alone any criteria, is difficult to pinpoint. Unless detailed reasoning is provided with each weight, which was not a component of AHP, expert-based weights can only be interpreted at face value. There are various theories which could be attributed to local experts having placed more emphasis on shorter distances to highway curvatures. The difference may be due to the over-accounting for the mountainous and winding nature of the highway and a potential overestimation of the importance of highway curvatures by local experts. All confidence intervals associated with the distance to highway curvature criterion did, however, overlap while the driver-based model ROC values between local and non-local experts displayed small differences.

The expert-based models were constrained by a number of technical and data related limitations. Most importantly, I did not allow the experts to directly rank and incorporate the importance of seasonality or time of day. Although biologically important, the MVC data I used to validate the models did not include this information. Second, the AHP required categorisation of each explanatory variable (e.g., slope > 20°). Specification of categorical break-points introduced an element of subjectivity to the weighting scores (Zahedi 1986).
The expert-based modeling approach used in this study may not be equally effective for all types of WVC. Collisions between less noticeable smaller species may be under represented or poorly recorded in wildlife collision databases. Furthermore, expert’s knowledge may be biased to species such as moose or deer that have a larger social and economic effect.

As outlined in this chapter, expert-based models should be used as a first-step approach for coarse-scale identification of areas that may be hotspots for MVC. Future studies should explore additional phenomena such as the links between coarse-scale predictors and local-scale features including highway design, mineral licks, specific forage types, or driver visibility. As with this study, a comparison of local and non-local experts would be of interest, further defining supporting the biases that individual experts bring to this modelling process.
3.5 References


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4.0 Chapter IV: An assessment of the techniques used to predict moose-vehicle collisions in Mount Revelstoke and Glacier National Parks

Abstract: The comparison of predictions from expert and logistic regression models from the two previous chapters offers a course-grained first step approach in the identification of high risk MVC areas and the factors behind them. I used the Kappa Index of Agreement (KIA) to compare the distribution of cells across the MVC susceptibility surfaces within each model type and the Spearman Rank Correlation (SRC) to compare the difference in frequency of observed MVC locations among ranked habitat MVC susceptibility classes. A positive KIA was found for all comparisons between the GIS logistic regression model and habitat-based expert models. The SRC coefficient suggested a strong positive correlation between the observed MVC locations with both logistic regression and habitat expert model MVC susceptibility values. The SRC and KIA suggested that the habitat-based expert models were more closely associated with the logistic regression model than were driver-based expert models. The logistic regression model was a slightly better predictor of MVC when compared to the expert-based model. However, logistic regression modeling required the effort of reporting effort empirical MVC data. Although more time consuming and expensive, the availability and use of empirical data provided a means of model evaluation. In many cases, empirical data may not be available, and expert-based modeling can be used as a substitute developing simple models in a relatively short period of time.
4.1 Introduction

The prevalence of wildlife-vehicle collisions (WVC) in British Columbia is increasing (Road Health-University Wildlife Collision Mitigation Research Team 2006.). Furthermore, collision induced human injuries and material damages as a result of animal-related vehicular collisions are on the rise across Canada (L-P Tardiff and Associates 2003). WVC (in particular with ungulates due to their large size) is gaining attention from government and private interests due to material damage and human injury (Road Health-University Wildlife Collision Mitigation Research Team 2006).

Although I used empirical data to validate expert-based models, the data are not required and can often be absent or difficult to collect (Marcot 1986, Clevenger et al. 2002, Johnson and Gillingham 2004). Though more expensive, the availability and use of empirical data required in logistic regression modeling provides a means of evaluation. The determination of whether expert or logistic regression modeling is more efficient in predicting MVC is therefore fundamental in achieving insight into the issue and reducing the problem.

Given the ecological and socio-economic consequences of MVC, we need to evaluate techniques for identifying and understanding their occurrence. The choice of model and variable set can influence the identification of areas for critical conservation or mitigation (Johnson and Gillingham 2005). Conservation professionals should choose a model and variable set based on the question, the ecology of the species, and the availability of requisite data (Johnson and Gillingham 2005). Previously, I developed
logistic regression and expert-based models to predict MVC in Mount Revelstoke and
Glacier National Parks, Canada. In this study, I compared and assessed the predictive
accuracy of logistic regression and expert-based models. I outline the strengths and
limitations of expert models and logistic regression models and I provide
recommendations on the most effective modelling approach for predicting and
understanding MVC.

4.2 Methods

The development of the GIS logistic regression and expert-based models is
detailed in Chapters 2 and 3, respectively. The study area of the Trans Canada Highway
1 bisecting Mount Revelstoke and Glacier National Parks is outlined in chapter 1. Both
logistic regression and expert-based models were constructed using landscape-scale
variables derived from GIS data. I used observed MVC locations to validate model
performance for each method. To assess the differences in prediction efficiencies
between model types, the single logistic regression GIS model was compared to each
type of expert-based model which either used local or non-local experts with habitat or
driver-related criteria.

I used the Kappa Index of Agreement (KIA) to compare the distribution of MVC
susceptibility map raster cells among each model type (Cohen 1960, Congalton et al.
1983, Rosenfield and Fitzpatrick-Lins 1986). The procedure used for the comparison of
two models using the KIA is detailed in chapter 3. I used the Spearman Rank Correlation
(SRC) to compare the difference in frequency of observed MVC locations among ranked
habitat MVC susceptibility classes (Zar 1972). A better correlation was present when more MVC locations were found within higher-ranked classes.

I used the KIA to measure the spatial association of the entire 500m buffered highway zone of the logistic regression model to each expert model. The SRC was calculated in order to gauge the accuracy of the MVC predictions of two models based solely on where past MVC have occurred. The SRC was performed based on the suggestion that well built models show a strong correlation between Resource Selection Functions (RSF) rank and number of detections (Boyce et al. 2002, Johnson and Gillingham 2005).

I used a SRC of the frequency of MVCs against susceptibility scores to assess the predictive accuracy of each model. This was a multi-step procedure requiring me to standardise and compare predicted susceptibility scores. First, I constructed maps representing the predicted susceptibility of a MVC. I then identified centiles that categorised continuous susceptibility scores into one of 10 susceptibility classes. Based on these classification breakpoints, I used Idrisi (Eastman 2006) to transform the maps from continuous to categorical scores. I extracted the susceptibility value for each observed MVC and ranked the frequency of MVCs within one of the 10 classes using Hawth’s Analysis Tools Version 3.05 in ArcGIS (Beyer 2004). I assumed that a predictive model would rank a greater frequency of MVCs in higher susceptibility classes (i.e., class 10 vs. class 1). The SRC measured this relationship in SPSS (Figure 1).
4.3 Results

The SRC suggested a strong positive correlation between the frequency of MVC and the susceptibility values for both the logistic regression and habitat expert model (Table 4.1). A weak positive correlation was found between the frequency of MVC and the susceptibility values for the driver-based model.

Table 4.1. The Spearman Rank Correlation compared the differences in ranked MVC susceptibility classes among the observed MVC locations (1968-2004) within Mount Revelstoke and Glacier National Parks.

<table>
<thead>
<tr>
<th>Model</th>
<th>Spearman Rank Correlation Coefficient</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistic Regression</td>
<td>0.91</td>
<td>0.004</td>
</tr>
<tr>
<td>Habitat Local</td>
<td>0.82</td>
<td>0.025</td>
</tr>
<tr>
<td>Habitat Non-Local</td>
<td>0.81</td>
<td>0.016</td>
</tr>
<tr>
<td>Driver Local</td>
<td>0.80</td>
<td>0.200</td>
</tr>
<tr>
<td>Driver Non-Local</td>
<td>0.36</td>
<td>0.550</td>
</tr>
</tbody>
</table>

A positive, but small KIA was found for all comparisons between the GIS logistic regression model and habitat-based expert models (Table 4.2). KIA values ranged from 0.123 to 0.153 when the GIS logistic regression model was compared with habitat-based expert models, indicating that agreement is slightly better than chance (Kappa > 0). Conversely, the KIA was negative between the GIS logistic regression model and all driver-based expert models (Table 4.2). When the GIS logistic regression model was compared to driver-based expert models, KIA values ranged from -0.004 to -0.003 suggesting that agreement occurred less often than chance alone (Juurlink and Detsky 2005). Both the SRC and the KIA suggest that the logistic regression model was more closely associated to habitat-based models than with driver-based models.
Table 4.2. A comparison of the MVC susceptibility values using the Kappa Index of Agreement within the 500 m buffered highway study area in Mount Revelstoke and Glacier National Parks. Each Kappa score represents the comparison between the GIS logistic regression model and the corresponding expert model.

<table>
<thead>
<tr>
<th>Expert Model</th>
<th>Kappa Index of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat Non-Local</td>
<td>0.153</td>
</tr>
<tr>
<td>Habitat Local</td>
<td>0.123</td>
</tr>
<tr>
<td>Driver Non-Local</td>
<td>-0.003</td>
</tr>
<tr>
<td>Driver Local</td>
<td>-0.004</td>
</tr>
</tbody>
</table>

4.4 Discussion

4.4.1 Model Comparison

In addition to the habitat-based expert models outperforming driver-based models (Habitat-based model ROC = 81.9%; Driver-based model ROC = 77.7%), the SRC and KIA suggested that the habitat-based models were more closely associated with the logistic regression model. This association is logical because a similar trend was observed with the MVC predictive abilities of the two model types. The most probable explanation for this finding was that the logistic regression model and habitat-based expert models were built on 5 of the same variables. The driver-based expert model did not share any of the same criteria with the logistic regression model (Chapter 2). In chapter 2, I followed the information-theoretic model selection process excluding criteria of land cover type, moose habitat classification, distance to rail, distance to power line, distance to built area, speed limit, distance to highway curve, and distance to wildlife risk sign.

The most notable criteria among logistic regression and habitat-based models included distance to wetland and to a lesser degree elevation. Differences in criteria
rankings included slope and distance to water body. Slope was of greater importance in the logistic regression model in comparison to the habitat-based expert model, while the opposite trend was seen with distance to water body. Moose habitat classification, land cover type, and distance to road curve were included in the expert models and excluded from the final logistic regression model. The distance to wildlife-risk signs was of low importance to both models.

The association among logistic regression and expert-based models yielded some differences depending on the expert type used. The SRC was higher for local experts than for non-local experts using the driver-based model (Table 4.1). Using the KIA, I found little difference between predictions from the local and non-local expert habitat models when compared to the final map produced by the logistic model (Table 4.2). This KIA agreement indicates similar distribution of high risk MVC highway segments no matter which expert groups is used.

4.4.2 Implications of Expert-Based Modeling

Future analysis into the performance of expert-based MVC modeling could include an investigation into the amount and type of experience. Expert-based model outcomes are affected by the format of the question, the scale upon which they are asked, and the career-related interests of the experts (Burgman 2005). In addition, the years of experience in the specific topic of interest could be directly compared and assessed to gain insight into more dependable expert selection procedures. This topic was only briefly explored in chapter 3 with no evident differences observed in the relationship.
between years of experience and MVC prediction success. Local experts combined for 100 years of experience while non-local experts totaled 85 years; the predictive abilities of both groups varied only slightly. An added factor could be the depth of expert knowledge on MVC in general or within the study area. For example, the relative success of non-local expert MVC predictions could potentially be explained by up to date reading of the scientific literature related to the study. Although, both groups developed opinions and ranked criteria based solely on memory and experience (Clevenger et al. 2002).

When expert opinion is used in conservation, it is usually obtained in an unstructured manner; for example by asking a single expert (Sutherland 2006). Applied ecologists need to consider more rigorous means of collating expert knowledge (Johnson and Gillingham 2004, Sutherland 2006). This study incorporated the weightings from 10 different experts, different geographic locations, and different experiences into a structured survey approach that allowed for a rigorous examination of differences in opinion among those factors.

4.4.3 Implications of Logistic Regression Modeling

Because empirical MVC data were available, logistic regression proved to be a practical technique (Boone and Hunter 1996, Apps et al. 1995). The application of presence/absence data, as used in logistic regression, have been proven to be just as successful for predicting distribution as abundance or density data (Pearce and Ferrier 2001, Nielsen et al. 2005). In addition, the collection of abundance data is time
consuming and expensive for conservation planning activities that require urgent action over large geographical areas (Pearce and Ferrier 2001). One issue, however, that arises in presence/absence modeling is the potential for pseudo-absences to occur (Johnson et al. 2006). In the case of this logistic regression model, the assumption of true absences was satisfied due to MVC having only occurred where reported in the database. Pseudo-absences may have occurred for locations where an MVC was not reported; however, absences in this sense of the MVC reporting procedure were relatively well documented in comparison to pseudo absences in wildlife studies in general (Pearce and Boyce 2006).

4.4.2 Model Selection

Deciding on the most practical and efficient modeling technique is not solely based on MVC prediction results. The logistic regression model had only a slightly higher MVC predictability than any of the expert-based models. All GIS models required data surfaces which were readily available with minimum manipulation. Logistic regression model construction required empirical MVC data locations that consisted of reporting throughout 3 decades. Though more expensive, the availability and use of empirical data provided a means of model evaluation. In many cases, empirical data may not be available, and expert-based modeling can be used as a substitute in developing models in a relatively short period of time. Clevenger et al. (2002) suggested that the use of expert-based modeling should not be used exclusively if spatially accurate empirical data are available for logistic regression modeling. Despite the flexibility in not requiring empirical data, the use of the AHP process does depend on expert availability, time commitment, and experience in the field of study. The AHP technique, however, requires little time and training.
4.5 References


5.0 Chapter V: Epilogue  
5.1 Practical Applications of Research

As observed in the comparison exercise, the simultaneous integration of an array of information including logistic regression analysis and expert opinion can increase a manager's ability to evaluate the biological and abiological processes influencing the location of MVC. Conversely, the practical decision making process can be overwhelmed with complex, wide ranges of information. Key processes correlated to the occurrence of MVC in the two parks have been exposed through either correlation using logistic regression or importance using expert opinion.

The primary objectives of the research were to gain insight into the processes driving MVC in order to predict and prevent future MVC. Extrapolation of MVC model predictions is realistic albeit with site-specific refinements. This study area was selected based on the high spatial accuracy of collision reporting even though MVC frequency is higher along certain other highways in British Columbia.

When a high-risk MVC area is identified using a landscape-scale model, mitigation should not proceed until local-scale investigations have been made. As detailed in chapter 2 and 3, GIS logistic regression and expert-based models can be a powerful tool in the initial identification of high-risk areas for highway planning and construction. Local-scale models involving field work have proven valuable, however, they require more time, money and energy to produce and should therefore be used when and where mitigation measures are deemed necessary and practical. If the need for local-
scale analysis is required, the Moose Evidence and Habitat models from chapter 2 should be consulted due to their reasonably high predictive abilities.

The time, money, and energy that go into this field of modeling should also be considered due to the need for highway planners to periodically update models for large-scale ecological changes. Land development influences how animals move across and use the landscape from year to year (Road Health-University Wildlife Collision Mitigation Research Team 2006). The difference in land use inside and outside park boundaries should be considered when modeling larger scales such as entire provinces for example. Periodic MVC and WVC modeling of this nature would depend on the availability of up-to-date spatial GIS data. If this spatial information is available, WVC data is accurate, and sufficient funding is available, this approach could be adapted into a monitoring study with an objective of decreasing WVC incidents.

5.2 Reporting Considerations

An empirical model is only as strong as the data used for model construction and validation. WVC data in British Columbia is collected and managed by numerous agencies, each with their own objectives and data management systems (Road Health-University Wildlife Collision Mitigation Research Team 2006). Further research and application of WVC data would benefit greatly from the generation of one standardized, central database for all agencies across the province and/or country. This standardized database would unite all reporting stakeholders, decreasing spatial inaccuracies and data overlap which currently exists. Highway safety planners, conservation groups, insurance
companies, and other stakeholders with an interest in considering mitigation measures would greatly benefit from having a single source for managing WVC data.

5.3 Scope of Highway Planning

The models I present in this thesis can guide future transportation development in the two national parks and beyond through extrapolation of cautionary site-specific refinements to similar mountain highway corridors. Our landscape-level MVC models suggest that highway planning needs to expand beyond the scope of design and engineering of the highway surface and consider broader factors such as the spatial juxtaposition of habitats and animal attractants. The road-effect zone is a prime example of the requirement for a more comprehensive consideration of the key environmental impacts during highway planning. The 500-m radius road-effect zone along both sides of a highway encompasses the majority of ecological effects resulting from highway construction and use and is typically the focus of planning and mitigation (Forman and Alexander 1998, Forman 1999). As roads continue to expand in extent, their impact will grow in ecological significance resulting in habitat creation, fragmentation, disturbance, corridor creation, mortality and barrier effects (Forman 1999, Hewison et al. 2001, Seiler 2005). The issue of MVC on an already dissected landscape must be acknowledged and incorporated into a larger-scale and integrated methodology examining patterns and processes of road corridor planning.
5.4 References


### 6.0 Appendix

#### - MVC Data Locations

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### Field Sheet

**Field Variable Checklist:**

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<th>C/D/A = Continuous/Discontinuous/Absent</th>
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#### Habitat Attributes:

**Roadside vegetation:**

- Quadrat every 5m for 25m on both sides of road

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<th>Side of Road: (N/S/E/W)</th>
<th>DISTANCE (m)</th>
<th>Browsed (p/a)</th>
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**Road clearance (m)** – Width in metres of area cleared (altered) by road, e.g., if road bisects forested.
area, the distance between two forest edges.

“N/A” if not possible to measure.

**Proximity to cover (m)** - Distance in metres to nearest cover, i.e., trees or shrubs ≥1.0m high

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**Presence of wildlife trail feature (high/low/absent)**

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**Highway Attributes:**

with readings at each road edge (m).

1) a) __________ m________________ direction of travel
   b) __________ m “ “

2) a) __________ m________________ direction of travel
   b) __________ m “ “

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1) 0
   ___ (side)
   0

2) ___ (side)
   ___ (side)

**Length of slope(m) & Side of road (u/s/w/e)**

1) ___(m)___
   (side)

2) ___(m)___
   (side)

Is ditch present (Y) yes otherwise blank
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<td>If yes, side of road</td>
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- Autocorrelation Correlogram Graphs

GIS Correlogram

Highway Design Correlogram
Moose Evidence Correlogram

Moose Habitat Correlogram
Expert Profiles

Local Experts:

1) John Woods

John Woods received his BSc in Biology from the University of Guelph in Ontario and started working for the Canadian National Parks Service as Chief Naturalist for St. Lawrence Islands National Park in the Thousand Islands area of Ontario. In 1975 he moved to Mount Revelstoke and Glacier national parks in British Columbia and in 1991, he completed a PhD in zoology at the University of B.C. His thesis topic was "Ecology of a Partially Migratory Elk Population". John is interested in movements and land use of vertebrates in relation to their population ecology and in parasites and diseases. He is currently Wildlife Biologist for Mount Revelstoke and Glacier Parks where he is involved with the above-mentioned studies including, wolverine, bats, and black bears.

2) Pat Wells

Pat Wells was a personal initiative and volunteer research associate for Parks Canada during the period 1993-98. As a recreational hunter and naturalist, Pat had 16 years of experience in observing wildlife in the study area. As an engineman and conductor employed by CPR, Pat had the opportunity to make observations from operational trains.

3) John Krebs

John has extensive experience in both wildlife management and technical forestry, particularly in the Columbia Basin region. A biology graduate from Simon Fraser University, he earned his Masters in Science Zoology from the University of Alberta as well as a Diploma in Fish, Wildlife & Recreation from BCIT. An active member of the Western Forest Carnivore Committee and the North Columbia Mountain Ecological Research Group, John has published over 15 reports on his research work. He has been with compensation programs in the Columbia Basin since 1992. John is a registered Professional Biologist.

4) Adam Christie

Adam has 13 years experience as a Conservation Officer in BC working in Nelson, Fort Nelson, & Revelstoke districts. During Adam’s career, he has been called to deal with many road & rail-injured animals. Of these quite a number have been moose. In Revelstoke in particular, Adam estimates at least 4 or 5 calls each year to respond to MVC.

5) John Flaa

A park warden for 26 years, John’s wildlife / highway work started in 1985 with a project to identify wildlife use areas for the Trans Canada Highway twinning project between
Castle Junction and Lake Louise in Banff Park. John has been in Mount Revelstoke and Glacier National Park since 1988 and has been involved with many major large mammal wildlife research projects including Revelstoke mountain caribou project, West Slopes bear project, Revelstoke wolverine project, and bear capture work for research projects in several areas of the province. John is currently the Senior Park Warden Wildlife / Human Conflict Specialist in Mount Revelstoke and Glacier National Parks. John has been responsible for the operational wildlife issues in the park since 1992.

Non-Local Experts:

1) Doug Heard

Doug Heard's research interests centre on the effect of predation risk from wolves and bears on the distribution, abundance and management of caribou, moose and mountain goats. Doug has been a wildlife biologist for 30 years but hardly ever saw or thought about a moose until he moved to Prince George in 1992 (14 years ago). Since then, moose management has been one of the major focuses of his work. Specifically, that work has been conducting inventory (estimates of population size, and age and sex composition), demographic analysis (population trend, reproductive performance and hunting impacts on population size, age and sex) and on behaviour (coarse movements, seasonal distribution by landscape attributes etc).

2) Yves LeBlanc

Yves Leblanc is a senior wildlife research biologist with Tecsys Inc. He has been working on impact assessments of hydroelectric development and road construction on wildlife, mainly moose, whitetailed deer, fur bearing animals and waterfow in Québec since 1986. He is currently under contract with the Quebec Ministry of Transportation to assess and reduce moose and white-tailed deer vehicles collisions in different upgrading and new highway projects. He has also been actively involved in wildlife management and research projects with the Québec Ministry of Natural Resources on beaver, fisher and woodland caribou. Yves Leblanc holds a B. Sc. in biology from Université Laval in 1983 and a M. Sc. in Zoology from the University of Alberta in 1986.

3) Gary Van Spengen

Gary has been with the BC Conservation Officer Service for 17 years, of which 10 have been located in Prince George. He has responded to hundreds of complaints regarding injured wildlife caused by vehicle collisions within the Prince George COS District.

4) Tammy Joyce

Tammy started working on a variety of moose related issues in 1992 as a Wildlife Biologist under the Big Game Research and Management Section of the Provincial Wildlife Division. Since that time, Tammy has maintained the MVC database, calculated
the estimates, maintained contact with other jurisdictions working on MVCs, reviewed all research/management initiatives related to MVCs being worked on elsewhere for application in NL and made recommendations to government. She developed the most recent public awareness campaign, and answers all inquiries related to the issue. For the last 4 years, Tammy has provided peer-reviews for a number of manuscripts submitted to Wildlife Society Bulletin for publication.

5) Kenneth N. Child

Ken worked in the Ministry of Environment, as the Regional Wildlife Biologist/Section Head for 20 years in the Omineca subregion of Region 7 (Omineca-Peace Region). His main area of specialty was moose management. Ken was particularly interested in selective harvest practices of hunters to ensure sustainability of both the resource fitness and recreational/economic benefits. The selective practices continue to this day as introduced in the 80s and are advertised annually in the Hunting Synopsis and Regulations.

During his stay in the Ministry, Ken studied and reported on collision mortality of moose by train, car and incidental accident. Ken published several papers on this problem and was fortunate to have been asked by his peers to contribute a chapter (Incidental Mortality) in the Wildlife Management Institute book: Ecology and Management of North American Moose. This work likely represents the most comprehensive treatment of the subject to date but as others study and research the problem and mitigative measures, Ken is sure the chapter will soon be obsolete.