Analyzing the Influence of Interstate 90 on

Elk Home Range Establishment and Resource Selection

by

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ABSTRACT

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Negative effects from roads are evident throughout many natural systems. Habitat fragmentation is among the most severe of these effects, with some wildlife species experiencing consequences on population viability. High volume interstates are among the most detrimental to wildlife. Interstate-90 (I-90) transects the North Bend area, as the primary East-West traffic corridor in Washington State, resulting in significant habitat fragmentation effects and a high number of elk-vehicle collisions. A partnership between The Upper Snoqualmie Valley Elk Management Group (USVEMG) and the Washington State Department of Transportation (WSDOT) was formed to study elk movement to inform management decisions of how to reduce elk-vehicle collisions while ensuring connectivity across I-90 for elk. I used locations from 10 Global Positioning System (GPS) collared female elk during the years 2010-2012. Home range and resource selection analyses were executed using the Brownian Bridges Movement Model and second order resource selection analysis to understand how elk are influenced by I-90. A majority of elk home ranges were located bordering I-90 with slight overlap, only two home ranges largely overlapped I-90 and only one individual had core use areas located on both sides. This suggests that some individuals approached I-90, but that few crossed and spent abundant time on the opposite side of the interstate. I addition, elk were found to avoid medium (35-45 mph) and high intensity (>55mph) roads. When space use was evaluated at different distances from I-90, elk were found to avoid areas at distances less than 50 meters. Therefore, it would appear that for many elk in this population, I-90 is a partial barrier to their movement. Identifying areas of potential connectivity across this partial barrier where bridges exist in accordance with riparian habitat can inform areas where connectivity exists and should be managed for if barrier fencing is implemented in order to prevent collisions.

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Chapter 1: Literature Review

Introduction

Roads and Wildlife

The extent to which North America's landscape has been modified to meet human demands has wide ranging impacts. Roads have been a major form of development, transecting the continent in linear patterns, linking people and commerce. Road development and construction increased dramatically in the 20th century in the United States to meet growing demands of automobile drivers (Forman et al. 2002). The human population has now become dependent on roads and vehicles for daily activities, resulting in a particularly expansive road system in America, with 4 million miles of public roads (Forman et al. 2002). The Federal Interstate Highway System carries 22.8% of all traffic in the US, despite only representing 1.2% of the country's total public road length (Fed. Hwy Adm. 2002, Forman et al. 2002). Between 15-20% of the US land area is ecologically affected by this highway system (Fed. Hwy Adm. 2002). Washington State has accumulated 7,046 miles of state and federal highways receiving 31.6 billion miles of vehicle travel annually, which has doubled since 1960 (Washington State Department of Transportation 2005).

Losses of wildlife due to wildlife vehicle collisions are among the most noticeable ecological effects of roads. Wildlife-vehicle collisions across the United States are estimated to be 300,000 each year, estimated to have grown from 200,000 to 300,000 during the 1990-2004 time frame (Huijser et al. 2008). Reasons for this increase could include growing deer populations in many regions of the U.S., but could also be due to increased traffic (Huijser et al. 2008). On Washington State highways vehicle collisions involved at minimum, 14,969 deer and 415 elk over the five year period 2000-2004 (Myers et al. 2008). These minimum values were based on carcass removals. Actual numbers of collisions with deer and elk in Washington State are unknown since not all collisions with deer and elk result in instant mortality, with some animals not being accounted for when death occurs at some distance from the roadway. Additionally, data are only available for state maintained roads, local road departments rarely record carcass removals.

Wildlife-vehicle collisions have safety consequences. Large ungulates, such as elk can cause serious injury to drivers and substantial property damage (Huijser et al. 2008). Large ungulates are highly mobile and are more likely to enter roadways than less mobile species, increasing the chance of collision (Gibbs and Shriver 2002, Forman et al. 2002). Driver safety is a primary goal for many transportation agencies and reducing or eliminating collisions with large ungulates is a common problem for DOT management. Therefore, transportation departments have invested in studies of wildlife-vehicle collisions with the goal of reducing impacts on both humans and wildlife. Studies completed to date underscore the complexity of factors that contribute to these accidents. Wildlife-vehicle collisions are influenced by many factors including road characteristics and human behavior (Bashore et al. 1985, Jaeger et al. 2005, Parris and Schneider 2008).

Commonly studied road characteristics include road geometry, dimensions, spatial distribution, density, traffic volume, speed limit, and placement on the landscape. Jaeger and colleagues (2005) found that road width and speed limit negatively impact wildlife, but not as significantly as traffic volume. This suggests that wider roads and a higher traffic speed result in greater wildlife-vehicle impacts (Forman and Alexander 1998, Jaeger et al. 2005). In addition, Gagnon and colleagues (2007) found that as traffic volume increases, wildlife mortality and collisions increase. Highways with high traffic volume have higher wildlife-vehicle collision rates and wildlife mortality, which negatively affect wildlife populations (Gunther et al. 1998; Gunson et al. 2005).

The placement of roads on the landscape in relation to topography also influences wildlife-vehicle collisions. The majority of roads in the US were constructed in locations where transportation agencies could minimize difficulty of construction. For example, several roads built in mountainous landscapes were placed in valley bottoms where terrain was least resistant (Kaszynski 2000). Unfortunately, for montane wildlife, preferred road locations often coincide with chosen travel corridors and wintering grounds in these milder valley areas (Moen 1976). Consequently, many highways built in valley floors of montane regions are faced with high wildlife-vehicle collisions and wildlife mortality rates because of this conflict (Gagnon et al. 2007).

In addition to road characteristics, behavior of humans and wildlife also influence wildlife-vehicle collisions and road mortality. Studies that have temporally quantified wildlife-vehicle collision data have discovered that collision rates are higher at night than during the day (Bashore et al. 1985, Gunson et al. 2005). At night, drivers have reduced visibility and decreased reaction time, subsequently increasing driver and wildlife vulnerability to vehicle collisions (Rost and Bailey 1979, Mastro et al. 2008). Some species of wildlife are most active at dawn, dusk and night, contributing to increased collisions at night (Jaarsma et al. 2006). In addition, most motorists don't actively pay attention to wildlife; instead, they usually look for other vehicles, which are usually the most dangerous objects encountered on roadways (Rumar 1990). Many different collision trends can be attributed to these variables but it is suggested that driver behavior is a major influence (Rumar 1990). Unfortunately, few studies have quantified human behavior as a factor influencing wildlife-vehicle collisions; therefore, further research is necessary.

Traffic disturbance can have negative impacts to wildlife that aren't as noticeable as mortality. Traffic disturbances include road noise and traffic volume that can interfere with normal wildlife behaviors, communication and reproduction, such as the functions of bird songs (Gagnon et al. 2007, van der Ree et al. 2011). Some species of birds have been reported to change their pitch and frequency to compete with road noise (Parris and Schneider 2008). Subsequently, hampered detection of songs by other birds can lead to difficulty in establishing and maintaining territories, attracting mates, and maintaining pair bonds (Parris and Schneider 2008). Such interferences could lead to reduced breeding success in noisy roadside habitats as found by Halfwerk and colleagues (2011) where traffic noise caused females to lay smaller clutches in noisier areas. The variation in the traffic noise frequency band overlapped most of the lower frequency part of the great tit (*Parus major*) song (Halfwerk et al. 2011). Unfortunately, this study is one of only a few that has researched road noise effects on breeding success of avian species. In general, little research has been done on analyzing the effects of road noise on the breeding success of wildlife.

Less obvious than wildlife-vehicle collisions, but likely more important impacts of roads occur at a landscape level, where habitat fragmentation is a result. Effects from habitat fragmentation influence habitat loss and reduced connectivity at both fine and broad scales. Such changes at a landscape level can indirectly influence behavior, survival, growth and reproductive success of individual animals, resulting in cumulative effects at the population level (Harrison and Bruna 1999, Crooks and Sanjayan 2006).

Habitat loss and fragmentation occur when new roads are built by destroying habitat, reducing patch size, and increasing the distance between patches (Andrén 1994). Roads fragment the environment by transecting the landscape with dense impervious surfaces and high volume traffic which may reduce wildlife access to essential resources (Van der Ree et al. 2011). When patch size is reduced and distance between patches increases, the result is often isolation effects; this can negatively impact population viability (Andrén 1994, Fahrig 1997). Population viability can become compromised when species cannot access resources, such as food, mates, and breeding sites (Jackson and Fahrig 2011). Inaccessibility to these essential resources can lead to lower reproductive and survival rates, which may reduce overall population persistence (Thomas and Hanski 2004).

Behavioral changes in wildlife as a response to roads and traffic are also known effects of fragmentation (Jaeger et al. 2005). Examples of behavioral modification include home range shifts, altered movement patterns, and reproductive success (Trombulack and Frissell 2000). When behavioral modification occurs, such as in road avoidance, populations can become isolated when individuals are unable to move between populations (Trombulak and Frissell 2000). Roads can alter an animal's home range selection, often as a road avoidance response, which has consequences when important resources are located near roads (Trombulak and Frissell 2000). For example, elk (*Cervus elaphus*) in Montana prefer feeding sites far from their visibility of roads reducing availability of resource located near roads (Grover and Thompson 1986). Several species, including frogs and snakes, have been found to avoid crossing roads (Row et al. 2007, Bouchard et al. 2001). In these cases, roads are considered barriers to movement, which can have negative effects at a population level (Beckmann et al. 2010). When movement of animals between populations is inhibited, gene flow is reduced and may cause significant genetic differentiation among populations (Crooks and Sanjayan 2006). In Germany, Reh and Seitz (1990) observed genetic drift caused by roads in the common frog (*Rana temporaria)*. When connectivity between populations is reduced and populations are subdivided, they inevitably become smaller and more vulnerable. With reduced connectivity a population becomes less likely to receive immigrants from other habitats and, as a result may suffer from lack of genetic input and subsequently exhibit inbreeding effects (Jaeger et al. 2005, Crooks and Sanjayan 2006). Lack of genetic input and the resultant inbreeding contribute to genetic defects which may lower the probability of population persistence (Fahrig 1997, Jackson and Fahrig 2011). Stochastic events can further exacerbate isolation effects by increasing risk of extinction through random demographic, genetic or environmental events (Crooks and Sanjayan 2006). Therefore, chances of recolonization after local extinction are reduced in a fragmented landscape (Hanski 1999).

Species life history traits may predispose populations to effects of roads caused by habitat fragmentation and reduced connectivity. Species that occur in low densities, have low reproductive rates and long generation times have increased risk of population level effects caused by road mortality and barriers (Beckmann et al. 2010). For example, many carnivore species have low reproductive rates, suggesting low turn over time to compensate for high mortality rates caused by roads, thereby leading to population declines. Many reptile species are inherently attracted to roads for thermoregulation benefits, most notably snakes, are attracted to road surfaces. In addition, some reptiles lay their eggs in gravel roads or on road shoulders (Sullivan 1981, Aresco 2005, Steen et al. 2006). Some research has shown that various animals do not behaviorally avoid roads, including some frogs and snakes, which increase their risk of road mortality (Row et al. 2007). Therefore, these species are more likely to enter road surfaces and experience higher mortality rates, ultimately affecting population persistence. Highly mobile species are also vulnerable to road movement. Species with large movement ranges encounter all types of landscape features more frequently than species with small movement ranges, which increases their likelihood of crossing a major roadway (Gibbs and Shriver 2002). For example, deer and elk are highly mobile species; males increase their mobility during certain seasons of the year to find mates and seek release from hunting pressure (Moeller

2010, Cleveland et al. 2012) Road mortality rates of these species are highest during individual dispersal in the fall (Rost and Bailey 1979). Unfortunately, few studies elucidate the effects roads have on population viability. Most of the knowledge about such effects has been acquired through monitoring animal abundance in relation to roadways. Conversely, more research is needed to determine how life history traits lend themselves to species specific vulnerabilities to roads. Testing theoretical knowledge of what life history traits influences species vulnerability will inform road management and mitigation to reduce impacts to wildlife.

Landscape Level Road Planning for Increased Connectivity

It was not until the mid-1990s that road ecologists increased their efforts to examine the effects of habitat fragmentation and reduced connectivity caused by roads. Scientists increasingly explored the dynamics at work over larger landscape scales. With the development of tools, such as remote sensing, Global Information Systems (GIS), and genetic techniques, scientists and road ecologists can now address land use change and ecological impacts simultaneously across multiple spatial and temporal scales. The field of landscape ecology has advanced by incorporating studies from road ecology. Road ecology studies broadened to combine ideas from the fields of wildlife management and conservation biology. This transdisciplinary approach to understanding how roads influence the environment fostered the growth of a discipline known as road ecology. Road ecology derives its theories from many different disciplines and its growth and maturation have increased research and planning at a landscape level.

By addressing wildlife interactions at a landscape scale, mitigation targeting wildlife habitat connectivity began to gain importance in North America, with Parks Canada leading the way (Forman et al. 2002). The Trans-Canada highway twinning process was planned for the late ‘90s; Parks Canada decided to take advantage of this highway improvement opportunity, recognizing reduced costs for mitigation during a highway upgrade in comparison to retrofitting efforts (Forman et al. 2002). While planning for the twinning of the Trans-Canada highway in Banff National Park in Alberta, Canada, the Department of Transportation understood the affects that the new, larger divided highway would have on the wildlife. Therefore, research on large mammal movement and highway crossings was implemented to inform the DOT of where and what type of mitigation was necessary to reduce negative impacts of a larger highway. Mitigation included installation of wildlife crossing bridges and culverts. After completing the first stage of construction in 1996, Anthony Clevenger and colleagues began monitoring 11 large mammal species, including bears, elk and cougars. They have documented these species using crossing structures more than 200,000 times (Parks Canada Agency 2012). For some individuals the use of crossing structures has been incorporated into daily movements. For example, a grizzly bear traveled 1,600 kilometers during the summer of 2012, using crossing structures 66 times (Highway Wilding 2012). This demonstrates the success of crossing structures to facilitate the movement of wildlife across the landscape. This project has resulted in being a seminal mitigation project, demonstrating the importance of reducing road effects and the benefits of increasing connectivity. Several projects in the United States have ensued since, recognizing the importance of this type of mitigation.

Since Banff’s seminal mitigation project, management actions intended to minimize negative ecological effects of roads have increased in the US. In Washington State several actions have been taken to minimize the effects of roads on wildlife. The Washington Habitat Connectivity Working Group was formed in 2007 to “ create tools and analyses that identify opportunities and priorities to provide habitat connectivity in

Washington and surrounding habitats" (WHCWG 2010). An aspect of this group's intent is to minimize the effects of roads by mitigating for areas of most concern. Current work with WSDOT has led to ranking sections of state highways based on specific habitat connectivity concerns to prioritize mitigation efforts (Kelly McAllister, personal communication, February 2013). In 2011 highway construction to reduce road effects and increase connectivity across I-90, east of Snoqualmie Pass was launched, culminating over a decade of negotiations and environmental permitting. Mitigation plans include fish barrier corrections, installment of bridges, box and round culverts for terrestrial wildlife, barrier fencing and two wildlife overpasses (Long et al. 2012). These are typical methods used to mitigate for road effects.

Crossing Structures

Crossing structures are commonly used to increase connectivity and safe crossings (Hardy et al. 2003). Overpass structures, sometimes referred to as wildlife bridges or wildlife overpasses, are an effective mitigation measure implemented for aiding most wildlife to safely cross roads (Clevenger and Waltho 2003). Ungulate species like deer, elk and antelope have been found to prefer utilizing these wide open structures because of their prey behavior (Kintsch and Cramer 2011). Carnivores prefer a more intimate structure, such as a culvert, where they have more cover which they require for stalking and hiding (Kintsch and Cramer 2011).Many recent structure designs have not been tested for their attractiveness to multiple species, thus increasing the necessity for on-going collaboration between engineers and biologists. Overpasses are costly, therefore not commonly implemented as a mitigation measure. Perhaps the most challenging aspect of crossing structure design is finding a structure that addresses the entire community of wildlife that require rescue from the barrier effects caused by roads. Often, a particular design is deficient in aiding all wildlife because it only functions well for select taxonomic groups. Despite the challenges for meeting the needs a diverse wildlife community, crossing structures are an effective measure for lessening barrier effects of roads for some taxonomic groups (Kinstch and Cramer 2011).

Fencing and Signs

Fencing and warning systems are additional methods used to mitigate wildlife-vehicle collisions. Fencing prevents wildlife from becoming casualties and guides them to safe crossing opportunities, preventing wildlife-vehicle collisions and ensuring safe crossings (Forman et al. 2002). By directing wildlife toward safe crossing opportunities, ecological effects caused by roads are reduced (McCollister and Van Manen 2010). Warning systems, such as wildlife crossing signs are another commonly used and cost effective way to mitigate for wildlife-vehicle collisions (Beckmann et al. 2010). By warning drivers that they are entering a wildlife-vehicle collision prone area, these systems attempt to alter driver behavior, increasing awareness and potentially mitigating for mortality caused by driver inattentiveness. Collision records are usually an indicator of where to deploy signs.

Evaluation of Effectiveness

Much of the literature in road ecology is composed of evaluations on the effectiveness of various mitigation techniques. Trail cameras are among the most frequently used method for evaluation. Camera traps are a noninvasive way to observe wildlife utilizing crossing structures (Hardy et al. 2003). Scientists analyze crossing rates as a way to quantify use of crossing structures. By counting the number of times an animal approaches and uses a structure, scientists can evaluate the structure's effectiveness. If wildlife are crossing and crossing at high volume, more than approaching and retreating, structures are deemed a success. Unfortunately, much of the surrounding species community composition is not accounted for when analyzing wildlife use of structures. Therefore, camera traps are not an accurate method to use when analyzing responses of the total community to crossing structures or potential gene flow. They can only observe those animals choosing to approach the crossing structure. Therefore, this is an insufficient way to understand which animals choose to avoid roads. There are more effective methods used to quantify wildlife movement in relation to highways and crossing structures.

Wildlife Movement, Advancement in Technology and Methodology – A novel approach to understanding landscape level effects

Commonly used technologies like Global Positioning Systems (GPS) and Very High Frequency (VHF) collars are put on wildlife as a way to monitor their movements when constant observation is impossible. GPS collars are technologically more advanced than VHF collars, as they store more location data derived from satellite communications, and, as a result, they are used more frequently despite being expensive (Coulombe et al. 2006). In conjunction with Geographic Information Systems (GIS), the movements of collared wildlife can now be observed and analyzed at larger scales, mapping movements in relation to roads to indicate behavioral responses like road avoidance behavior (Dodd et al. 2007). These methods are a tremendous advancement over older methods for quantifying road effects which entailed the collection of wildlife-vehicle collision and carcass removal data. GPS telemetry and GIS can ultimately be used to pinpoint where wildlife are avoiding roads and where they are crossing roads identifying potential mitigation sites (Dodd et al. 2007, Lewis et al. 2011, Vaughan et al. 2012). Identifying key habitat variables, land use characteristics, and road characteristics in GIS is an effective way to understand what variables influence wildlife movement in relation to roadways.

Home range analyses identify areas used by tracked animals, including both size of area used and intensity of use ('utilization distribution' or UD) (Burt 1943, Worton 1989). Home range analysis using GIS allows scientists to quantify home ranges spatially. These are commonly used methods for understanding wildlife movements in the field of wildlife management. When applied to studies of road effects of wildlife, transportation agencies can better understand wildlife behaviors and barriers to their movements. Commonly used wildlife-vehicle collision and carcass removal records provide limited information describing where wildlife are being hit, while analyzing wildlife movements can show where they avoid crossing and suggest reasons for choosing to cross where they are crossing (Lewis et al. 2011). Knowing how wildlife move in relation to roads provides critical information to resource managers and transportation planners, as they can identify areas where wildlife are likely to cross roads and cause wildlife-vehicle collisions (Vaughan et al. 2012). Subsequently, they can also identify where wildlife aren't crossing roads and why. Further research on the applicability of such methods is needed. With advancement in technology and methods for analyzing wildlife movement in conjunction with multiagency collaboration, new insights can be gained and improved mitigation of road effects on wildlife can be developed. There are multiple ways to estimate home ranges or UDs of wildlife including the convex polygon, kernel density estimation and Brownian bridge movement model.

The convex polygon method is one of the oldest methods used to estimate home ranges; it is a relatively simple approach to defining an animal's home range. In this method, a polygon circumscribes all of the known locations of the animal. This indicates to the researcher that all of the animal's activities are confined within this area. Unfortunately, this method does not describe where animals spend a lot of time or chosen movement paths. Therefore, this method does not lend itself well to analyzing where animals choose to cross a roadway. The commonly used fixed kernel density method describes an animal's activities with nested polygons that encompass increasing proportions of the locations gathered for the animal (Fieberg 2007). This approach summarizes home ranges and highlights where animals spend most of their time; additionally, it describes the outer bounds of area the animal inhabits. Many authors have chosen to use this approach over the convex polygon method because it does not assume that sample points lie on the home range boundary. Instead, it generates contours of relative density (Worton 1989, Fieberg et al. 2010).

The Brownian bridge movement model (BBMM) is a recent advance in methodology for analyzing wildlife movement that is thought to more accurately portray paths and responses to roads. BBMM uses coordinate data that contains information on the date and time of each point, calculates the average movement rates of individuals and incorporates time intervals between GPS points to establish contour probabilities of an animal being in an area (Bullard 1991, Horne et al. 2007). This method incorporates location errors commonly associated with coordinate data into the equation, reducing bias of results. Minimum convex polygon and fixed kernel density do not account for location errors. BBMM can accommodate more detailed animal tracks provided by modern GPS, providing a more realistic depiction of animal paths (Kie et al. 2010). By providing a more realistic depiction of paths, scientists can then estimate attributes of an animal's preferred path. Therefore, the BBMM provides a more robust view of an animal's use of its surroundings, which transportation agencies can then use to better understand how wildlife move in response to roads. This method can be used by DOTs to identify areas where wildlife are likely to cross roads, predicting locations based on the identification of preferred attributes through resource selection analyses. In addition, this method can be used to identify areas where habitat connectivity objectives call for improvements, identifying barriers to wildlife movement.

Conclusions

Roads are a prevalent linear features found throughout developed landscapes in North America. Their negative effects are evident among many natural systems, with habitat fragmentation effects among the most severe, affecting population viability of some wildlife species. Transportation agencies are inherently invested in securing the safety of drivers including prevention of wildlife-vehicle collisions. Mitigation for fragmentation effects by roads is growing among transportation agencies as the importance of connected landscapes becomes widely recognized by road planners and biologists alike. Wildlife-vehicle collision and carcass removal data alone cannot be used to understand the large landscape level effects of roads. Therefore, other methods, such as monitoring wildlife movements in relation to roadways are good alternatives to choose when trying to understand how roads fragment wildlife populations. With the advancement in technologies and methods, DOTs and road ecologist are more equipped then ever to fully understand the ecological costs associated with roads. Unfortunately, technologies used to analyze wildlife movements remotely are expensive, and when coupled with budget cutbacks, agencies are limited in the analyses they can choose from. Therefore, multiagency collaboration could be an alternative to counteract costs involved with these technologies, increasing the attainability of wildlife movement data. We know that landscape level effects are the most costly of road effects and, therefore, it is of great importance for DOTs to account for such affects when planning for mitigation. A way to better understand those landscape level effects is through monitoring wildlife movements in relation to roadways. By analyzing wildlife movements road planners and road ecologists can more fully understand the effects of roads including many effects not apparent when using wildlife-vehicle collision and carcass removal data alone.

Benefits of Multiagency Collaboration and Future Research

With advanced technology and techniques come costs. GPS collar tracking of individual animals is an expensive approach and, therefore, it is not commonly used by DOTs when planning for mitigation. In addition, many agencies are in a time of budget cut backs, reducing the likelihood of using such methods. DOTs can benefit from collaborating with wildlife agencies and other entities through sharing wildlife movement data to better understand how roads they manage are affecting wildlife species of interest, thus cutting costs of performing their own field research. Consequently, wildlife agencies are then better able to achieve their wildlife protection goals when transportation agencies increase their consideration of wildlife during planning and design of highway improvements. The BBMM is available to DOTs and can lend itself to more accurately understanding where wildlife are moving and what resources they are using in relation to roadways. By understanding how wildlife are moving and what resources they are selecting for in relation to roads, appropriate mitigation at a landscape level can occur. In the long term, DOT agencies will be saving money and time, while increasing the efficiency of mitigation for fragmentation effects.

The Upper Snoqualmie Valley Elk Management Group (USVEMG), the Washington State Department of Transportation (WSDOT) and myself, a graduate student at The Evergreen State College (TESC) have teamed up to better manage for elk in the Snoqualmie Valley around North Bend Washington. The community of North Bend has a relatively new problem with elk that have become habituated to humans in a heterogeneous landscape near a large, high volume interstate. Interstate-90 (I-90) transects the North Bend area, as the primary East-West traffic corridor in Washington State, resulting in significant habitat fragmentation effects and high wildlife-vehicle collisions. The fragmentation effects, include elk behavior changes caused by Interstate 90 are poorly understood. As mentioned earlier, Forman and Alexander (1998) suggest that behavioral avoidance of roads may have the most pervasive effects. Gagnon and colleagues (2007) found that elk may avoid roads during periods of high traffic volume. If elk behavioral changes are positively correlated with traffic volumes, such affects could be magnified in light of future population growth and traffic volume increases on I-90. Therefore, I will be studying GPS collared individuals from this herd to understand their current home range distribution and resource use in relation to I-90. This will give insight into how large human habituated ungulates respond to high trafficked interstates. Most research on how roads affect elk and large ungulates have taken place in remote areas (Rost and Bailey 1979, Grover and Thompson 1986, Cole et al. 1997)

Few studies have looked at human habituated elk (Lee and Miller 2003, Cleveland et al. 2012) with none analyzing how habituated elk respond to large interstates. In light of future human population growth and ever increasing wild-urban interfaces, understanding how human habituated elk respond to heavy traffic interstates necessitates further investigation. In addition, the gray wolf (*Canis lupus*) an apex predator of elk has been absent from this ecological system since the 1930s (Becker et al. 2013). Its recent return to Washington state, continual population growth and potential return to forests near North Bend, has the potential to change the dynamics of the herd. To manage for the resiliency of this herd for the future, all large ecologically influential factors need to be understood. We currently lack a complete understanding of the behavioral response of these human-habituated elk to high-traffic interstates and the potential damaging fragmentation effects of roads on their persistence. Few studies have quantified fragmentation effects through the approach of analyzing movement patterns remotely (Dodd et al. 2007, Gagnon et al. 2007, St. Clair and Forrest 2009) and none using the BBMM method. As presented in Chapter 2, I address these unknown aspects of road effects of Interstate 90, by analyzing the North Bend herd's movement and resource selection using BBMM and ArcGIS 10.

Chapter 2 – Analysis of Elk Home Ranges and Resource Selection

Introduction – Road Impacts on Wildlife

Roads are a main form of development transecting vast areas of the Earth's surface, often negatively affecting ecosystems and associated wildlife (Forman et al. 2002, Coffin 2007). Effects of roads include increased wildlife mortality rates; with vehicle collisions among the most noticeable and in some cases primary causes of mortality for large vertebrates (Huijser et al. 2007, Coffin 2007). The less obvious but also influential impact of roads on ecosystems is habitat fragmentation. Road networks fragment landscapes and populations by impeding wildlife movement through physical barriers and behavioral avoidance, impacting population viability and resilience to changing environmental conditions (Beckmann et al. 2010). Restriction of movements can reduce migration, dispersal and opportunities for mating, leading to population subdivision and genetic differentiation (Andrén 1994, Fahrig 1997). Maintaining connectivity between subdivided populations of large ungulates in landscapes fragmented by road networks can be challenging, however efforts to mitigate road effects are necessary (Gibbs and Shriver 2002).

Human conflicts with large ungulates can be serious when the animals attempt to cross roads, resulting in collisions. Large ungulates can cause substantial property damage and human injury when wildlife-vehicle collisions occur (Nielsen et al. 2003). It is therefore of interest to transportation agencies to manage for driver safety in high wildlife-vehicle collision prone areas. Mitigating for large ungulate connectivity and driver safety by transportation departments has historically been a product of analyzing wildlife-vehicle collisions (Huijser et al. 2007). Unfortunately, this approach undermines barrier and behavioral effects of roads, which are better observed by analyzing wildlife movement. By analyzing wildlife movements and resource selection in relation to roads, a more insightful representation of behavioral response to roads can be obtained and inform mitigation decisions made by transportation planners and wildlife managers.

Near the community of North Bend in western Washington State, a high incidence of elk-vehicle collisions has become a relatively new problem. Elk have become habituated to humans in a heterogeneous landscape near a large, high volume interstate. Habituation to humans can be a result of high elk density, maximization of reproductive fitness, and reduced lethal interactions with humans, and when human activities are consistent and predictable (Thompson and Henderson 1998, Walter et al. 2010, Cleveland et al. 2012). Interstate-90 (I-90) transects the North Bend area, as the primary East-West traffic corridor in Washington State, resulting in significant habitat fragmentation effects and a high number of wildlife-vehicle collisions. A partnership between The Upper Snoqualmie Valley Elk Management Group (USVEMG) and the Washington State Department of Transportation (WSDOT) was formed to study elk movement and minimize elk-vehicle collisions. USVEMG was initially created as an effort to gain information to help minimize property damage and public safety risks associated with human habituated elk in North Bend. One outgrowth of this partnership involved equipping local elk with GPS collars to monitor their movements. USVEMG has accumulated several years' worth of coordinate data on members of this habituated herd that has not been analyzed. Therefore, it is currently unknown how these elk behaviorally respond to roads and utilize resources in the highly human modified area of North Bend. To manage this herd and mitigate for collisions, understanding elk movement and space use in relation to I-90 is important.

This research addressed movement patterns and resource selection of members of this elk herd in North Bend, WA. Spatial locations of elk home ranges in relation to I-90 were examined to understand whether I-90 influenced elk movement. I asked whether elk would establish home ranges and core use areas away from I-90. A comprehensive review of ungulate-highway interactions found that high volume interstates like I-90 interrupt elk behavior or had a "road effect zone" up to 425 meters (Gagnon et al. 2007). Therefore, it was expected that elk would avoid areas at distances less than 425 meters from I-90. A resource selection approach was used to gain insight into elk space use at a fine scale. I also hypothesized that elk used resources disproportionately to what is available in the study area, with elk displaying preference or avoidance for specific resources. By understanding the location of home ranges and which resources were selected for, transportation planners can improve mitigation efforts for ungulate species by ensuring safe crossing areas and prevention of crossing at unsafe sites where selected resources are located; thus both ensuring connectivity and reducing wildlife-vehicle collisions.

Materials and Methods

Study Area

The study area was centered around North Bend, WA (UTM 10T 591432, 5260765) within a small southern section of game management unit (GMU) 460, located 50 km east of Seattle in the foothills of the Cascade mountain range. The study area encompassed 363 km^2 in the upper Snoqualmie Valley (Figure 1). Elevation ranged from 130 m to 4,167 m, from the valley bottom to the top ridge line with Mount Si, the tallest topographic feature within the study area. The project area was a matrix of different land use and habitat types. Within the valley, land uses included housing, subdivisions, private agriculture lands, commercial buildings, and main county and state arterial roadways. Roadways consisted of residential, main city arterials and major state highways and interstates (Hwy 202 and I-90). I-90, the largest interstate located in the project area is located in the middle of the valley as the main West/East interstate. Traffic volumes average 28,000 vehicles per day and are increasing by ~ 2.1% per year (WSDOT 2008). The North Fork Snoqualmie River flows through the middle of the valley floor and the South Fork Snoqualmie River follows the I-90 corridor, providing abundant riparian habitat. Upland from the valley, forests are dominated by Douglas Fir (*Pseudotsuga menziesii*), Western Hemlock (*Tsuga heterophylla*), and Pacific Silver Fir (*Abies amabilis*). Weather is characterized by maritime conditions with average annual precipitation approximately 1,500 mm (NOAA 2012). The average summer temperature was 16 deg. C. and the average winter temperature was 4 deg. C.

During the mid to late 1800s, human encroachment and over hunting led to local extinction of the Snoqualmie Valley herd. Rocky Mountain elk were then shipped by railcar from Montana to reestablish a herd within the valley during the early 19^{th} century (Couch 1935). The non-migratory behavior of this herd, in conjunction with human development and human habituation has led to considerable human-wildlife conflicts. Common human-wildlife conflicts found in wildland-urban interfaces like North Bend include damage to agriculture and private property (Walter et al. 2010). Columbian Black-tailed deer (*Odocoileus hemionus columbianus*), another native ungulate, was present in the study area. Predators included the occasional presence of cougar (*Puma concolor*), black bear (*Ursus americanus*) and humans. Some of the study area allowed limited hunting with special damage tags. Additionally, elk encountered fatal interactions with motorists on roadways, with I-90 being the main contributor. Between the years 2009 and 2011 a total of 62 elk carcasses were removed from I-90 and Hwy 202 within the project area (WSDOT 2011)(Table 1).

Elk Capture and Telemetry

The Upper Snoqualmie Valley Elk Management Group captured 9 adult female elk from 2010-2012. An additional female elk that entered the study area during this time period was monitored and included in this study. This 10^{th} elk was originally captured and collared by the Muckleshoot Indian Tribe and fitted with a Vectronics GPS Plus collar (Vectronics, Starkville, Mississippi). The other 9 elk were fitted with global positioning system (GPS) telemetry collars, LOTEK 4400S and 4400M (Lotek Wireless, Newmarket, Ontario, Canada). Seven LOTEK 4400S collars were refurbished collars supplied by WSDOT and two LOTEK 4400M collars were purchased new. Elk were captured using clover traps (Thompson et al. 1989). One collared elk died during the years 2010-2012, this collar was then reused, totaling ten females collared. If necessary, immobilization was accomplished using telazol/xylazine HCL with Yohimbine as the reversal drug. Handling procedures were under the direct control of state or Muckleshoot Tribal biologists or a veterinarian experienced at handling elk (USVEMG 2010). Due to the random nature of elk capture, collars were deployed at varying dates with a variety of collar schedules (Table 2 and Appendix B). Downloaded GPS locations were converted to North America Datum (NAD) of 1983, Universal Transverse Mercator (UTM) Zone 10 using ArcGIS 10 Convert Coordinate Notation (ESRI 2013). Global positioning system-collar fix-rates varied greatly between collars (19% - 96.15%) and location error was marginal (error = 24 m). Location error was obtained by testing one LOTEK 4400S collar for position accuracy with a handheld Trimble GPS GEOXT explorer 6000 series unit. Due to the variability in collar fix-rates and location error, habitat could bias the location data (Frair et al. 2010). Dense canopy cover and steep terrain found in the project area could have decreased fix-rates and increased location error.

Home Ranges and Utilization Distributions- BBMM

To delineate home ranges and utilization distributions (UDs) for each animal, the Brownian bridge movement model was used (Horne et al. 2007). Calculated home ranges were used to explore the spatial relationship of elk space use with I-90, to determine if I-90 influences elk movement. UDs were used to define use contours, described in detail later. The Brownian bridge movement model is a continuous-time stochastic movement model in which the probability of an animal being in an area is calculated. BBMM requires (1) time-specific location data, (2) the estimated error associated with location data, (3) the distance and time between successive locations (4) the animals average movement rate and (5) the grid-cell size for the output (Horne et al. 2007). The BBMM is based on the properties of a conditional random walk between successive pairs of locations, dependent on the time between locations, the distance between locations, and the Brownian motion variance that is related to the animal's mobility (Horne et al. 2007). The BBMM estimates the probability of various animal paths between sequential locations irrespective of the density of locations where the width of the Brownian bridge is conditioned on time duration between beginning and ending GPS locations and GPS location error. Unlike other kernel density methods, BBMM is able to predict animal movement paths. A program developed in the R language for statistical computing (R Development Core Team 2007); (Appendix A) was used to create home ranges. Since collar types and schedules differed among different individual’s BBMM max lag and location error, inputs were unique to individual collar schedules. A grid-cell size of 30 X 30 meter was used to provide high-resolution mapping, while maintaining a reasonable processing time.

Cell values for each elk’s UD were summed and then re-scaled with their cumulative cell values summing to 1, such that the home ranges of each elk was represented by one UD. As the accumulated cell values reach 1, use is considered to be low. Core use areas were defined by 50% contour lines and home ranges boundary by 95% contour lines. Normal activity of an individual is commonly accepted at 95% of the locations of an animal within the entire home range area (White and Garrott 1990). Core use areas are areas within the home range that are used more frequently than any other area (Samuel et al. 1985). They usually contain home sites and areas of most dependable resources (Kaufmann 1962). Both home ranges and core use areas were used to explore space use in relation to I-90. It is important to examine both since activity patterns differ between the two.

In order to explore space use by elk in relation to I-90, digitized polylines between core use areas and I-90 buffer (pixel size 9m) were created in ArcGIS 10 as a measure of the average distance between core use areas and I-90. Visual observations of core use areas and home range locations were explored in ArcGIS 10 to understand compass location of home range and core use areas in relation to I-90 (north, east, south, west), if home ranges overlapped I-90 and to what extent. Visual observation of core use areas and home ranges in relation to I-90 can give insight into behavioral avoidance, with elk spending a majority of their time far from I-90 or vice versa. Previous research shows that the higher the traffic volume of a road is, the less wildlife cross and the greater the distance is that wildlife spend from the road (Gagnon et al. 2007b). Average land use composition within each home range was also calculated

Estimating Resource Selection

GPS locations of 10 female elk were analyzed to describe second order resource selection (Manly et al. 2002). Resource selection for each elk was determined by overlaying coordinate points contained by the calculated 95% home range contour on resource category layers and then summed in ArcGIS 10. Proportions of use for each variable in each category were calculated to define use. For estimating proportions of available resources, each resource category was censused for the extent of the project area in ArcGIS 10. The project area was defined by mapping all the coordinate points found within the 95% contour line for each home range and using the minimum bounding geometry tool in ArcGIS 10 to draw a minimum convex polygon around all points, defining the project area boundary.

The term resource will be used here when referring to 27 variables in five broad "resource" categories. The five categories included 1) distance to I-90, 2) distance to I-90 and use of riparian habitat, 3) road intensity, 4) land use and 5) topographic position index. Distance bands were created using ArcGIS 10 buffer tool, to understand space use in relation to I-90 at different distances (<50 m, 50-250 m, 250-450 m, 450-1,000 m and >1,000 m) (Appendix E). Distances were based on distances used by Dodd and colleagues (2007) with adjustments to accommodate for the smaller size of our study area (Gagnon et al. 2007b). Previous research found that large mammals like elk, exhibit a behavioral response to highway disturbance up to 425 m (Gagnon et al. 2007a). Use of riparian habitat was also evaluated at different distances from I-90, using the same distance bands as noted above (Appendix F). Riparian habitat was chosen because of its use by elk as a corridor for movement (Arizona Game and Fish Department 2011). A road layer obtained from ESRI was classified into 3 different variables defining road intensities based on speed limit, with roads greater than 55mph classified as high intensity, 35-45mph classified as medium intensity, and less than 25mph were classified as low intensity (Table 3 and Appendix D). Speed limit was used to define intensity level because research has shown that roads with higher speed limits are found to impact wildlife more than roads with lower designated speed limits (Jaeger et al. 2005). Land use variables were digitized spatially using ArcGIS editor tool and a 2011 NAIP image at a 1:24,000 scale (USDA 2012). Variables included development intensity (high and low), developed open space, open/forage, wetland, riparian, forest and open water (Table 3 and Appendix C). Variables were chosen based off of similar land classifications used in the REGAP analysis done by the Washington Wildlife Habitat Connectivity Working Group (WHCWG 2010). The Topographic Position Index (TPI) was used to calculate the influence of slope and topographic features on elk movement. This information was used as opposed to other topographic information due to the accuracy at which TPI defined slope position (Weiss 2006). TPI can distinguish between valley floors and ridge lines that resemble the same percent slope. Variables included ridge, upper slope, middle slope, flat slope, lower slope and valley. The TPI layer was developed from a 30 x 30 meter pixel USGS Digital Elevation Model (DEM) data using TPI v. 2.3a (Jenness 2006)(Appendix G).

Statistical Analysis/Resource Selection

Once the proportions of used and available resources were known, selection was assessed by estimating log-likelihood chi-square test statistics and selection ratios (ratio of the proportion of resource used and available) for different resource variables (Manly et al. 2002). This is a widely used method to test for selection of resources by wildlife (Neu et al. 1974). The log-likelihood chi-square test was calculated as $\chi^2_{L2} = 2\sum\{\log e \frac{U_{ij}}{E(U_{ij})}\}$, where $E\left(U_{ij}\right)$ is the expected value of U_{ij}, to test the null hypothesis that resource selection is proportional to availability or that resource selection is random (4.27 Manly et al. 2002). When the χ^2_{L2} statistic was significantly larger than the chi-square distribution, with n(I-1) df, there was evidence of non-random selection by at least some of the elk, suggesting resource selection occurred.

Selection ratios were used to test the null hypothesis that elk do not display preference or avoidance of resources. Selection ratios ($\widehat{\mathcal{W}}i$) were calculated for each resource variable $\widehat{\mathcal{W}}_i$=U_{i+}/π_i, where U_{i+} is the proportion of used units in variable i by all elk, and π_i is the proportion of available resource units in variable i (4.31 Manly et al. 2002). Standard errors for selection ratios were calculated as s.e.($\widehat{\mathcal{W}}_i$)=$\widehat{\mathcal{W}}_i\sqrt{O_i}(1 - O_i)/(U_+\pi_i^2)$ where O_i is the used resource units in variable i , U_+ is the total number of used units sampled and π_i is the proportion of available resource units in variable i (4.14 Manly et al. 2002). Since multiple tests were computed across variables within a category simultaneous Bonferroni adjusted confidence intervals were calculated as $100(1-\alpha)\%$ for each variable in order to locate significant selections. The Bonferroni correction is considered the simplest and most conservative method to control for type 1 errors. Adjusted confidence intervals were calculated as $\widehat{\mathcal{W}}_i \pm Z_{\alpha/2I}\ se(\widehat{\mathcal{W}}_i)$, where I is the number of resource variables in the category (4.33 Manly et al. 2002). Significant selection was considered to occur when 1 < the confidence interval, significant avoidance occurred when the 1 > confidence interval, neither selection nor avoidance occurred when 1 was found inside the confidence interval (Manly et al. 2002).

Results

Home Ranges

Ten female elk were fitted with GPS collars between the years of 2010 and 2012. Location data for all ten individuals were used to estimate home ranges. The number of locations from the 10 individuals ranged from 149 to 14,119 (Table 2). For this population of elk, the average home range (95% contour) was 9 km^2 (range = 4 to 23 km^2) (Table 2). Eight individuals excluding elk 1326 and 601_2 had home ranges bordering I-90 (Figure 2). Six out of these 8 overlapped slightly with I-90 (Figure 2). Two elk, 351 and 324 had home ranges that overlapped I-90 substantially, displaying abundant space use on the North and South side of I-90 (Figure 2). Every home range was found to overlap with at least one other forming 4 distinct groups, group 1 (601_2 and 1326), group 2 (351 and 324), group 3 (3870 and 1550) and group 4 (341, 601_1, 337, and 339) (Figure 3). Average composition of land use within home ranges was primarily forest (53.39%), open/forage (18.37%) and developed-low (9.54%) (Table 4, Figure 4).

Core Use Areas

For this population of elk, the average core use area (50% contour) was 2 km^2 (range = 0.41 km^2 to 4 km^2) (Table 2). Eight individuals (all elk 1326 and 601_2) had their core use areas bordering I-90, with elk 1550's core use area slightly overlapping (Figure 5). Elk 324 was the only elk that displayed core use areas on the North and South side of I-90 (Figure 5). Average distance between elk core use areas and I-90 was 1,647 meters (range = 384 m to 2,759 m). When elk 3870 was excluded distance decreased to 1,400 meters. Elk 324 had the smallest average distance between core use area and I-90 with 384 meters (range = 145 m to 894 m). Average composition of land use within core use areas differed from composition within home ranges, with forest at 48.73%, open/forage 23.22% and developed-low 8.08% (Table 4, Figure 4).

Resource Selection

Only coordinate data that resided within 95% contours from all ten female elk were used to analyze resource selection. Since elk 3870's coordinate data comprised 60% of the total dataset, a subsample of 1,176 random points were sampled using excel to avoid resource selection bias by the individual. A total of 10,297 points were used to assess second order resource selection. For all five resource categories the null hypothesis that selection is proportional to availability was rejected at significant p value of 0.001

(Table 5). This result suggested that selection of resources by elk was not random. Further investigation of resource selection using selection ratios and confidence intervals, revealed selection of variables within categories differed significantly, displaying preference for some variables and avoidance of other variables (Table 6). Therefore, the null hypothesis that all resource variables are selected equally was rejected.

Within the land use category elk selection differed between different land use variables, with significant differentiation of selection between developed-open and open/forage from the rest (Figure 6 and Appendix C). Developed-low and riparian were similarly selected for while wetland and open water were similarly selected against, with all other variables showing unique selection or avoidance (Figure 6). Elk showed preference for developed high, developed low, developed open, open/forage and riparian habitat, avoiding forest, wetland and open water variables (Table 6). However, the selection for developed high and selection against forest was slight.

Within the road intensity category elk avoided medium and high intensity roads, while slightly selecting for low intensity roads within the road intensity category (Table 6). Selection against medium and high intensity roads was similar (Figure 7).

Elk displayed differential selection for different distances from I-90, selecting for distance bands of 50-250 m, 250-450 m and 450-1,000 m (50-1,000 m range), while avoiding distance bands close to I-90 at <50 m and distance bands far from I-90 at >1,000 m (Table 6). Selection for distances of 50-250m and 250-450 were similarly selected while distances 250-450 m and 450-1,000 m were similarly selected against, showing that selection of 50-250 m and 450-1,000 m differed (figure 8).

Riparian habitat selection differed at varying distance from I-90. Elk selected for riparian habitat far from I-90 at distances of >450 meters, while avoiding distances of

<50 meters, 50-250 m and 250-450 m (Table 6). Selection against distances of 50-250 and 250-450 m were similar, while all other selections displayed unique selection (Figure 9).

Lastly, elk displayed a strong selection for flat slopes, avoiding all other topographic positions (Table 6). Topographic positions ridge, lower slope and valley were similarly selected against, while elk significantly selected for flat slopes (Figure 10).

Discussion

Home Ranges

The results show that most elk home ranges are located bordering I-90, with some slightly overlapping I-90; only two home ranges largely overlapped I-90. These results suggest some individuals approach I-90, but few crossed and spent abundant time on opposite sides of the interstate. Only two individuals, 351 and 324, displayed abundant time spent on both the north and south sides of I-90, suggesting that they crossed I-90 multiple times to access resources while others did not. These results contradict expectations that elk would avoid I-90 at great distances. Previous research suggested that large mammals like elk are negatively influenced by large interstates similar to I-90, displaying strong behavioral avoidance (Rost and Bailey 1979, Dodd et al. 2007, Gagnon et al. 2007a). However these studies evaluated space use of non-human habituated elk which behave differently than habituated elk. Human habituated elk are less disturbed and display a more mild behavioral response to constant human presence in contrast to their more wild counterpart (Stankowich 2008, Walter et al. 2010). Reasons for habituation include the need for elk to maximize reproductive fitness, and due to learned behavioral responses to non-lethal interactions with humans (Thompson and Henderson

1998). Therefore, human habituated elk may respond to high volume interstates and roads in general differently than remote, non-habituated elk populations.

It is important to note that home ranges were calculated using the highly accurate Brownian bridge movement model, however poor fix rates and high lag time between fixes could influence the precision of the contours, increasing contour width, possibly accounting for the slight overlap of home ranges on I-90. Therefore, the results could show an overly conservative home range size, creating larger home ranges than what actually occurred. Future research with standardized collar schedules and reduced lag time between fixes could provide a more refined home range and better depiction of behavioral response to I-90 by the elk. Nonetheless, these results suggest that the human habituated elk in the North Bend area are spatially influenced by I-90, with some displaying behavioral avoidance. Therefore, I-90 could be considered a partial barrier to elk in the North Bend area but not a completely impassible structure, due to the riparian underpasses or bridges present, as will be discussed below.

Average annual home range size (95% contour) of 9 km^2 (range = 4 km^2 to 23 km^2) falls within the lower range for what is commonly found in the literature (Anderson et al. 2005). Annual home range size of elk can be as small as 3 km^2 and as large as 245 km^2, depending upon many different factors (Peek 2003, Anderson et al. 2005). A study on two non-migratory female groups located in a mesic California redwood forest, reported annual home ranges of 3 km^2 (Franklin et al. 1979). Some individuals within North Bend displayed similar home range sizes as to what was found by Franklin and colleagues, with half displaying annual home range size of less than 6 km^2. It is important to note that these individuals were found in spatially different groups (Table 2, Figure 3). However, non-migratory home ranges of elk found by Moeller, south of this study area, located south of Mount Rainier had average annual home ranges of 62 km^2, ranging between 5.40 km^2 and 102 km^2 (Moeller 2010). This area is fairly undeveloped in comparison to North Bend, potentially influencing the difference found in home range size between the two herds. In addition, they had a longer telemetry monitoring period.

Many factors can influence small home range size. For example, elk may reduce travel distance in order to balance the needs of minimizing predation risk and energy demands, while meeting forage uptake, minimizing thermal stress and maintaining social contacts (Anderson et al. 2005). Home range size must meet the energy and nutritional demands of wildlife, when such demands are not met, wildlife increase distances traveled to access additional resources. Therefore, when forage is scare or patchily distributed, wildlife range over large areas (Ford 1983, Relyea et al. 2000). Consequently, the small home range size of the elk in this population suggests that energy and nutritional demands are being met. High-quality forage such as lawns, gardens, golf courses, pastures, and hay meadows found in this urban setting could be part of the reason for their small home range sizes, in addition to human habituation (Thompson and Henderson 1998). If North Bend increases development concurrent with elk population growth, resources for elk could become scarcer, forcing elk to increase home range size to access and compete for resources, thus increasing interactions with humans and I-90. Therefore, it is important to identify potential safe crossing opportunities so that elk can access additional resources that may be located on the other side of I-90.

Substantial space use overlap was found among several individuals. Groups appeared to utilize similar spaces in relation to I-90, with some groups staying away from I-90, as seen with group 1 and some staying close, as seen with groups 2, 3 and 4. Group 2 displayed space use on both North and South sides of I-90, however only 324 had core use areas on both sides. This could indicate that these individuals belong to similar family groups. Therefore, these individuals' home ranges may be spatially auto correlated, displaying similar resource selection, reducing the effective sample size. Further testing for autocorrelation should be executed.

Core Use Areas

Most core use areas bordered I-90, but at a great distance from I-90 on average > 1,500 m, suggesting elk spend considerable time away from I-90. Only one elk displayed core use areas located on both sides of I-90. These results suggest that this elk crossed I-90 multiple times to access resources, while most individuals did not. Therefore, these findings imply that I-90 has a spatial influence on core use location. In addition, evidence that few individuals displayed core use areas on opposite sides of I-90 despite bordering I-90, also supports the conclusions that most elk could be behaviorally avoiding I-90, implying that I-90 is a partial barrier to their movement.

Resource Selection

The results confirm that elk select for resources in their home range (95% contour) disproportionately to what is available in the study area, displaying preference and avoidance of specific resources. As such, the null hypothesis that resources are selected proportionately to availability was not supported. It is important to note that these results were treated with conservative log-likelihood chi-square test and Bonferroni adjusted confidence intervals and were found to be significant. However, habitat bias and collar schedules could potentially affect the results of selection.

Within the land use layer elk were found to select for developed-low, developed-open, and open/forage. Selection of these variables was as expected since North Bend offers high-quality forage and security. Human habituated elk have been found to prefer forage offered by lawns, ornamental plants, golf courses and pasture due to the accessibility and quality in an urban setting (Thompson and Henderson 1998). In addition, some land owners enjoy viewing elk from the comfort of their homes, providing artificial feed. Non-lethal interactions with humans teach elk that security corresponds with urban settings. Subsequently, elk seek the refuge of urban areas to increase their reproductive fitness (Thompson and Henderson 1998). Therefore, the selection for developed-low, developed-open and open/forage is evidence of habituation. In addition, the avoidance of the forest resource variable could also be an indication of security in this study area, displaying reduced need to seek refuge from natural and human predators in a forest environment (Lee and Miller 2003, Anderson et al. 2005, Cleveland et al. 2012).

I-90 and highway 202 structures were expected to be avoided in all categories. Out of all roads, highways and interstates are found to have the most influential effects on wildlife species (Forman et al. 2002, Gagnon et al. 2007a, Fahrig and Rytwinski 2009). Road effect zones increase as traffic volume and size of road increases (Forman et al. 2002, Dodd et al. 2007, Gagnon et al. 2007b, 2007a). Results found in the road intensity category supported previous research results of elk-highway interactions, showing avoidance of medium (Hwy 202) and high (I-90) intensity roads. Contrarily, within the land use category elk selected for developed-high, which included I-90 and Highway 202 structures. Reasons for such selection could be because this classification included many different land use types which could have influenced the selection of the variable as a whole.

Few previous studies have addressed road interactions with human habituated elk, therefore it is not fully understood how habituated elk respond to roads (Rost and Bailey 1979, Gagnon et al. 2007a). Low intensity roads have reduced effects on elk than medium and high intensity roads. Most research is done on elk-road interactions in areas with low intensity roads, and these studies have shown smaller road effect zones of 200 meters than what is found with high intensity roads like highways (Gagnon et al. 2007a).

In contrast, this study found that elk in North Bend select for low intensity roads. The difference in this result is perhaps explained by the fact that most studies on elk-road interactions are with non-human habituated elk. The more habituated elk in this study area may have become familiar to low intensity roads due to the overall abundance of such roads in the project area and likelihood of interaction (Thompson and Henderson 1998, Walter et al. 2010). Low intensity roads were found to intersect every home range in this study. The selection for low intensity could be an indication of human habituation and reduced wariness near such road types or an artifact of the correspondence between elk home ranges and the valley bottom where roads are more numerous that they are throughout the peripheral higher elevations of the project area.

The evaluation of space use in relation to I-90 at different distance bands found that elk prefer distances between 50 meters and 1,000 meters, avoiding distances less than 50 meters and greater than 1,000 meters. Selection against distances less than 50 meters was as expected however; selection for distances less than 450 meters was not as expected. A literature review of ungulate interactions with roads by Gagnon and colleagues found that elk were affected by highways at distances up to 425 meters, therefore it was expected that elk would select against distances less than 425 meters (Gagnon et al. 2007a). This affected distance is termed the “road effect zone”. Therefore, the road effect zone of 50 m for these human habituated elk is far less than what is found in the literature. Therefore, these habituated elk may be less affected by highways than their non-human habituated counterparts. Moreover, available open areas and other preferred habitats provide important resources at distances relatively close to I-90 in the valley floor. Thus the juxtaposition of where transportation planners constructed I-90, the development of North Bend near the Interstate, and the local topography, likely influenced selection of elk use between 50 meters and 1,000 meters, avoiding distances greater than 1,000 meters, where topographic relief increases. Therefore, elk movement could be confined by these steep slopes due to their preference for flat slopes. In addition, elk were found to select for flat slopes within the topographic position index category, avoiding all other positions. Exclusive selection of only one topographic position was not as expected, since elk are capable of utilizing a variety of slope positions. However, this could be an indication of habitat quality and security located on flat slopes that correspond with much of the urban and residential valley bottom. Therefore, selection for flat slopes could also be an artifact of their non-migratory and human habituated behavior. Migratory elk usually cross a variety of topographic positions during their seasonal movements (Anderson et al. 2005). Unfortunately, many high intensity roads are built on flat slopes, as such for I-90 and Hwy 202 in the project area, which could be an explanation for the high collision rates in this area. Therefore, if these elk choose to cross I-90 it may be in topographically flat areas.

Riparian habitat at distances greater than 450 meters from I-90 was selected by elk, avoiding this cover type at distances less than 450 meters. This was not as expected since riparian habitat is known to be utilized as corridors for movement (Arizona Game and Fish Department 2011). It was expected that riparian habitat would be selected for at all distances. Two forks of the Snoqualmie River flow through the study area, one following right along I-90 and another residing at greater distances, elk may be choosing to utilize the riparian corridor farther away from I-90. Their preferential use of riparian habitat at distances greater than 450 meters could indicate that they like to utilize such corridors and cover away from I-90. Therefore, elk avoidance of both available and known preferred habitat type adjacent to I-90, demonstrates I-90’s influence on elk resource use.

However, two individuals, elk 351 and 324 were found to move along the South Fork Snoqualmie River corridor near I-90, crossing under I-90 to utilize resources located on the southern side. These two elk were the only individuals that both crossed I-90 and spent abundant time on both sides of I-90. Evidence obtained from game cameras deployed by WSDOT for habitat connectivity research at bridges along I-90 that cross riparian habitat, have captured elk utilizing these structures to pass safely under I-90 (Figure 11). One of the I-90 bridges along the South Fork Snoqualmie River is also located along elk 324's and 351's movement paths. Therefore, these two individuals could be using this structure to pass safely under I-90 (Figure 11 A. and B). Elk 324 was the only elk that had core use areas on both sides of I-90. Within the project area, I-90 crossed the South Fork Snoqualmie River several times, creating several opportunities for safe passages at bridge structures. Previous literature shows that bridges are preferred crossing structures used by ungulates like elk; however in this study, only two individuals utilized these structures (Forman et al. 2002, Beckmann et al. 2010). This analysis of elk 351 and 324 home ranges, as well as, game camera images obtained at bridge locations along the South Fork Snoqualmie River, provide proof that elk utilize riparian habitat and bridge structures to cross I-90 safely if they chose to move close enough to I-90, however most elk did not despite available structures and habitat.

Conclusions

Roads can significantly impact wildlife through a variety of mechanisms. Prior to this study, home ranges and road interactions of elk located around North Bend was generally undocumented. This research informed where elk establish home ranges in relation to I-90 and how elk utilize resources in the North Bend area. Since this herd is human habituated, results from this study offer insight into previously under-researched aspects of the behavior of human habituated elk and their road interactions. Most previous research on elk-highway interactions were conducted with non-human habituated elk which behave differently than their habituated counterparts. Results from this study supports previous research showing habituated ungulate tendencies for why certain resources were chosen or avoided. Interactions with I-90 were different than what is commonly found in the literature, with elk utilizing space fairly close to I-90, but at distances greater than 50 meters. However, few elk chose to cross the interstate to utilize resources located on the opposite side, riparian habitat was generally avoided at distances close to I-90 and high intensity roads were avoided, suggesting I-90 may be a partial barrier to elk movement. Those elk that crossed followed a riparian corridor, most likely utilizing a bridge structure to pass safely under I-90.

Despite the conservative measures taken to analyze home ranges and resource selection, it must be noted that there were some limitations with the data. The variety in collar schedules between elk and the limited number of fixes per day for some individuals gave a less than complete view of daily movements. Low fix rates of some collars could have been a product of local satellite blocked by topographic features or vegetation, potentially biasing the analysis of selection. These data were accrued during the early stages of collaboration, when funds and staffing were limited. Collars were scheduled to maximize battery life and deployment time by limiting the number of transmissions each day. Currently, more elk are being collared, new collars have been purchased and collar schedules are improving. Therefore, the quality of data gathered for future analysis will likely improve the accuracy to detect fine scale movements of these elk. Regardless of limitations with the coordinate data, this study is one of only a few that has researched human habituated elk interactions with high traffic interstates. In addition, it is a great example of interagency collaboration.

Suggestions for future research would include temporally analyzing home ranges and space use for trends, which could be used to predict if seasonality influences elk movement in relation to I-90. Secondly, increasing the sample size (collaring more elk) and standardizing collar schedules would improve the accuracy of analyses on elk crossings of I-90. Lastly, research should be implemented on how selections of resources are correlated. A more in-depth resource selection function using utilization distributions could give a more detailed depiction of elk spaces use.

In conclusion, this research brings insight into how human habituated elk respond to I-90. By understanding how elk respond to high traffic interstates like I-90 and utilize resources and space adjacent to this high-volume interstate, transportation planners and wildlife managers gain invaluable information to better manage for connectivity and to reduce wildlife-vehicle collisions. It appears that for many elk in the population, I-90 is a barrier to elk movement; however two individuals followed a riparian corridor and crossed I-90 safely, mostly at a bridge structure. Understanding habitat selection combined with existing knowledge of riparian habitat corridors used by wildlife can pinpoint linkages and opportunities for safe crossings where bridges are located (Arizona Game and Fish Department 2011). Several authors stress the need to identify linkages across barriers and maintaining connectivity between preferred resources when placing crossing structures (White and Ernst 2004, Singleton et al. 2004, Kindall and van Manen 2007). In addition, studies have found that road mortality sites and road crossings by wildlife occur near preferred resources (Cain et al. 2003). By ensuring connectivity between existing bridges where I-90 crosses riparian areas, costs associated with implementation of crossing structures can be avoided while ensuring connectivity. Construction of barrier fencing is a measure that can be taken to prevent elk from crossing over the surface of I-90 and function to direct them to safe crossing opportunities, preventing wildlife-vehicle collisions and ensuring connectivity. As North Bend becomes more developed, resources for elk may become scarce and fragmented. If such effects occur, elk may be forced to increase the size of their home ranges, and thus an increase in elk/human interactions is expected. Therefore, human wildlife conflicts may increase in the area of North Bend. Further research is recommended to ascertain where permeability for elk in landscapes adjacent to high-traffic interstates exist, in order to provide safe movement of animals between resources and to mitigate for associated negative road effects.

Chapter 3 – Conclusions and Management Implications

Negative effects from roads are evident throughout many natural systems. Habitat fragmentation is among the most severe of these effects, with some wildlife species experiencing consequences on population viability. Transportation agencies must confront complex issues of how roads affect natural systems, while simultaneously creating safe transportation corridors for humans. Mitigation for fragmentation effects is a growing priority among transportation agencies as the importance of maintaining connected landscapes becomes recognized by road planners. Traditionally, road planners used data from wildlife-vehicle collisions and carcass removals as the basis for mitigation decisions. However, this data cannot be used alone to understand the larger landscape-level effects of roads. With the advancement in wildlife tracking technologies and methods, transportation agencies and road ecologists are more equipped than ever to fully understand ecological impacts of roads. By analyzing wildlife movements, road planners and road ecologists can comprehensively understand the effects of roads which are not apparent when using wildlife-vehicle collision and carcass removal data alone.

Knowledge of how human habituated elk respond to I-90 in the North Bend, WA area was largely undocumented prior to this study. Overall, knowledge of human habituated elk is lacking in the greater body of literature, let alone interactions with and response to high volume interstates. Elk herds habituated to human-dominated environments respond to human infrastructure, especially developed structures like roads and developed spaces differently than their non-habituated counterparts. In light of continued human population growth and development in many regions, it is important to understand how habituated elk respond to high volume interstates and developed areas, to ensure appropriate management.

This research studied how human habituated elk responded to I-90 by analyzing home range establishment and resource selection in a developed area. A majority of the home ranges were established away from I-90 with few individuals crossing I-90 to access resources on the other side, suggesting that I-90 may be a partial barrier to their movement. Based on the spatial location of home ranges in relation to I-90 one can infer that I-90 does in fact influence elk movement and behavior up to at least 50 meters. However, to fully understand the relationship between I-90's influence and resource allocation, further multivariate tests are recommended. Camera evidence showed that utilization of riparian corridors under bridge structures by elk, provided safe passages under I-90 and informs efforts to reduce elk-vehicle collisions while ensuring connectivity. Several authors stress the need to identify linkages across barriers and between preferred resources when applying mitigation techniques (White and Ernst 2004, Singleton et al. 2004, Kindall and van Manen 2007). By using existing bridges where I-90 crosses riparian areas, transportation planners can reduce costs associated with the implementation of creating crossing structures while ensuring connectivity. Additionally, constructing barrier fencing in strategic locations to prevent elk from crossing I-90 can direct them to these safe crossing opportunities. Although road ecologists and planners have gained substantial knowledge about mitigation actions, further research to understand what constitutes connectivity between resources is necessary, as well as site specific information on how to provide safe crossing opportunities across high-volume interstates.

Recommendations for further research include the following:

1. Continued monitoring of elk movement with these suggested changes:

- Increase Sample Sizes by Collaring Additional Elk

- Improve Collar Schedules to Obtain More Frequent Locations
- Analyze Elk Crossings Spatially and Temporally

As we had access to data on only 10 elk for this study, a larger sample size would improve future analyses. With a larger sample size a more accurate depiction of how I-90 affects elk at a population level can be done. With more elk collared and collar schedules improved, road ecologists can improve their understanding of crossing behavior. Currently, this dataset does not provide enough accounts of elk crossing to conduct a detailed analysis. With additional data on elk crossings, road ecologists can understand both temporal and spatial patterns of when and where elk cross I-90. Collar schedules will need to be improved if such analyses are to be conducted. Currently, collar schedules receive fixes too infrequently to get precise data of when crossings actually occurred. However, schedules are being improved so that they receive fixes at higher frequency and at standardized schedules.

2. Analysis of bridge structures:

- Improve Accessibility To and Connectivity Between Bridges.
- Implement Passage Assessment System (PAS)

Elk are selective when utilizing structures to pass safely under roadways. For passage, open span bridges are preferred, but there are things that can prevent the elk from utilizing them. The surrounding environment could prevent the utilization of bridges if conditions conducive to connectivity do not exist. Further spatial analysis could evaluate the surrounding environment for potential barriers that might prevent the elk from utilizing otherwise available structures. In addition, connectivity between structures should be evaluated if mitigation measures such as fencing are to be implemented. If structures are inaccessible or connectivity between structures is highly fragmented, fencing could potentially increase the barrier effects associated with I-90 by inhibiting crossings at grade. (McCollister and Manen 2010). Lastly, implementing PAS, a "Passage Assessment System" developed to assess the permeability of existing structures for terrestrial wildlife by Julia Kintsch and Patricia Cramer (2011), can be used to determine if existing bridges in the North Bend area are attractive to and accessible to elk. Rating each structure can inform improvement actions necessary to make the structure more suitable for elk.

3. Improved Resource Selection Analysis

- Conduct Additional Multivariate Analysis Using Utilization Distributions (UDs)

The resource selection analysis implemented in this study was fairly straightforward, analyzing resources for selection at an individual level. Performing a full resource selection function can bring insight into how resources influence the selection of certain resources. A full resource selection function can pin point what combination of resources are most preferred by elk.

4. Ensure good management of riparian corridors near and adjacent to bridges:

Riparian habitats are known corridors for wildlife movement, however within this study elk disproportionally selected for habitat away from I-90. However, game cameras have caught images of elk utilizing bridge structures along riparian habitat to cross safely under I-90. Therefore, these areas should be managed appropriately to ensure that excellent habitat quality exists around bridges now and into the future, providing connectivity for elk and other wildlife.

Interdisciplinary Effort

Society is increasingly faced with complex environmental issues that require dynamic and thoughtful solutions. Many environmental problems today are inter-tangled between balancing our need to protect the environment with the growing human demands on natural systems. Humans are no longer able to perceive ourselves and our activities separate from the environment; we are now experiencing feedback from our past actions. Many of our roads were built long before we knew their environmental impact; therefore a lot of our current management decisions are to rectify that damage. As scientists and transportation managers seek to understand ways to mitigate current or past damage and reduce future impacts of roads, it has become critical that the field of road ecology "quantifies the ecological effects of roads, with the ultimate goal of avoiding, minimizing and compensating for their negative impacts on individuals, populations, communities, and ecosystems" (van der Ree et al. 2011). To meet these objectives it takes an interdisciplinary effort with many professionals from a variety of backgrounds. The collaboration between biologists, road planners and structural engineers is essential in planning for mitigation measures to minimize the negative effects of roads. Without this collaborative approach between multiple disciplines mitigation would fail to meet all objectives. Within an interdisciplinary framework, mitigation can ensure that wildlife, the environment and human structures are resilient to future change.

In Washington State, the problem with elk-vehicle collisions in the North Bend area requires a dynamic solution where driver safety is increased while ensuring connectivity of elk populations living near I-90. To address this problem, we took a dynamic approach to this applied research question, combining the disciplines of road ecology, road planning, and landscape ecology with methods commonly found in wildlife management. This research involved a collaborative effort between WSDOT and the USVEMG to tackle a complex, multidimensional problem. In an era of budget cutbacks and ever-growing natural resource management issues, collaboration between agencies, non-governmental groups, academia and local citizen science groups is necessary. It took the collaborative effort between WSDOT and USVEMG to research elk movement since neither group alone had the resources to conduct this research. It is these collaborative efforts that should continue and be enriched in other regions facing similar budget shortfalls and decreased funding. Wildlife movement research used to analyze wildlife-highway interactions is costly, but fortunately collaboration is a solution.

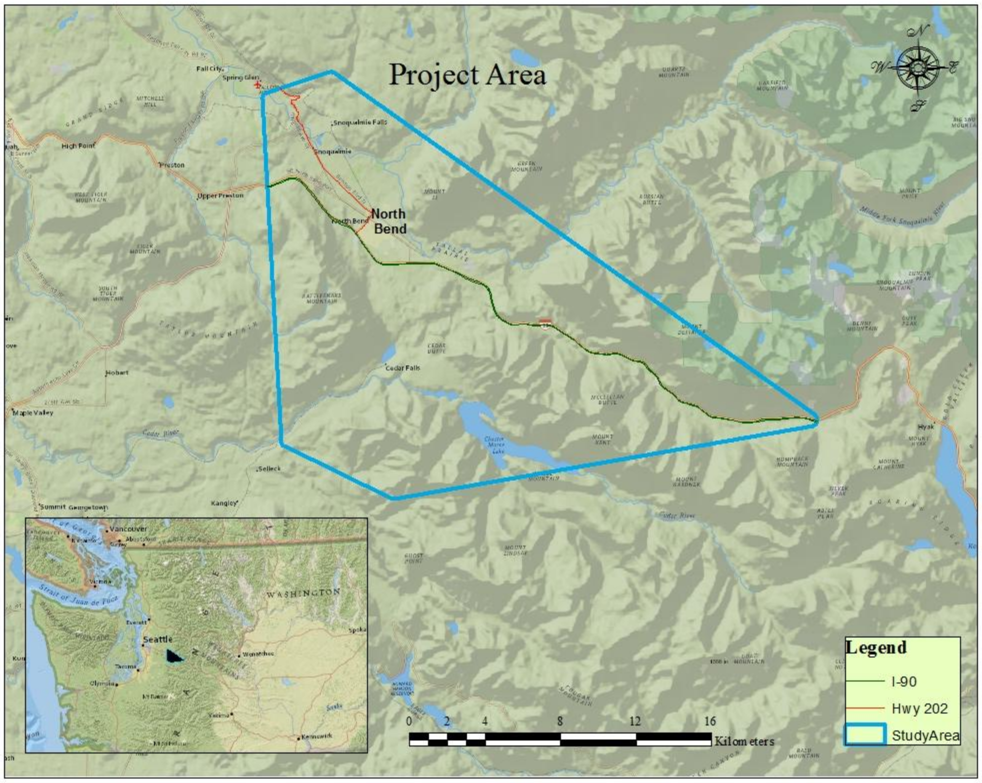

Figure 1. Map of Washington State and defined project area around North Bend, WA (area=363km^2).

Table 1. Number of elk carcasses removed and number of elk-vehicle collisions along I-90 and Hwy 202 within the project area. Data Source: the Washington State Traffic Data base.

Year	Elk Carcasses Removed	Elk-Vehicle Collision
2007	7	NA
2008	10	NA
2009	36*	18*
2010	10*	9*
2011	16*	9*

*Note the difference between elk carcasses removed and elk-vehicle collisions. Collision records are recorded when an officer is present at the accident and require a minimum of $750 in property damage or a human injury. Collision records are fewer because not all collisions with elk are reported. Elk-vehicle collisions were not tracked separate from other wildlife-vehicle collisions until 2009.

Table 2. Home range (95% contour, in km^2) and core use area (50% contour, in km^2) for elk in the vicinity of North Bend, WA.

Elk Number	50%	95%	Fixes Per Day+	Total Number of Fixes	Start Date	End Date
601_2	1.28	7.23	5	267	12/10/2011	4/25/2012
324	0.74	5.02	6	742	8/15/2010	3/30/2011
341	1.39	5.47	6	1933	2/14/2011	4/11/2012
351	0.41	4.60	6	1050	2/18/2012	9/18/2012
339	3.13	10.14	6	1300	3/11/2011	4/12/2012
1326	0.79	4.13	7	1176	4/12/2012	8/22/2012
337	0.98	4.73	7	149	4/9/2010	6/28/2010
601_1	1.19	7.23	7	1445	4/7/10	2/4/2011
1550	3.35	14.03	12	1261	3/11/2011	4/18/2012
3870	3.81	22.53	29	14119, 1176*	3/27/2011	8/3/2012

*Subsample for resource selection analysis.
+Reference Appendix B for collar schedule.

Table 3. Definitions of resource variables found in the project area, North Bend, WA.

Category	Variable	Definition
Land Use	Developed-High	High traffic roads, I-90, highway 202, North Bend Way, commercial development, quarries, mines, and gravel pits.
	Developed-Low	Residential roads, subdivisions, rural houses.
	Developed-Open	City parks and recreational fields.
	Forest	North pacific Douglas-fir, western hemlock, spruce, and silver fir forest.
	Open/Forage	Pasture, lawns, and successional fields.
	Riparian	North pacific lowland riparian forest and shrubland.
	Wetland	North pacific bog, shrub swamp, and hardwood-conifer swamp.
	Open Water	Lakes, ponds, and open bodies of water.
Road Intensity	Low	< 25 mph
	Medium	35- 45 mph
	High	> 55 mph

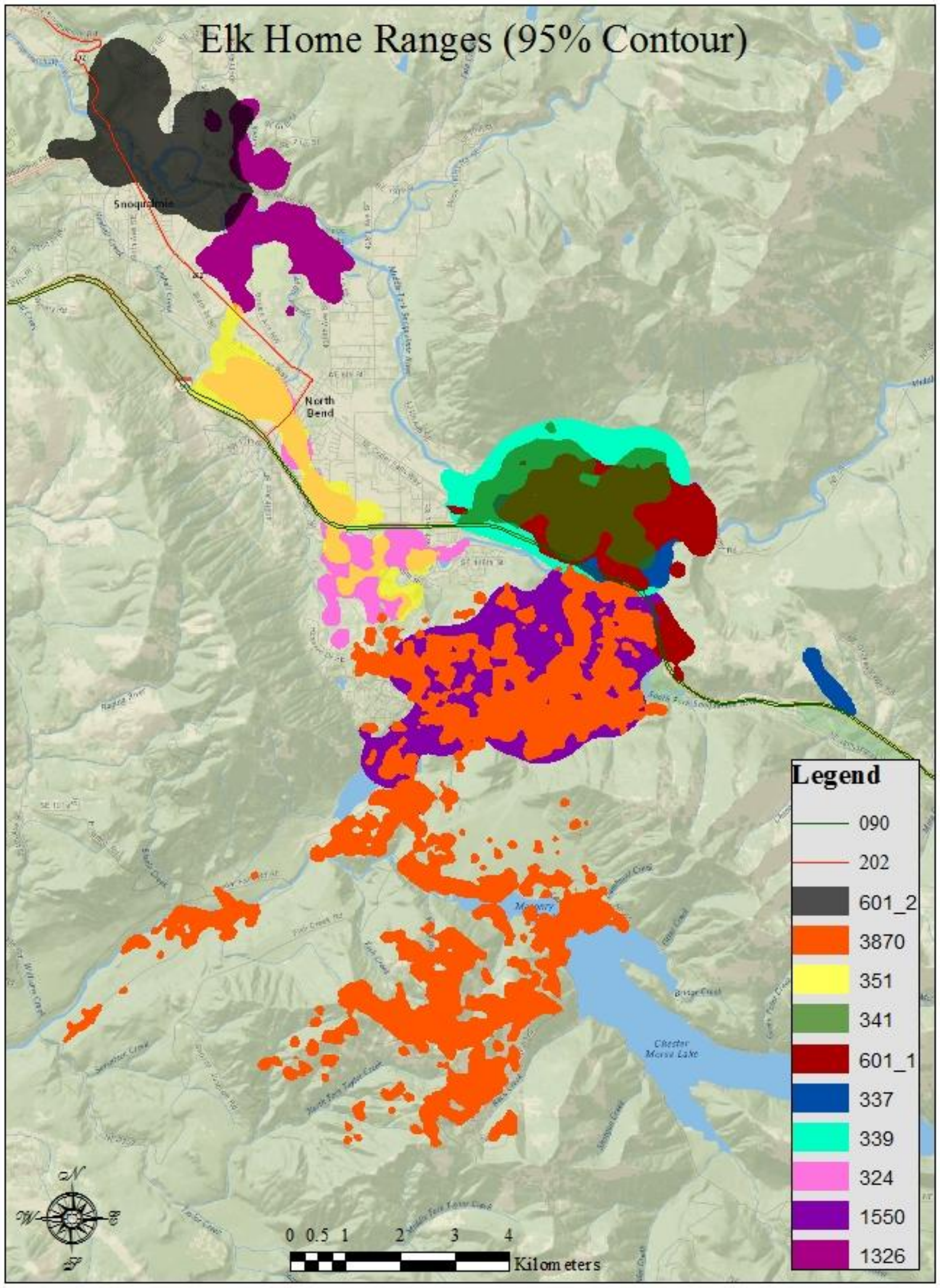

Figure 2. Elk home ranges (95% contour, in km^2) of ten elk in North Bend, WA determined from a Brownian Bridge Movement Model.

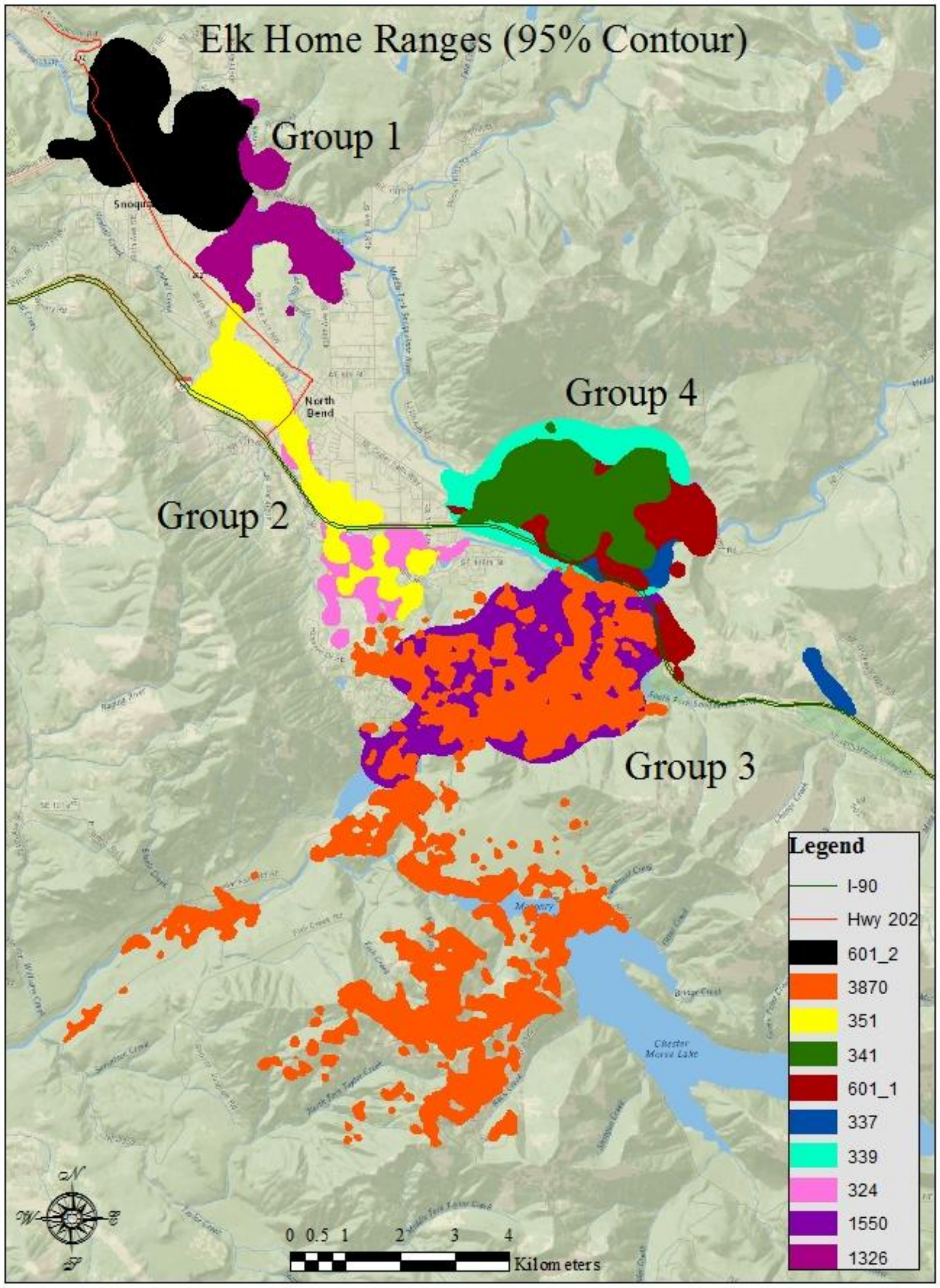

Figure 3. Overlapping elk home ranges (95% contour, in km^2) of ten elk identified as four groups in North Bend, WA determined from a Brownian Bridge Movement Model.

Table 4. Land use composition for the study area and elk home ranges. Core use area 50% contour and home range 95% contour.

Class	**Study Area**	**Home Ranges 50%**	**95%**
Developed-High	2.49%	3.51%	3.68%
Developed-Low	3.14%	8.08%	9.54%
Developed-Open	0.82%	10.93%	8.92%
Forest	87.22%	48.73%	53.39%
Open/Forage	1.22%	23.22%	18.37%
Riparian	2.03%	5.04%	5.70%
Wetland	2.72%	0.46%	0.36%
Open Water	0.38%	0.03%	0.04%
Total	100.00%	100.00%	100.00%

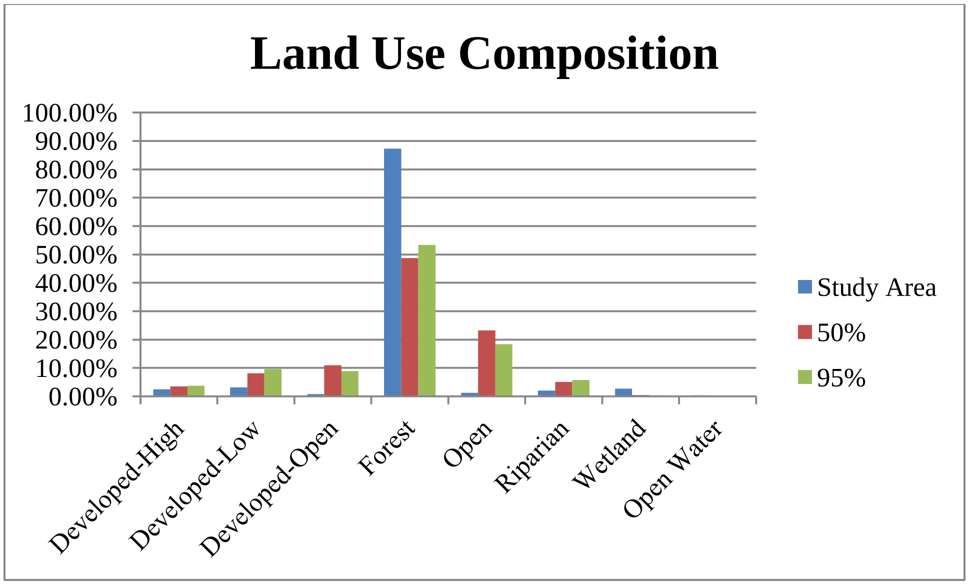

Figure 4. Composition of Land Use within the project area, North Bend, WA.

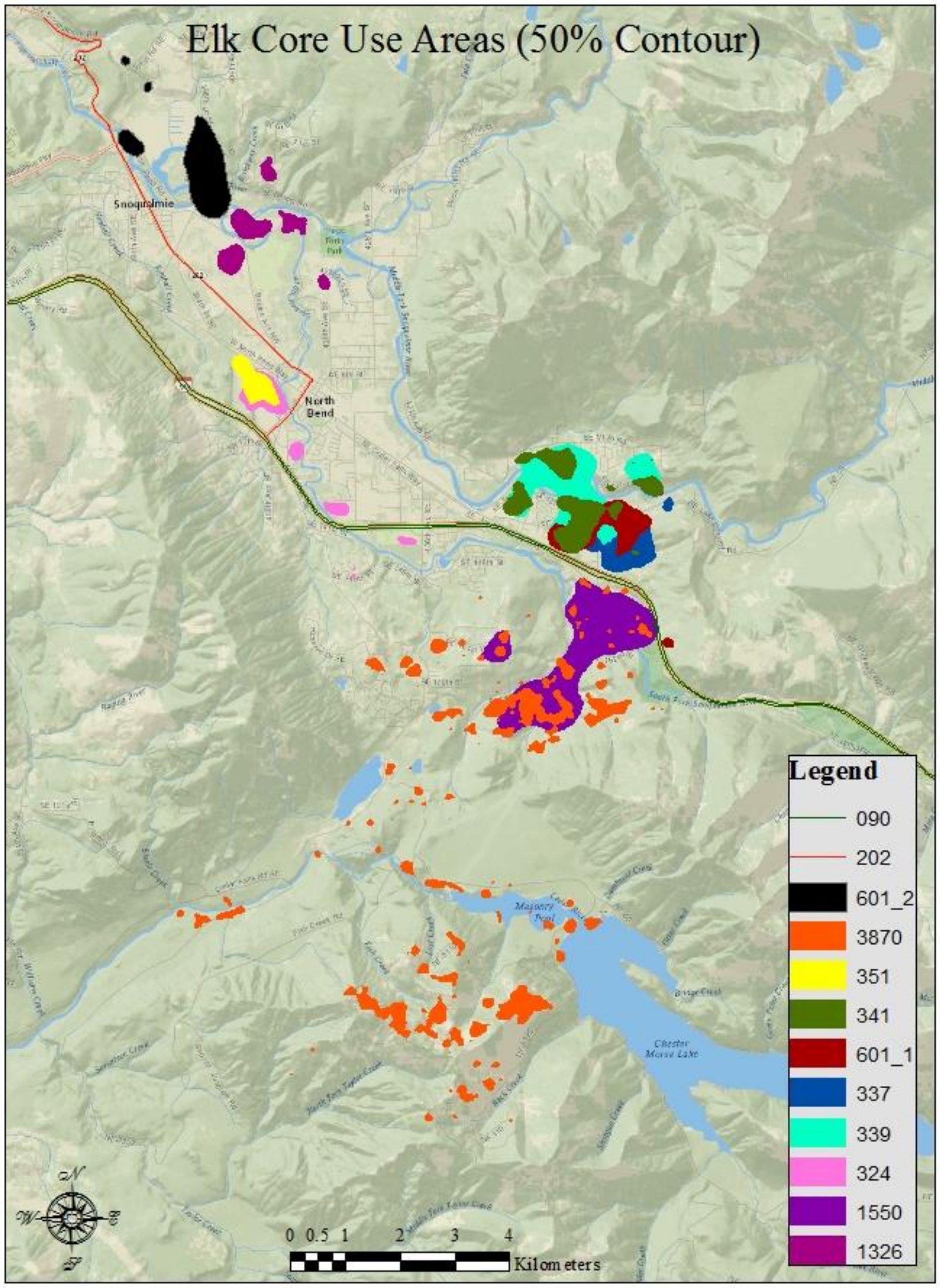

Figure 5. Elk home ranges (50% contour, in km^2) of ten elk in North Bend, WA determined from a Brownian Bridge Movement Model.

Table 5. Estimated resource selection log-likelihood chi-square test statistics for elk in North Bend, WA.

Category	χ^2_{L2}	**Df**	**p-value**
Land Use	11226.90	70	0.001
Road Intensity	153.18	40	0.001
Distance to I-90	28164.64	40	0.001
Distance to I-90: Riparian	642.41	40	0.001
Topographic Position Index	14778.61	50	0.001

Table 6. Estimated resource selection indices for elk in North Bend, WA. $\widehat{\mathcal{W}}_i$ = estimated habitat selection ratio, $se(\widehat{\mathcal{W}}_i)$ = standard error of selection ratio, $\widehat{\mathcal{W}}_i(l)$ and $\widehat{\mathcal{W}}_i(u)$ are Bonferroni -adjusted 95% lower and upper confidence intervals.

Category	**Variable**	**Selection**	$\widehat{\mathcal{W}}_i$	$se(\widehat{\mathcal{W}}_i)$	**Bonferroni Confidence** $\widehat{\mathcal{W}}_i(l)$	**Interval** $\widehat{\mathcal{W}}_i(u)$
Land Use	Developed-	+	1.48	0.07	1.28	1.68
	Developed-	+	3.04	0.09	2.79	3.29
	Developed-Open	+	10.91	0.34	9.99	11.84
	Forest	-	0.61	0.01	0.60	0.63
	Open/Forage	+	15.11	0.31	14.26	15.95
	Riparian	+	2.81	0.11	2.51	3.12
	Wetland	-	0.13	0.02	0.07	0.19
	Open Water	-	0.10	0.05	0.00*	0.24
Road Intensity	Low	+	1.09	0.01	1.08	1.11
	Medium	-	0.44	0.12	0.15	0.73
	High	-	0.10	0.04	0.01	0.19
I-90 Distances	<50 m	-	0.22	0.05	0.08	0.35
	50-250 m	+	2.10	0.10	1.86	2.34
	250-450 m	+	2.60	0.11	2.34	2.87
	450-1000 m	+	2.91	0.06	2.76	3.06
	>1000 m	-	0.67	0.01	0.65	0.69
I-90 Distances: Riparian	<50 m	-	0.04	0.04	0.00*	0.13
	50-250 m	-	0.45	0.06	0.29	0.61
	250-450 m	-	0.62	0.11	0.35	0.88
	450-1000 m	+	2.06	0.17	1.62	2.49
	>1000 m	+	1.30	0.03	1.22	1.37
Topographic Position Index	Ridge	-	0.31	0.01	0.28	0.35
	Upper Slope	-	0.74	0.03	0.66	0.82
	Middle Slope	-	0.53	0.01	0.49	0.56
	Flat Slope	+	3.25	0.02	3.19	3.31
	Lower Slope	-	0.35	0.02	0.31	0.39
	Valley	-	0.28	0.01	0.25	0.32

+ Significant selection above what would be expected by chance.
- Significant selection against what would be expected by chance.
*A zero replaced a negative value, as a proportion cannot take a negative value.

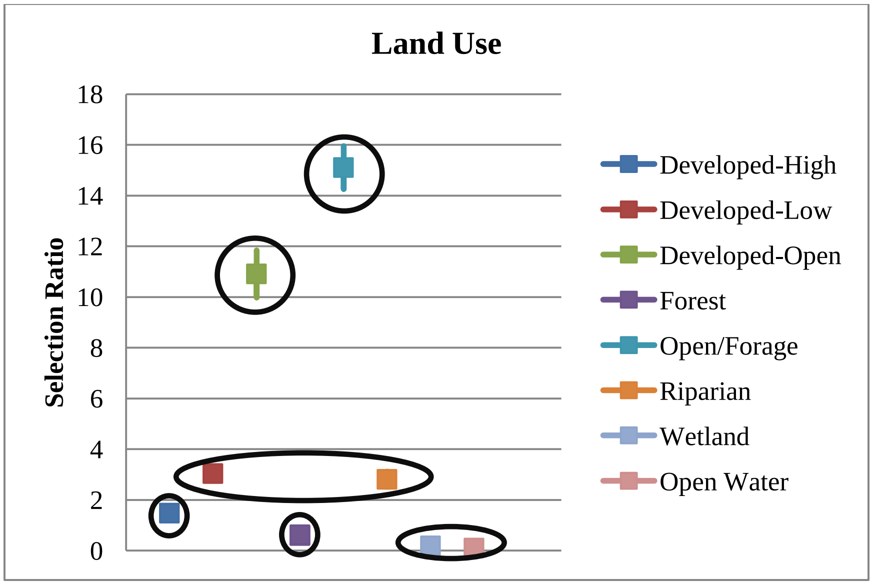

Figure 6. Bonferroni 95% confidence intervals (CI) for selection ratios ($\hat{w}_i$) of land use variables by elk in the project area, North Bend, WA. When 1<CI selection occurred, 1>CI avoidance occurred and when 1 is found within CI neither selection or avoidance occurred.

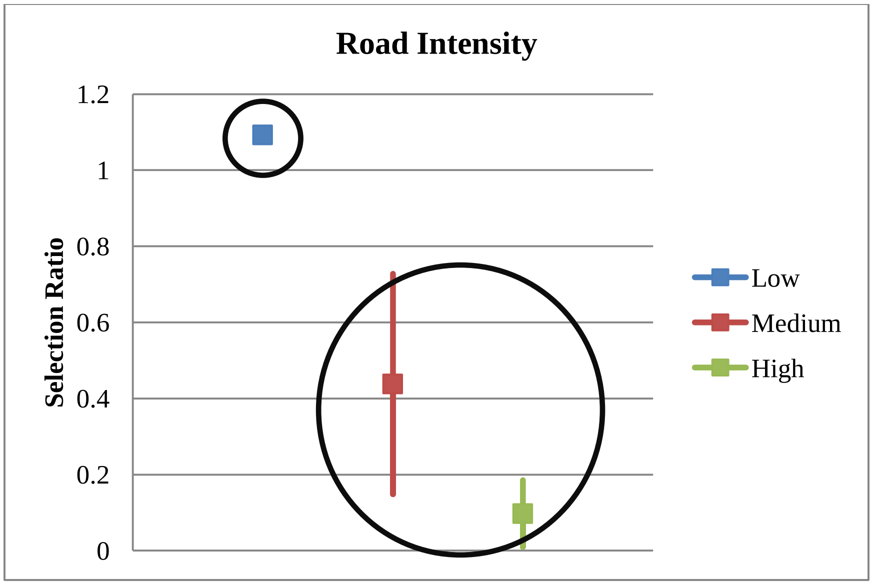

Figure 7. Bonferroni 95% confidence intervals (CI) for selection ratios ($\widehat{w}_i$) of road intensity variables by elk in the project area, North Bend, WA. When 1<CI selection occurred, 1>CI avoidance occurred and when 1 is found within CI neither selection or avoidance occurred.

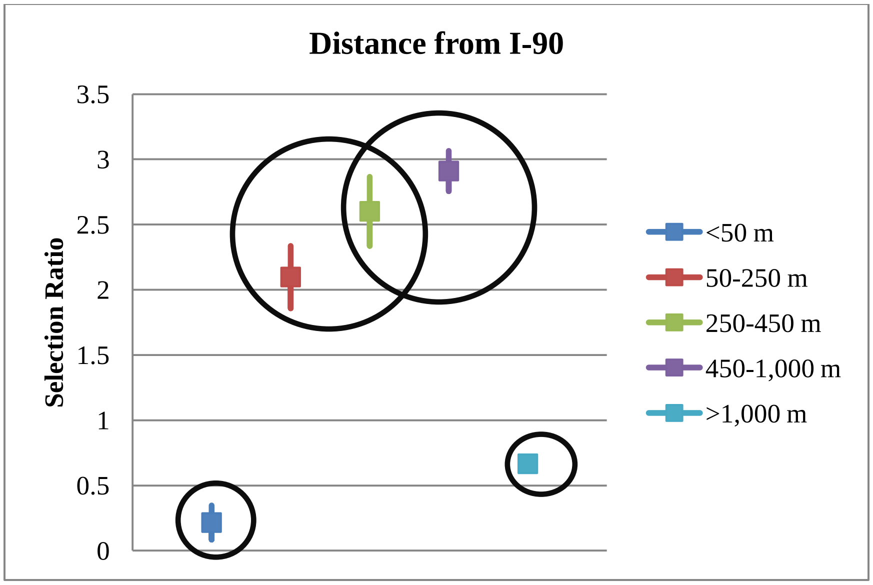

Figure 8. Bonferroni 95% confidence intervals (CI) for selection ratios ($\widehat{\mathcal{W}}_i$) of distances from I-90 by elk in the project area, North Bend, WA. When 1<CI selection occurred, 1>CI avoidance occurred and when 1 is found within CI neither selection or avoidance occurred.

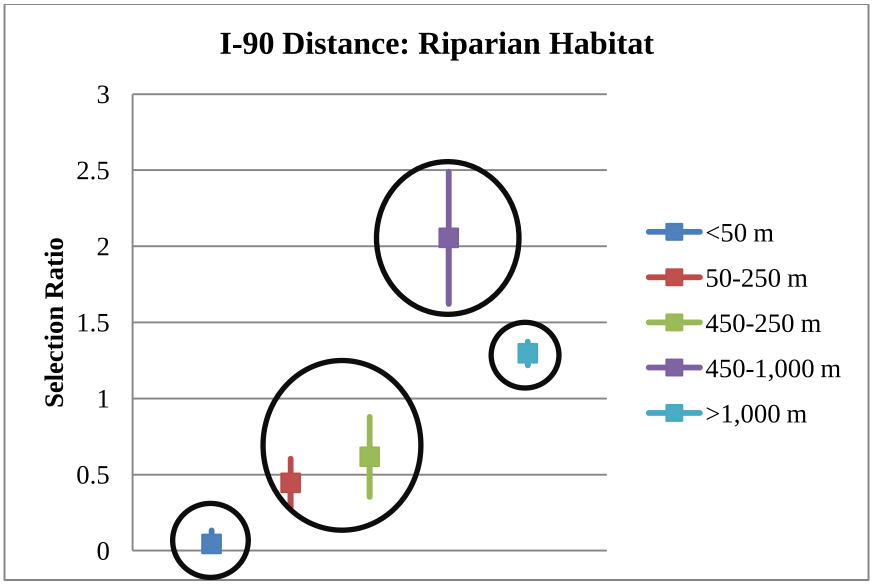

Figure 9. Bonferroni 95% confidence intervals (CI) for selection ratios ($\widehat{w}_i$) of riparian habitat at different distances from I-90 by elk in the project area, North Bend, WA. When 1<CI selection occurred, 1>CI avoidance occurred and when 1 is found within CI neither selection or avoidance occurred.

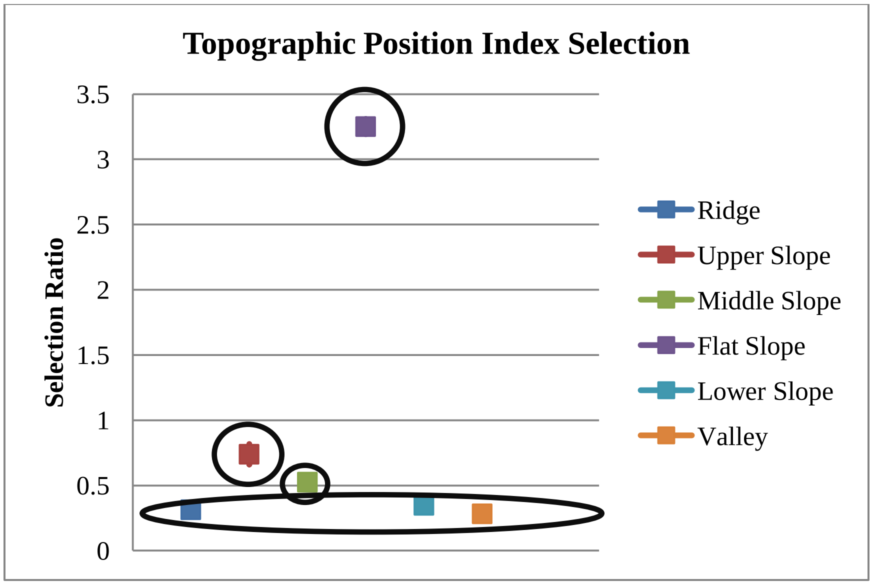

Figure 10. Bonferroni 95% confidence intervals CI for selection ratios ($\widehat{W}_i$) of topographic positions by elk in the project area, North Bend, WA. When 1<CI selection occurred, 1>CI avoidance occurred and when 1 is found within CI neither selection or avoidance occurred.

A. MP 31.6

B. MP 31.6 West Bank

C. MP 39 West Bank

D. MP 38 East Bank

Figure 11. Elk captured by Reconyx game cameras utilizing riparian habitat and bridge structures to cross safely under I-90 near North Bend, WA.

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Appendices

Appendix A. Example of the Brownian Bridge Movement Model R Script for elk 337.

```
##Set the working directory
##My working directory
directory <- "h:/Collars"

setwd(directory)

##Read a csv file into data frame. This is an example for elk collar 337
tele <- read.csv("Collar337.csv", header = TRUE)

## variable for range id (elk) ##this one is best for trajectory example
range <- "337"

## Get the current range from the data frame
tele.range <- subset(tele, tele$AnimalID == toString(range))  ##I modified this,
tele$RangeID references a field in the dataset for subsetting, yours should be
tele@AnimalID

##Get only the coords
tele.range.xy <-
data.frame("x"=tele.range$EastingUTM83,"y"=tele.range$NorthingUTM83)

##Need sp to make spatial objects
library(sp)

##Define projection of coords
proj4string <- CRS("+proj=utm +zone=10 +datum=NAD83 +units=m +no_defs
+ellps=GRS80 +towgs84=0,0,0")

##Make SpatialPointsDataFrame
tele.range.spdf <- SpatialPointsDataFrame(tele.range.xy, tele.range, proj4string =
proj4string , match.ID = TRUE)

plot(tele.range.spdf)  ##Run this to see your data

##DF is used for a number of things including attaching additional attributes to the
trajectory (activity needed by BRB)
tele.range.df <-
data.frame("x"=tele.range$EastingUTM83,"y"=tele.range$NorthingUTM83,
"ObsStepMin"=tele.range$ObsStepMin, "ObsDaText"=tele.range$ObsDaText)
##REmoved variables not needed
```

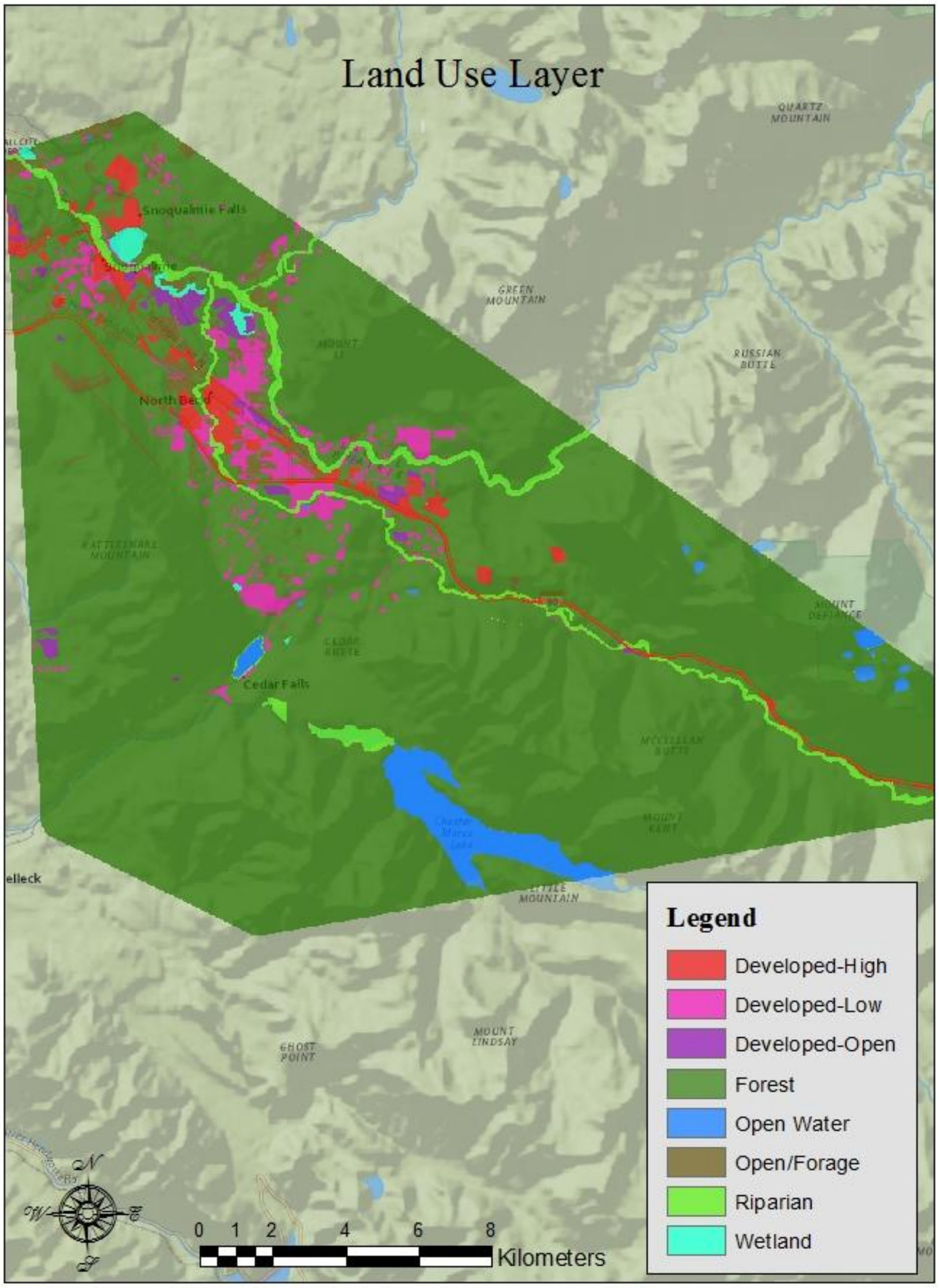
```
##Set up for Elk data

##Home ranges

##First create a bounding box for a mask grid we will project home ranges to.
##Get the bounding box from subset data from exercise above(tele.range) which
##will be modified to make a region of interest grid for calculating homeranges.
##For home range calculations, some packages require evaluation points (KS) while
others require
##a grid as spatial pixels (adehabitat).  In preperation I made several different versions.

##Set the expansion value for the grid and get the bbox
expandValue <- 2500 #This value in meters is used in the calculation
boundingVals <- tele.range.spdf@bbox

##Get the change in x and y and adjust using expansion value
deltaLong <- as.integer(((boundingVals[1,2]) - (boundingVals[1,1])) + (2*
expandValue))
deltaLat <- as.integer(((boundingVals[2,2]) - (boundingVals[2,1])) + (2* expandValue))

##200 meter grid for testing, watch part in BBMM where cell size is set too
gridRes <- 30
gridSizeX <- deltaLong / gridRes
gridSizeY <- deltaLat / gridRes

##Offset the bounding coordinates
boundingVals[2,1] <- boundingVals[2,1] - expandValue
boundingVals[2,2] <- boundingVals[2,2] + expandValue
boundingVals[1,1] <- boundingVals[1,1] - expandValue
boundingVals[1,2] <- boundingVals[1,2] + expandValue

##load raster
library(raster)

##Grid Topology object is basis for sampling grid (offset, cellsize, dim)
gridTopo <- GridTopology((boundingVals[,1]), c(gridRes,gridRes),
c(gridSizeX,gridSizeY))

##Define the projection of the coords
proj4string <- CRS("+proj=utm +zone=10 +datum=NAD83 +units=m +no_defs
+ellps=GRS80 +towgs84=0,0,0")

##Using the Grid Topology  create a SpatialGridClass
```

```
sampGrid <- SpatialGrid(gridTopo, proj4string = proj4string)

##Cast over to SP
sampSP <- as(sampGrid, "SpatialPixels")

##convert the spatialgrid class to a raster
sampRaster <- raster(sampGrid)

##set all the raster values to 1
sampRaster[] <- 1

##Get the center points of the mask raster with values set to 1
evalPoints <- xyFromCell(sampRaster, 1:ncell(sampRaster))

##Here we can see how grid has a buffer around the locations
plot.new()
plot(sampRaster)
points(tele.range.spdf, pch=1, cex=0.5)

##BBMM home range

library(BBMM)

#Run the BBMM using the data frame
BBMM <- brownian.bridge(x=tele.range.df$x, y=tele.range.df$y,
time.lag=tele.range.df$ObsStepMin, area.grid=evalPoints, time.step=10,
location.error=24, max.lag=300)


# Create a data from of x,y,z
BBMM.df <- data.frame("x"=BBMM$x,"y"=BBMM$y,"z"=BBMM$probability)

# Rescale the Probabilities to PDF
#BBMM.df$z <- BBMM.df$z/sum(BBMM.df$z)

##Make a raster from the x, y, z values, watch cell size parameter
tele.range.df.bbmm.raster <- rasterFromXYZ(BBMM.df, res=c(30,30), digits=5)
plot(tele.range.df.bbmm.raster)

library(adehabitatHR)

tele.range.bbmm.px <- as(tele.range.df.bbmm.raster, "SpatialPixelsDataFrame")
tele.range.bbmm.ud <- new("estUD", tele.range.bbmm.px)
tele.range.bbmm.ud@vol = FALSE
```

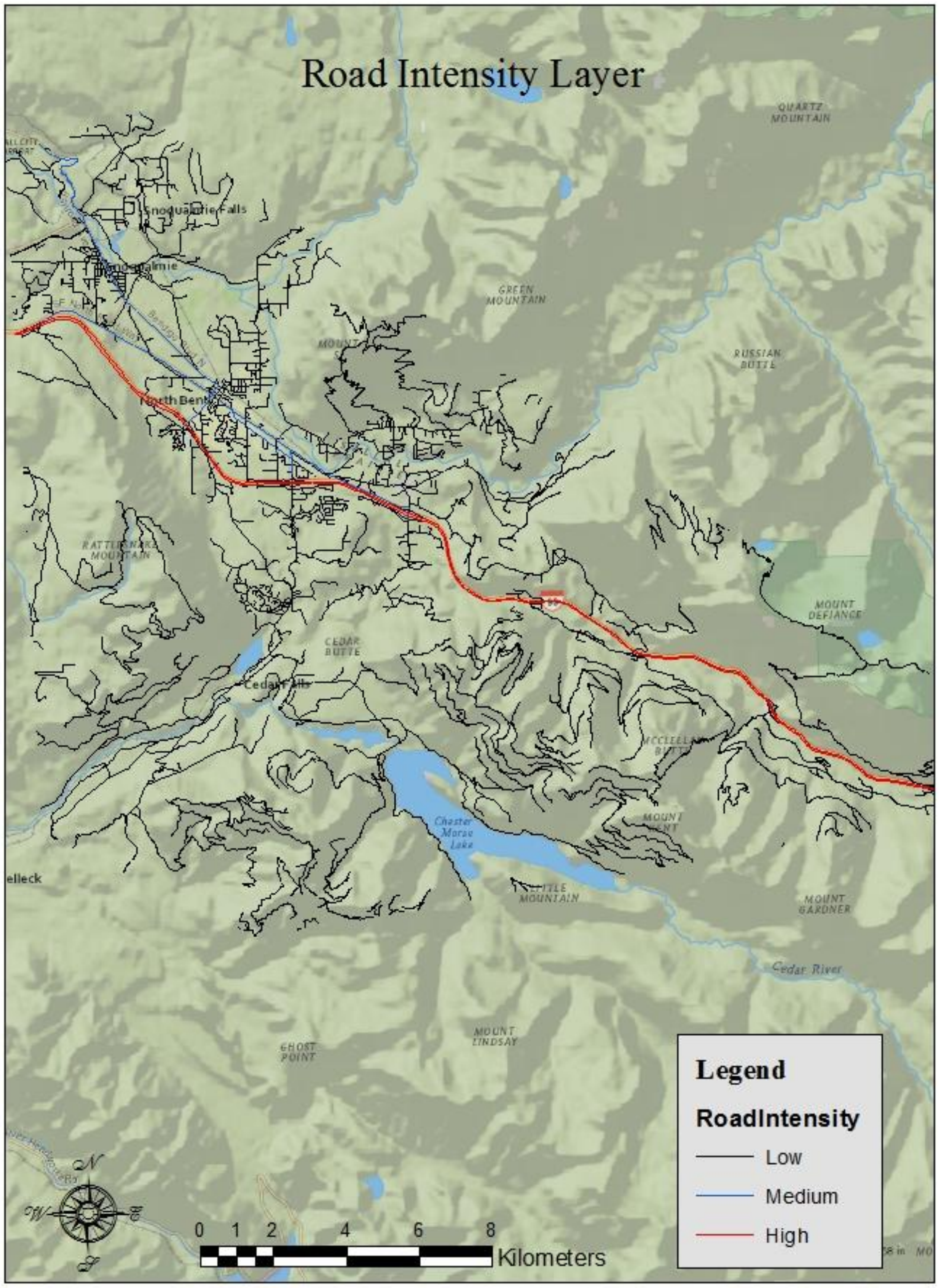
```
tele.range.bbmm.ud@h$meth = "BBMM"

##Convert the UD values to volume
tele.range.bbmm.ud.vol <- getvolumeUD(tele.range.bbmm.ud, standardize=TRUE)

##Create a raster object
tele.range.bbmm.ud.vol.raster <- raster(tele.range.bbmm.ud.vol)

tele.range.bbmm.99vol <- getverticeshr(tele.range.bbmm.ud, percent = 99, ida = NULL,
unin = "m", unout = "ha", standardize=TRUE)
tele.range.bbmm.95vol <- getverticeshr(tele.range.bbmm.ud, percent = 95, ida = NULL,
unin = "m", unout = "ha", standardize=TRUE)
tele.range.bbmm.50vol <- getverticeshr(tele.range.bbmm.ud, percent = 50, ida = NULL,
unin = "m", unout = "ha", standardize=TRUE)


##Put the HR, volume, volume contours, trajectory, and points on a plot
plot.new()
breaks <- c(0, 50, 95, 99)
plot(tele.range.bbmm.ud.vol.raster, col=heat.colors(3), breaks=breaks,
interpolate=TRUE, main="Brownian Bridge Movement Model", xlab="Coord X",
ylab="Coord Y", legend.shrink=0.80, legend.args=list(text="UD by Volume (%)",side=4,
font=2, line=2.5, cex=0.8))
plot(tele.range.bbmm.50vol, add=TRUE)
plot(tele.range.bbmm.95vol, add=TRUE)
plot(tele.range.bbmm.99vol, add=TRUE)
points(tele.range.spdf, pch=1, cex=0.5)


##Write out the BBMM raster for external GIS
writeRaster(tele.range.df.bbmm.raster , paste(directory, "/bbmm_", range, ".tif", sep=""),
overwrite=TRUE)
writeRaster(tele.range.bbmm.ud.vol.raster , paste(directory, "/bbmm_", range, "_vol.tif",
sep=""), overwrite=TRUE)

##Write out the
writeOGR(tele.range.bbmm.99vol, ".", paste("bbmm_vol99_", range, sep=""),
driver="ESRI Shapefile",overwrite_layer=TRUE)
writeOGR(tele.range.bbmm.95vol, ".", paste("bbmm_vol95_", range, sep=""),
driver="ESRI Shapefile",overwrite_layer=TRUE)
writeOGR(tele.range.bbmm.50vol, ".", paste("bbmm_vol50_", range, sep=""),
driver="ESRI Shapefile",overwrite_layer=TRUE)
```

Appendix B. Schedules for collared elk in North Bend, WA.

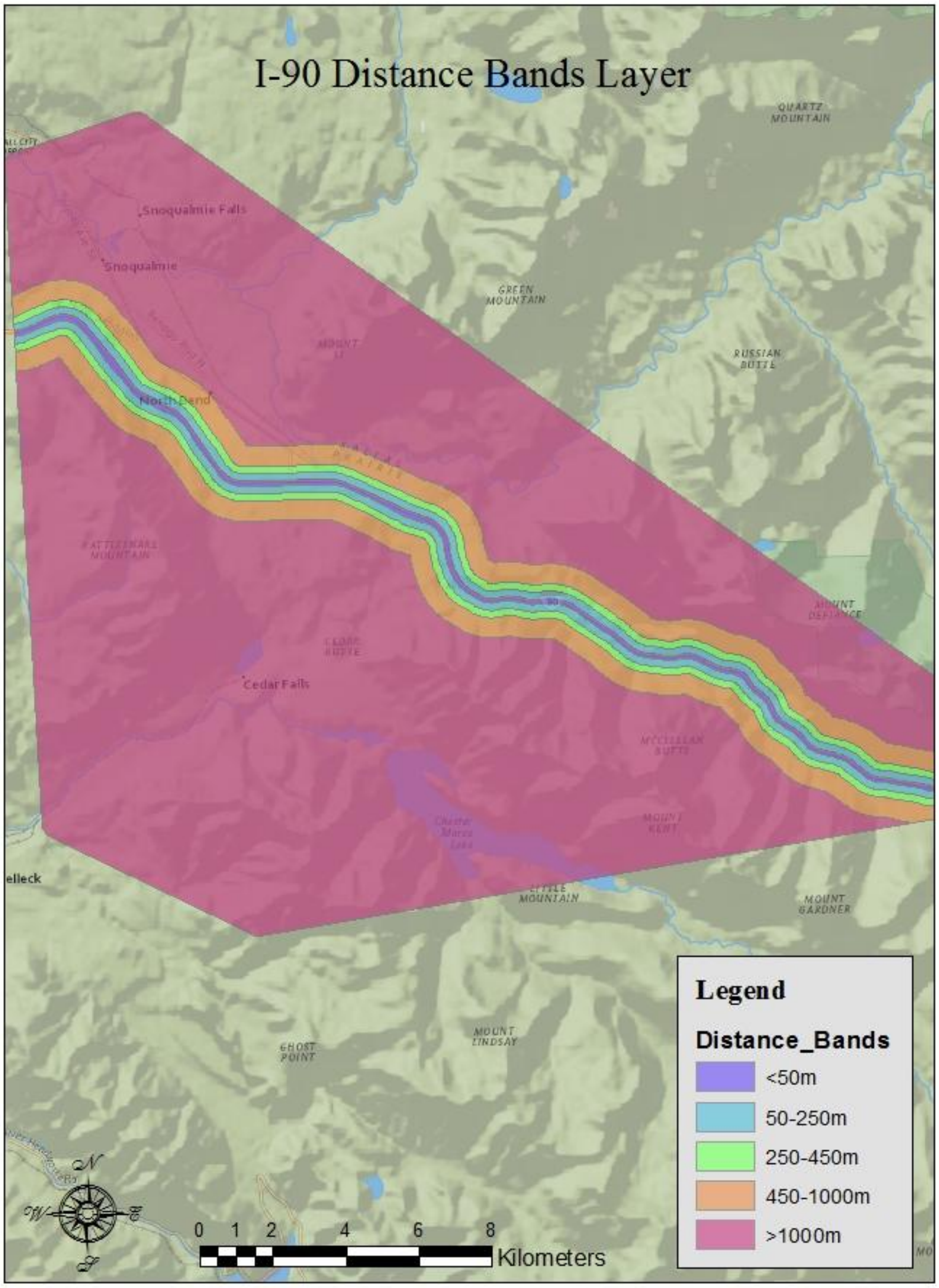
Elk Number	Fixes Per Day	Collar Schedule
601_2	5	Every 5 hrs
324	6	Every 1.5 hrs, 3 times after 12:00am and 12:00pm
341	6	Every 1.5 hrs, 3 times after 12:00am and 12:00pm
351	6	Every 1.5 hrs, 3 times after 12:00am and 12:00pm
339	6	Every 2hrs from 4pm to 12:00am then every hour from 12:01am to 2:00am
1326	7	Every 2.5 hrs
337	7	Every 2.5 hrs
601_1	7	Every 2.5 hrs
1550	12	Every 2 hrs
3870	29	Every 50 mins



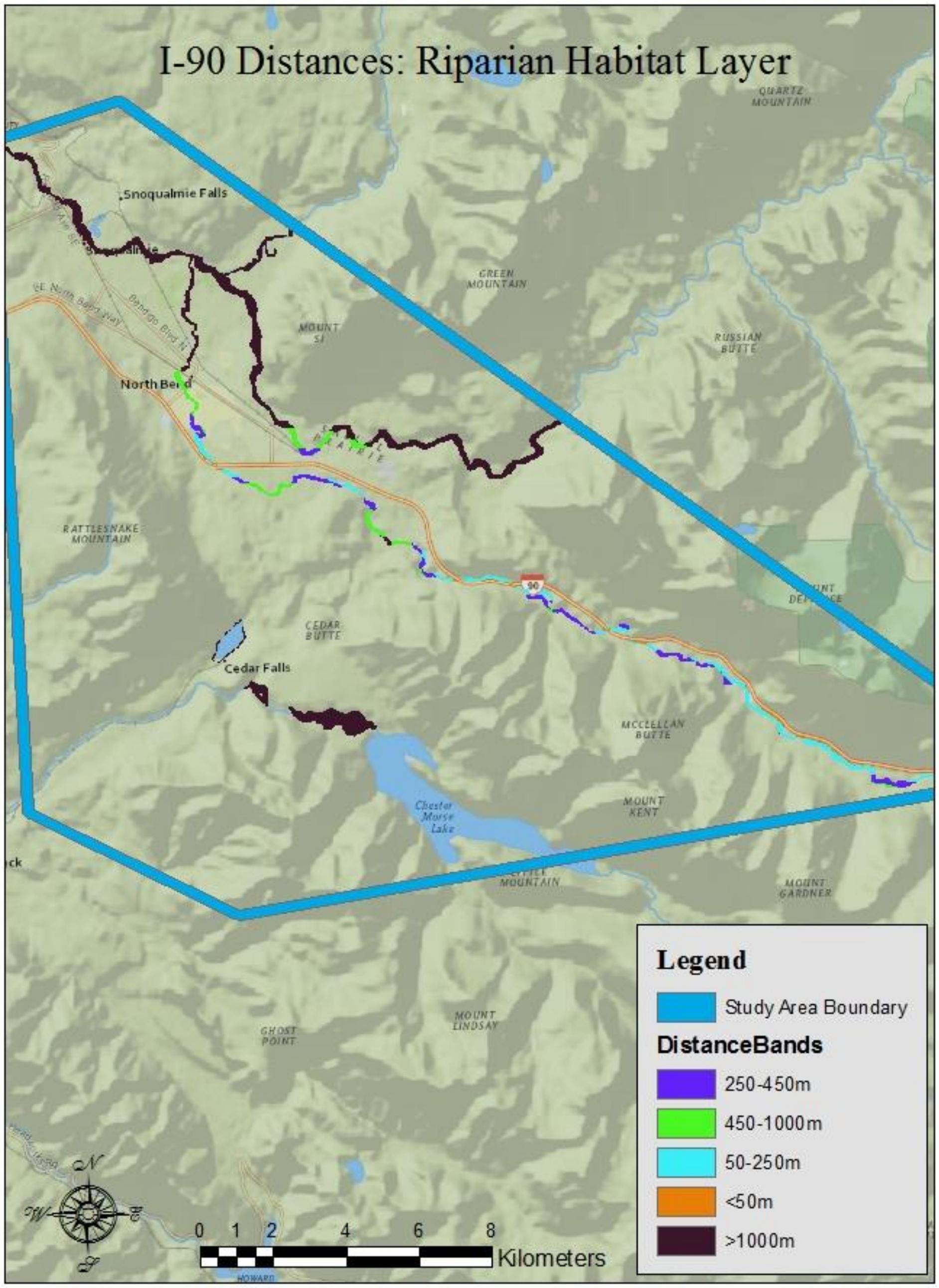
Appendix C. Land use layer created in ArcGIS 10.



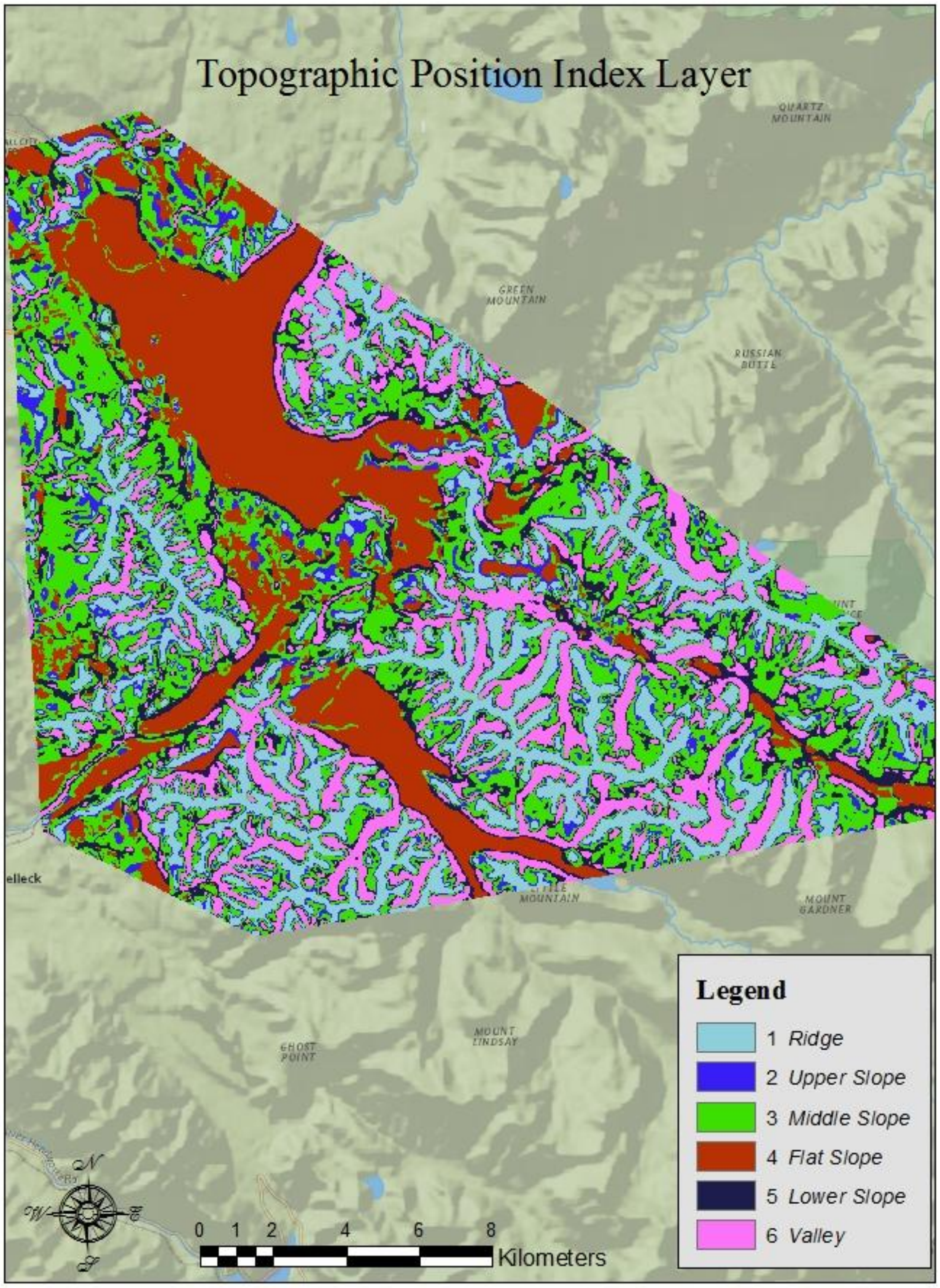
Appendix D. Road intensity layer created in ArcGIS 10.



Appendix E. I-90 distance band layer created in ArcGIS 10.



Appendix F. Riparian habitat at different distance bands from I-90 layer created in ArcGIS 10.



Appendix G. Topographic Position Index layer created in ArcGIS 10.