US 20, Island Park Wildlife Collision Study

an examination of

Road Ecology in the Island Park Caldera:
Elk and Moose Migrations Across US Highway 20

Final Report

Alyson M. Andreasen, Renee G. Seidler, Shane Roberts, Hollie Miyasaki, Pete Zager, Mark Hurley, Scott Bergen, Daryl Meints, Paul Atwood, Joel Berger, Tim Cramer, and Jon P. Beckmann

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TABLE OF CONTENTS

Page

US 20, ISLAND PARK WILDLIFE COLLISION STUDY
AN EXAMINATION OF
ROAD ECOLOGY IN THE ISLAND PARK CALDERA:
ELK AND MOOSE MIGRATIONS ACROSS US HIGHWAY 20
FINAL REPORT
TABLE OF CONTENTS (CONT.)

US 20, ISLAND PARK WILDLIFE COLLISION STUDY
AN EXAMINATION OF
ROAD ECOLOGY IN THE ISLAND PARK CALDERA:
ELK AND MOOSE MIGRATIONS ACROSS US HIGHWAY 20
FINAL REPORT
TABLE OF CONTENTS (CONT.)

LIST OF FIGURES

Page

LIST OF FIGURES (CONT.)

Page

LIST OF FIGURES (CONT.)

Page

LIST OF FIGURES (CONT.)

LIST OF FIGURES (CONT.)

LIST OF FIGURES (CONT.)

Page

LIST OF TABLES

LIST OF TABLES (CONT.)

Page

LIST OF ACRONYMS

BBMM	Brownian bridge movement model
BLM	Bureau of Land Management
GIS	Geographic Information System
GPS	Global Positioning System
GYE	Greater Yellowstone Ecosystem
HoRAE	Home Range Analysis and Estimation
IDFG	Idaho Department of Fish and Game
I-15	Interstate 15
IFWIS	Idaho Fish and Wildlife Information System
ITD	Idaho Transportation Department
MP	Mile post
NGO	Non-Governmental Organization
OpenJUMP	Jump Unified Mapping Platform freeware
RSF	Resource Selection Function
UHF	Ultra High Frequency
USFS	United States Forest Service
US 20	United States Highway 20
VHF	Very High Frequency
WCS	Wildlife Conservation Society
WGA	Western Governors' Association
WVC	Wildlife Vehicle Collision
YNP	Yellowstone National Park

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EXECUTIVE SUMMARY

Roads, highways, fencing, and other infrastructure associated with expanding transportation corridors in the western U.S. can be detrimental to wildlife, particularly through direct effects on migration and dispersal (Beckmann et al. 2010). Highways and associated traffic can impact wildlife populations by: 1) decreasing habitat amount and quality; 2) increasing mortality from collisions with vehicles; 3) limiting access to resources; and 4) fragmenting populations into smaller and more vulnerable subpopulations (Jaeger et al. 2005). This is particularly concerning for wildlife populations that make long-distance migration movements, such as elk (*Cervus elaphus*) and moose (*Alces alces*), as highways can sever migration routes and potentially lead to population loss in localized regions (Beckmann et al. 2010). Additionally, millions of vehicle collisions with wildlife occur annually in North America, causing nearly $9 billion dollars in property damage, over 200 human fatalities, and thousands of human injuries, in addition to countless wildlife fatalities (Huijser et al. 2008).

One highway that may be impacting ecological processes for ungulates (e.g., long-distance migration), is U.S. Highway 20 (US 20) in southeast Idaho in the western portion of the Greater Yellowstone Ecosystem (GYE; see Figure ES.1). This highway bisects known migration routes for both elk and moose, along with other species. Migrating elk and moose may cross US 20 twice yearly (spring and fall) as they move between summer range in the Island Park Caldera of the Greater Yellowstone Ecosystem, and winter range on the Snake River Plain near the St. Anthony Sand Dune Special Recreation Management Area (Figure ES.1). Additionally, non-migratory moose also cross US 20 numerous times throughout their daily and yearly movements. Unfortunately, elk and moose die

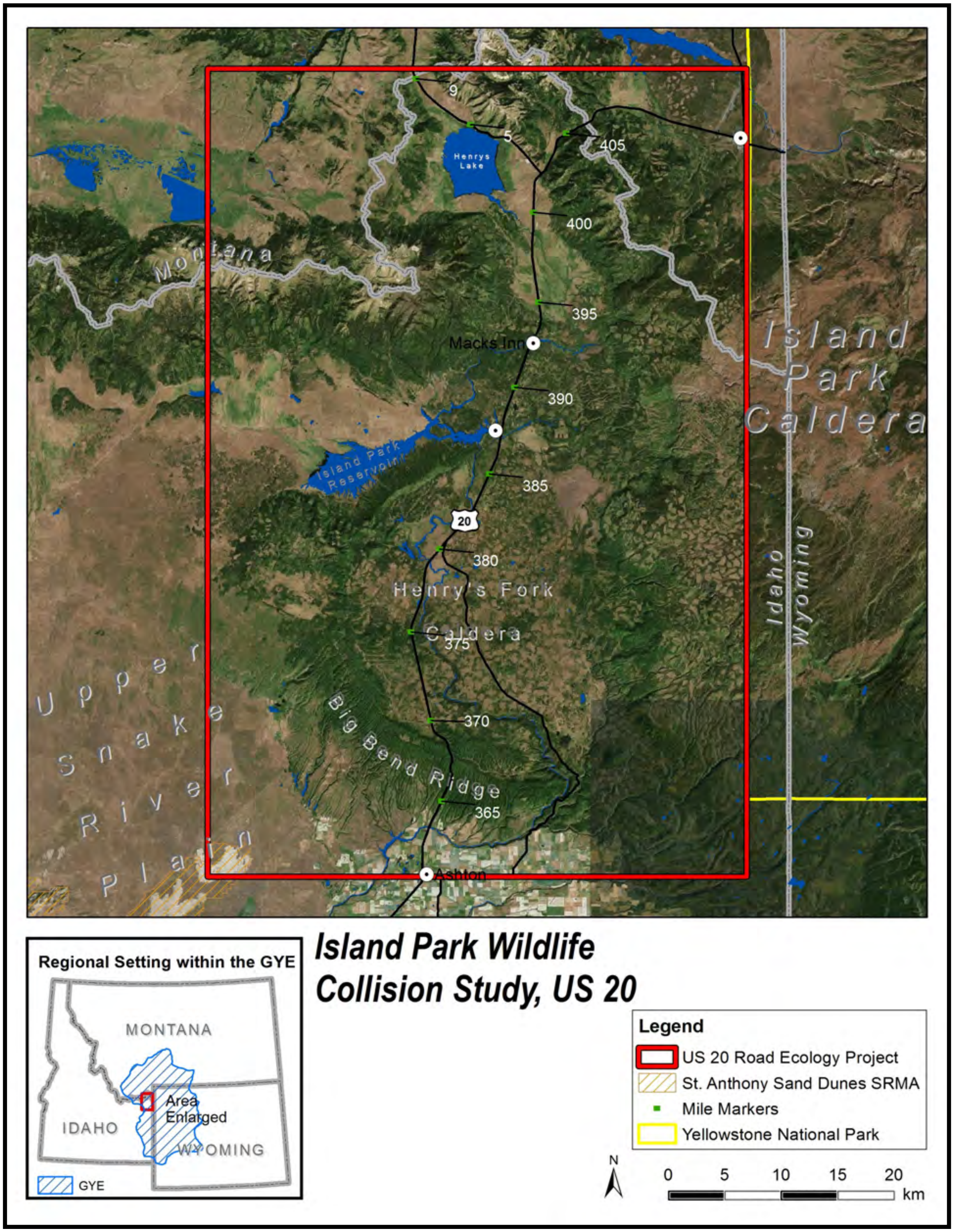

Figure ES.1. The Island Park Wildlife Collision Study area is in southeastern Idaho along U.S. Highway 20 and beyond.

every year due to traffic collisions while attempting to cross this highway. The impact of highway crossings on the persistence of regional ungulate populations is of substantial concern (e.g., Beckmann et al. 2012), as is the safety of the traveling public.

The Wildlife Conservation Society (WCS), Idaho Department of Fish and Game (IDFG), and Idaho Transportation Department (ITD) together examined the impacts of US 20 on seasonal and daily movements and habitat use of both elk and moose. The major goal of this project was to identify highway crossing locations, patterns of resource selection at those crossing locations, and timing of crossings (e.g., daily and seasonal). Further, we were interested in understanding the habitat parameters (e.g., habitat type, terrain ruggedness, amount of horizontal concealment cover, distance to water) and features associated with roads (e.g., number of lanes, speed limit, road width) that both elk and moose were using when crossing highways. Finally, we examined the movement corridors connecting winter and summer range for migrating elk and moose. This cooperative project was devised to help inform management plans to reduce wildlife-vehicle collisions and wildlife mortality while maintaining habitat connectivity.

Our study began in 2010 with the capture and collaring of adult, female elk and moose during winter. We collared 79 animals total: 37 migratory elk and 42 migratory and non-migratory moose were collared with multi-year GPS collars during two capture periods in 2010-2012. The first captures were completed in December 2010 and the second captures were completed December 2 – 3, 2011 and February 26, 2012, to redeploy collars that dropped or were recovered from deceased animals.

During the course of the study from December 2010 until December 2013, 15 moose crossed US 20 a total of 354 times. When examining only those locations collected during

30-minute GPS collar intervals, non-migratory moose (year-round residents of the Island Park Caldera) made the majority of the crossings (*n* = 120) and migratory moose made fewer crossings (*n* = 13) of US 20. In contrast to moose, all elk were migratory and made 152 total crossings of US 20. When examining only those locations collected during 30-minute GPS collar intervals, elk crossed US 20 a total of 57 times. However, for both elk and moose, not all individuals crossed US 20.

Key findings

For elk, non-migratory and migratory moose, 2-point Brownian Bridge movement models (BBMM) and resource selection function (RSF) models demonstrated there were multiple specific locations along US 20 and Highway 87 where the highest probability of road crossings were similar between elk and moose. These specific areas were:

1. on Highway 87 from the junction with US 20 to the north shore of Henry's Lake between mile post 0-5,
2. on US 20 in the vicinity of the Valley View RV Park Campground to north of the junction with Highway 87 from mile post 402-405,
3. on US 20 just north of the junction with Sawtelle Peak Road near mile post 394,
4. The relatively open flats along US 20 south of Island Park Reservoir near the bend in the Henry's Fork of the Snake River when the river is just west of US 20 (i.e., just south of the Buffalo Run RV Park and Cabins continuing to the south of Trout Hunter Lodge) from mile post 382-384,
5. US 20 near Railroad Ranch and again where US 20 crosses the river at Osborne Bridge near mile post 381 and 379, and

6. south of Swan Lake to the bridge north of Ashton between mile posts 365-376.

Thus, these six areas are the sections of US 20 and Highway 87 we recommend to target initially for mitigation to achieve the greatest impacts for both species. However, there are two additional locations that we suggest be a target for mitigation given their importance for non-migratory moose. Non-migratory moose were responsible for the largest number of crossings of US 20 in this study and thus likely were more susceptible to wildlife-vehicle collisions (WVCs). These regions include:

7. where US 20 crosses the Henry's Fork of the Snake River at Mack's Inn from mile post 392-393, and
8. on US 20 where it crosses the Buffalo River south of the Island Park city offices, from mile post 386-388.

There is one additional region of high probability road crossing by elk that should be considered for mitigation. This area is:

9. the flats along US 20 just west and north of Sheep Falls, from mile post 370-376.

We do recognize that these areas represent the locations of the highest probability of road crossings by these species and do *not* represent the only locations that elk or moose (non-migratory or migratory) cross US 20. In fact, the entire stretch of US 20 in the study area has some probability of crossing by both species associated with each section and thus eliminating all WVCs would likely require mitigation efforts on the level of Banff National Park along the Trans-Canada Highway (see Ford et al. 2010). However, based on the locations described above, we offer more targeted recommendations of how to mitigate the impact of US 20 on ungulate movements.

CHAPTER 1

SEASONAL MOVEMENTS, DISTRIBUTION, AND MIGRATION IN RELATION TO ROADS

INTRODUCTION

Dwight D. Eisenhower is credited with leading the creation of the national system of interstate highways across the United States in the 1950s, an infrastructure that formed the basis of today's commerce and travel. These interstate highways and the many other highways and roads constructed across the United States and the world since then, were largely built without consideration of impacts on wildlife and biodiversity (e.g. see Forman et al. 2003). However, since the 1970s, society has been aware of the effects our transportation systems have on our air and water quality. Today, we are increasingly conscious of the adverse effects roads have on our wildlife and fish populations. While more traffic, new road construction, and road maintenance continue to expand, we are now more able to address wildlife and biodiversity conservation that were once largely overlooked. Currently, North Americans are more aware than in the time of Eisenhower about conservation of wildlife and the large landscapes they need for survival. These concerns are coupled with a growing interest in conservation tools and applications for addressing the diverse issues linking transportation, ecology and local communities. We have an opportunity to bring emerging science, policy and innovations into the standard transportation practices of planning, design and construction.

Road-wildlife mitigation projects are challenging as decisions must be made as to which species should benefit. Given funding constraints and design limitations, it is unlikely that a project will benefit all possible species. The challenge is even more daunting when one considers that many road mitigation projects for wildlife have to be targeted at existing roads. In the past, roads were generally placed in the easiest location due to terrain and soil constraints on construction, logistics and costs; the needs of wildlife were rarely considered. This is particularly true for our federal and state highway systems initiated in the prior century. As a result, many roadways sit in what once were the best habitats for wildlife, such as in valley bottoms, along and crossing streams or rivers. Today we are left trying to redesign and/or mitigate existing roadways to restore connectivity for wildlife. Where new roads are being constructed or older roads are being modified, there are increasing opportunities to consider wildlife early and throughout the decision-making process.

While the field of road ecology has expanded in recent years to document the consequences of roads on wildlife, relatively little information is yet available about how wildlife species navigate lands bisected by roadways and how they cross roads (Transportation Research Board 2002; Forman et al. 2003). Such gaps in knowledge impede prudent management and conservation. With increasing awareness and knowledge, transportation and land management agencies have the opportunity to make more informed decisions about where and how roads are designed and retrofitted to better accommodate wildlife needs.

Long-distance migrations have declined globally in response to overharvest, anthropogenic barriers, and habitat loss (Bolger et al. 2008, Wilcove and Wikelski 2008, Seidler et al. 2014). Harris et al. (2009) called for scientific enumeration of extant paths, an analysis of threats, and population objectives in order to protect migrations globally.

Spatially explicit modeling techniques have provided important information for site-specific management of migratory animals, and have numerous implications for conservation of migration on a broad scale (e.g., Saher and Schmiegelow 2005, Horne et al. 2007, Sawyer et al. 2009, Seidler et al. 2014). Roads represent significant anthropogenic barriers or impediments to migration for large ungulates across the globe including the North American continent, with the GYE containing some of the longest remaining migrations for several species of ungulates, including moose (*Alces alces*; Berger 2004).

An estimated 1 to 2 million collisions between vehicles and large animals occur every year in the United States and that number is increasing (Huijser et al. 2008). Wildlife-vehicle collisions (WVCs) pose a significant threat to human safety and wildlife (Hughes et al. 1996, Forman et al. 2003, Nelson et al. 2006, Beckmann et al. 2010). WVCs cause approximately 200 human fatalities and over 26,000 injuries annually (Conover et al. 1995, Huijser et al. 2008). Collisions with larger animals are more likely to result in human injury. For example, in one study from Maine, moose accounted for 82% of WVCs resulting in a human fatality (Huijser et al. 2008). Thus, mitigating WVCs with large mammals is of great importance, particularly in systems such as the GYE where many of the world's longest migrations for a wide variety of large bodied species occur (see Berger 2004).

WVCs also carry significant economic costs; over $8.3 billion are spent annually across North America (Huijser et al. 2008.) The Idaho Department of Fish and Game (IDFG; Gregg Servheen, personal communication) estimates the total cost of wildlife-vehicle collisions is $8,000 per deer, $17,500 per elk, and $28,600 per moose (estimates include vehicle repair, consumptive and non-consumptive recreational loss of the animal, removal of the carcass, police investigation, and human injury or fatality). These figures are very similar to national estimates calculated by Huijser et al. (2008). Besides the direct costs of each WVC, small local communities of Western states benefit from hunting, tourism, and recreation dollars brought in by the diverse and abundant wildlife populations of the West (Western Governors' Association 2008).

Roads can greatly reduce the size of animal populations (Fahrig and Rytwinski 2009). In addition to mortality caused by WVCs, roads reduce available habitat and impede animal movement, which in turn can subdivide populations, reduce gene flow, and hinder migration (Trombulak and Frissell 2000, Forman et. al 2003, Coffin 2007, Harris et al. 2009, Beckmann et al. 2010). The Western Governors' Association's (WGA) 2008 "Wildlife Corridors Initiative" recognizes that, "healthy fish and wildlife populations … contribute to the West's quality of life and economic well-being. Important wildlife movement corridors and crucial wildlife habitats within these landscapes are critical to maintaining these Western qualities." The authors of that report also recognize that roads can be an impediment to wildlife and WVCs pose a challenge to departments of transportation. To address these challenges, the WGA Transportation Working Group recommends "the preservation of Wildlife Corridors and Crucial Habitat [be made] priorities for transportation planning, design and construction."

Objectives of the study

In 2009, the Idaho Transportation Department (ITD) secured funding from the Federal Highway Administration to study wildlife corridors, habitat connectivity, and WVCs along United States Highway 20 (US 20) in southeast Idaho, where the Henry's

Fork Caldera serves as summer range for hundreds of elk and moose (Figure 1.1). Many of these animals cross US 20 either daily as residents of the region or seasonally as they migrate from summer areas in the caldera to winter range. In crossing this busy highway, they risk collision with vehicles.

The overarching aim of this 3-year study was to "[conduct] research to improve the safety of the traveling public and to reduce vehicle-caused wildlife mortality while maintaining habitat connectivity" (Memorandum of Understanding between ITD, the Wildlife Conservation Society [WCS], and IDFG, 2009, amended 2010, key number 11963). In this study, we collected data on 2 species, elk (*Cervus elaphus*) and moose (*Alces alces*), which both exhibit: 1) long-distance migrations in our study area; and 2) significant potential to cause human injury or even death in WVCs because of their large body size.

ITD, WCS, and IDFG specified in an interagency Memorandum of Understanding 6 objectives intended to determine where, when, and why elk and moose cross US 20. The objectives were:

1. Identify areas that ungulates (elk and moose) cross or attempt to cross US Highway 20 between Ashton Hills and Island Park.
2. Define and characterize habitat and road traffic at specific locations where elk and moose consistently cross or attempt to cross US 20.
3. Evaluate the effects of variables such as topography, road parameters and vegetative cover on crossing/attempted crossing locations and frequency.
4. Determine whether subject ungulates are residents or migrants, and how that status affects crossing location and frequency.

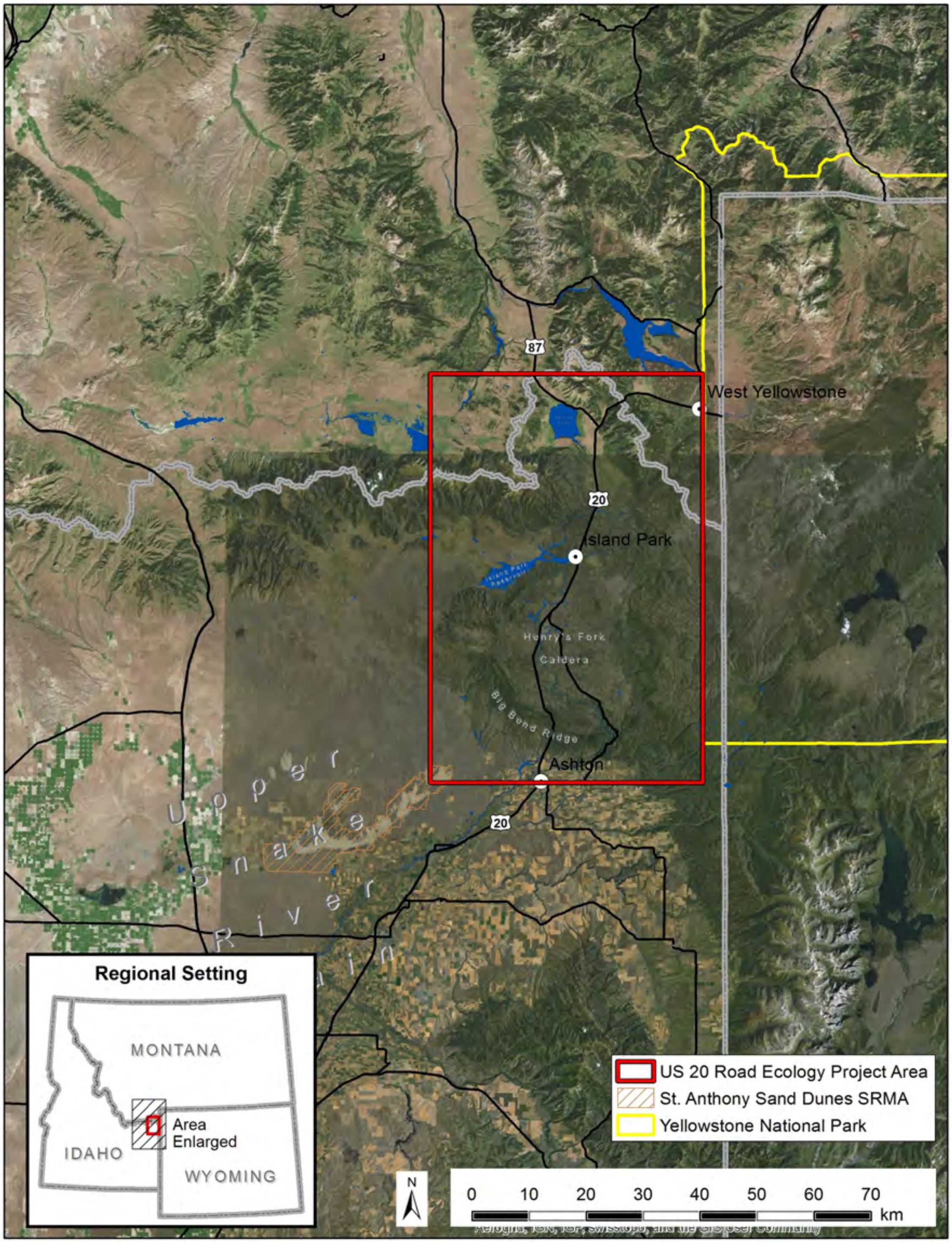

Figure 1.1. The study area along the western edge of the Greater Yellowstone Ecosystem is highlighted in red.

5. Determine seasonal and daily patterns of ungulate crossings and attempted crossings.
6. Document ungulate mortality associated with US 20, including time and cause of death, location, habitat and traffic features.

Species-specific models examining selection for the habitat parameters (e.g., habitat type, terrain roughness, amount of horizontal concealment cover, distance to water) and features associated with roads (e.g., number of lanes, speed limit, road width) that elk and moose select when crossing US 20 can be found in Chapter 2. In Chapter 1, we present data on the larger landscape-perspective to understand the potential impacts of US 20 on ungulate movement ecology in the study area. Also here in Chapter 1 we summarize the overall objectives of the study, methods for data collection, seasonal movement patterns (i.e., defining migration paths using spatially explicit models), seasonal ranges (i.e., summer and winter range), seasonal and daily movements across US 20, and mortality data for both species.

METHODS

Study system

The study area was centered on the city of Island Park, Fremont County, Idaho. The focal segment of US 20 runs from the Henry's Fork River at the foot of Big Bend Ridge to the Idaho-Montana border, specifically mile-markers 364-406 (Figure ES.1). Most of this stretch transects the Ashton/Island Park Ranger District of the Caribou-Targhee National Forest and runs through the western edge of the Henry's Fork Caldera. The caldera floor rises to 1,900 m, punctuated by a few higher buttes, and is covered largely by lodgepole pine (*Pinus contorta*) forests with occasional grassland-sagebrush openings (Brown 1985). Riparian willow flats and streams intermittently intersect US 20, as do small (< 1-5 km^2) centers of human development. In addition to US 20, there are several other paved roads (e.g., Idaho State Highway 87) including numerous roads in Island Park and dirt/gravel US Forest Service roads in the caldera. Average temperatures range from -5 to 11 C, average annual precipitation is 74 cm and average annual snowfall is 214 cm (Western Regional Climate Center 2011).

The caldera serves primarily as summer grounds for elk and moose, although a previously unknown percentage of the moose population is non-migratory. The migratory periods for elk and migratory moose occur approximately in late November (fall migration) and between May and June (spring migration), granting variation among individuals. Wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), black bears (*U. americanus*), and mountain lions (*Puma concolor*) live in the caldera but are relatively uncommon on ungulate winter grounds.

Elk and moose migrate approximately 50-70 km between the caldera summer range and winter range (1500 m elevation) west of St. Anthony, Idaho below Big Bend Ridge (Figure 1.1). This area of the Snake River Plain is characterized as high desert shrub steppe dominated by sagebrush (*Artemisia* spp, Brown 1985, Miller et al. 2011). Land managers are the Bureau of Land Management, state of Idaho, the Shoshone-Bannock tribe, and private entities (Figure 1.2). Most Bureau of Land Management lands in the region are closed to entry in the winter (1 January -1 May) due to being designated critical winter range for various ungulates (elk, moose, mule deer [*Odocoileus hemionus*], and pronghorn [*Antilocapra americana*]).

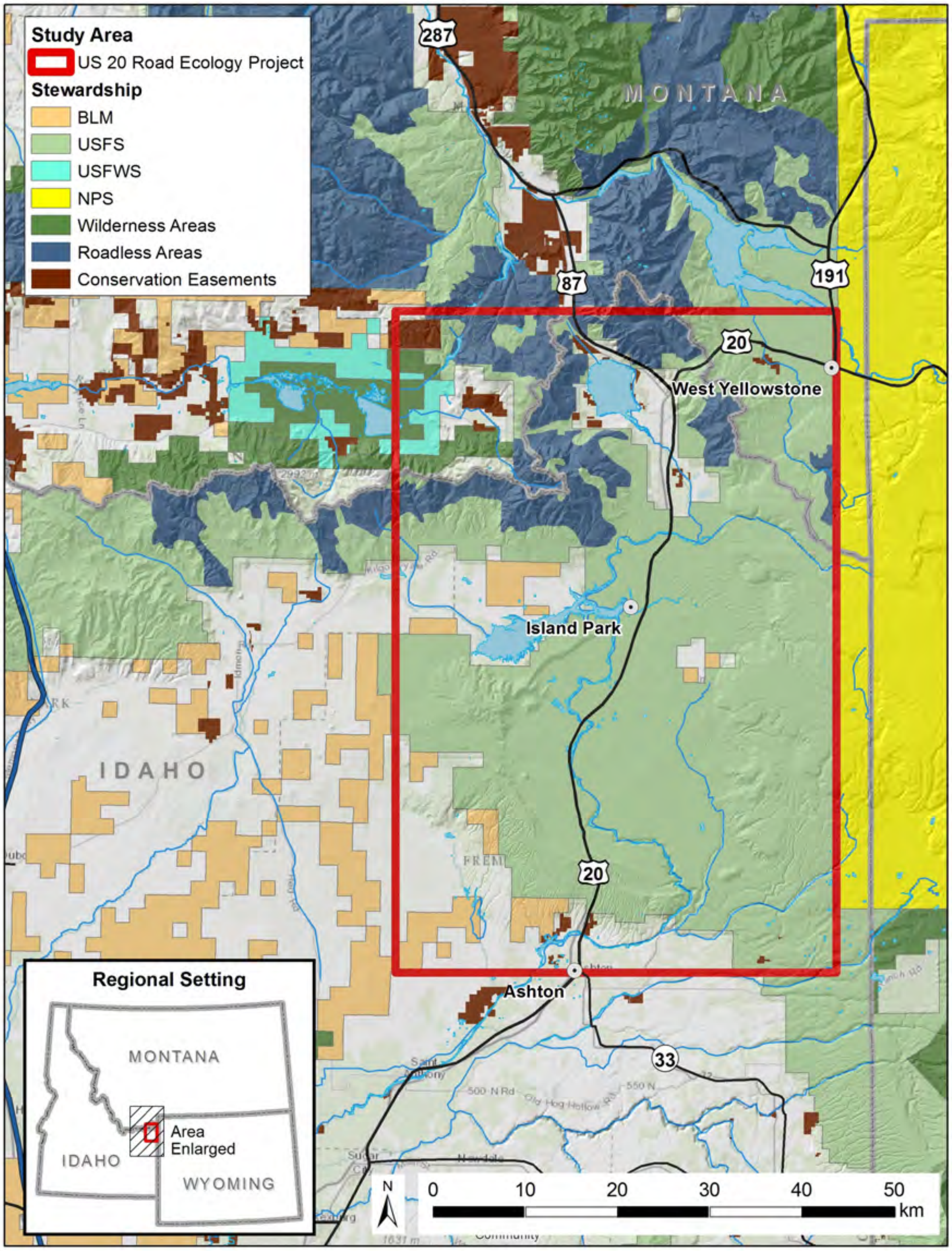

Figure 1.2. Land ownership in project study area examining elk and moose road ecology, 2010-2013.

Data collection

Animal capture and telemetry

The movements of elk and moose were tracked using 60 remotely downloadable global positioning system (GPS) collars (Lotek Ltd, Newmarket, Ontario, Canada, model 4400M). Thirty of these collars were sized to fit elk and 30 to fit moose. Moose collars were initially targeted to 15 migratory moose and 15 moose that reside in the Island Park area year-round. Elk and migratory moose (identified by their presence on winter range in the Snake River Plain) were captured from a helicopter by net-gun (elk) or darting (moose). Moose were immobilized at a dose of ~1.5 ml of 3 mg/ml Carfentanil citrate per dart and the antagonist, Naltrexone hydrochloride, was used to reverse the effects. Suspected non-migratory moose were identified by their presence on the Henry's Fork Caldera in January and February. We identified moose as migratory if they had distinct summer and winter ranges and as non-migratory if they had overlapping seasonal ranges (Figure 1.3). Due to heavy forest cover, non-migratory moose were captured by ground darting. Capture methods are detailed in IDFG Standard Operating Procedures (IDFG on file) and the American Society of Mammalogists (Gannon et al. 2007).

A total of 79 animals were collared for this study; 37 elk and 42 moose (Figure 1.4). The initial capture effort in which 58 collars (30 elk and 28 moose) were deployed took place in December 2010-February 2011. A second capture effort was conducted 2-3 December 2011 and 26 February 2012 to redeploy 7 elk and 14 moose collars retrieved from animals that died in year one. Only migratory moose were targeted in year 2, because in the previous year only 3 migratory moose crossed US 20. Collars were programmed to record locations every 30 minutes from May 1^{st} – June 15^{th} and November 1^{st}

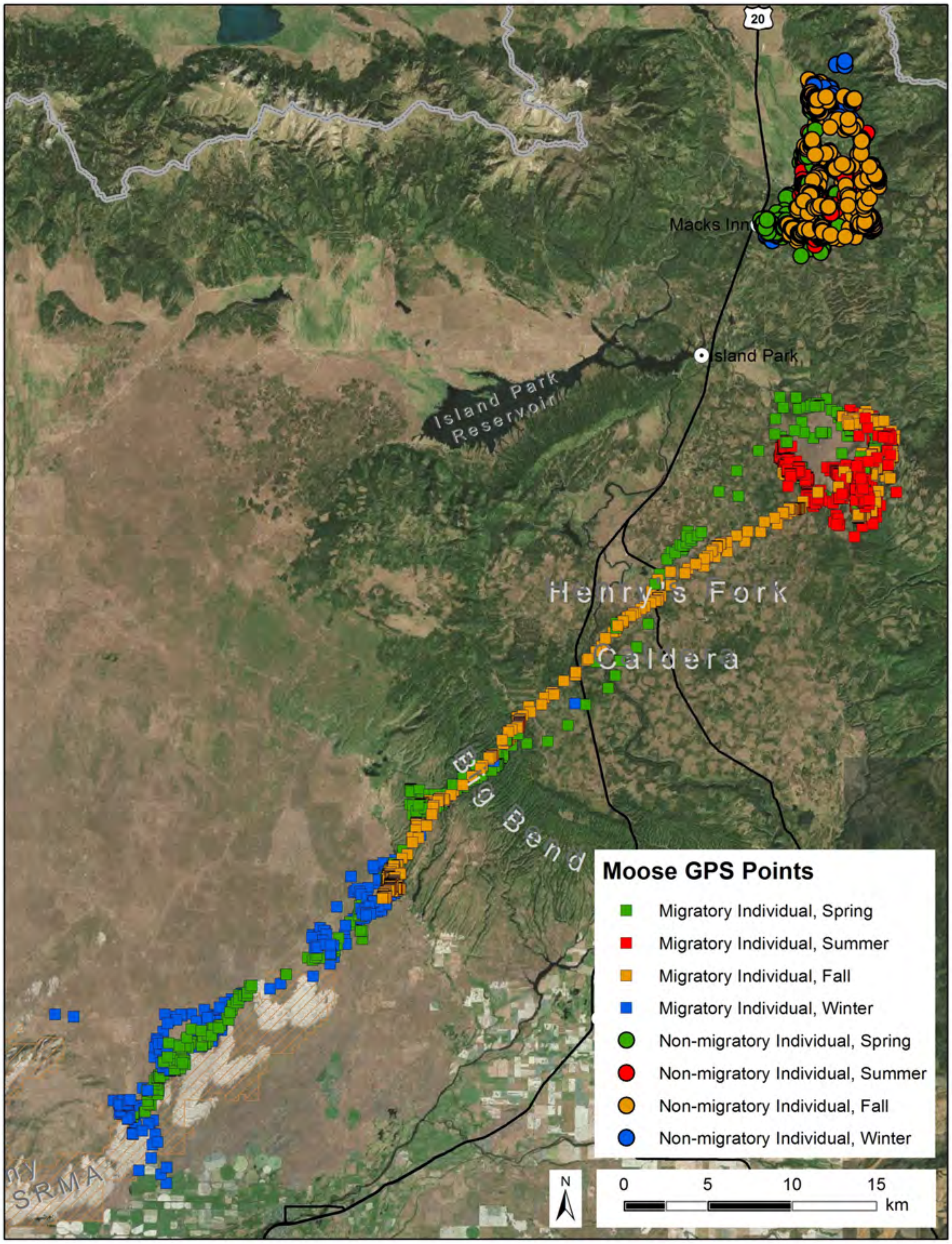

Figure 1.3. We identified moose as migratory if they had distinct summer and winter ranges and as non-migratory if they had overlapping seasonal ranges. An example of a migratory moose with annual GPS locations shown with squares; a non-migratory moose with annual GPS locations shown with circles. Seasons are color-coded. Spring months: March, April, May; Summer months: June, July, August; Fall months: September, October, November; Winter months: December, January, February.

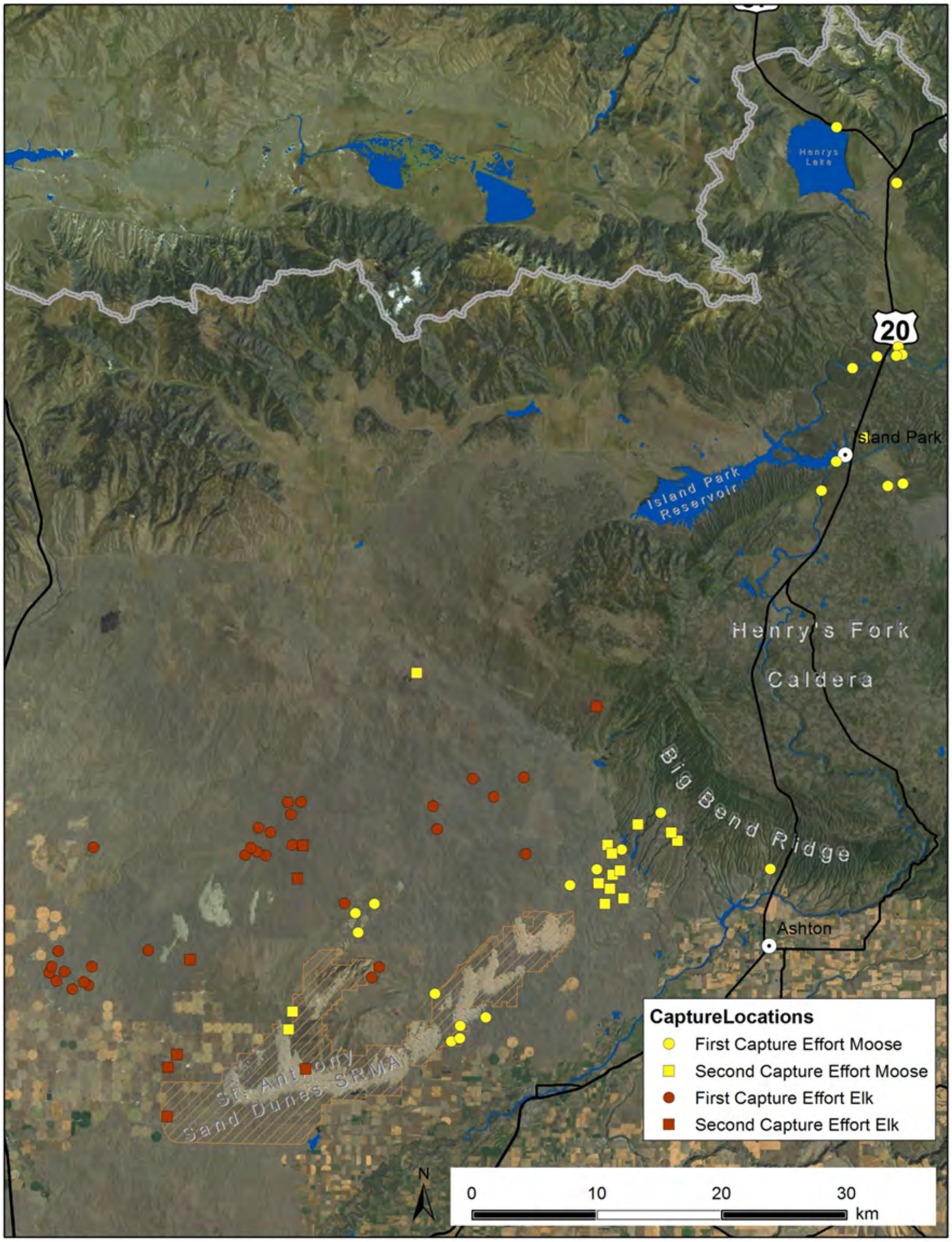

Figure 1.4. The first capture effort of elk (n = 30) and moose (n = 28) occurred between December 2010 - January 2011. The second capture effort was conducted on 2-3 December, 2011 and 26 February, 2012. Seven elk and 14 moose were captured in the second effort.

– 30th, and twice per day (12-hour interval) the remainder of the year. With this schedule we attempted to optimize the frequency of fixes during the *a priori* estimated migration periods of interest while maintaining a battery life in excess of 2 years. Improved batteries available in year 2 allowed the fall 30-minute fix schedule on redeployed collars to be extended to December 10th. Collars were programed to release after 2 years. Those deployed in 2010-2011 dropped-off animals in December 2012 and those deployed in 2011-2012 dropped-off in 2014. After each spring and fall migration, animals were located with VHF telemetry from the air or ground. Data from active collars were downloaded in the field using a remote handheld UHF unit. All dropped collars were retrieved from the field and data subsequently downloaded. Data from GPS collars for all animals were plotted in annual maps for reference (Figures 1.5 - 1.12). A detailed summary of all captured elk and moose data included from each individual in various analyses throughout this report can be found in Appendix A.

Analyses

Winter and Summer Range

We analyzed winter and summer ranges for all radio collared migratory elk and moose using the kernel density estimator, as described in Worton (1989) and Steineger and Hunter (2012). First, we plotted all 12-hour interval GPS locations. Second, we excluded dates from winter and summer seasons if animals were still migrating. Migration locations were those that occurred outside of the cluster of winter and summer points (Sawyer et al. 2009). If directional movement outside of a cluster of individual's points was apparent, the movement was considered migratory (Becker 2008). All winter and

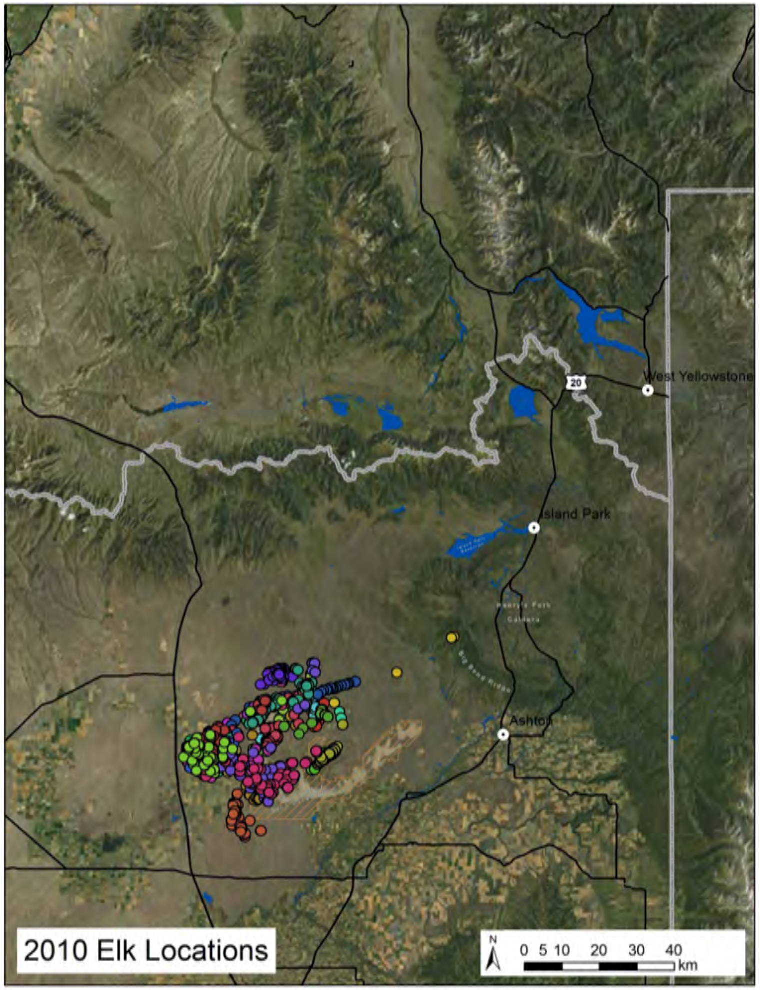

Figure 1.5. Locations of adult female elk fitted with GPS collars (n = 27) in southeastern Idaho in 2010.

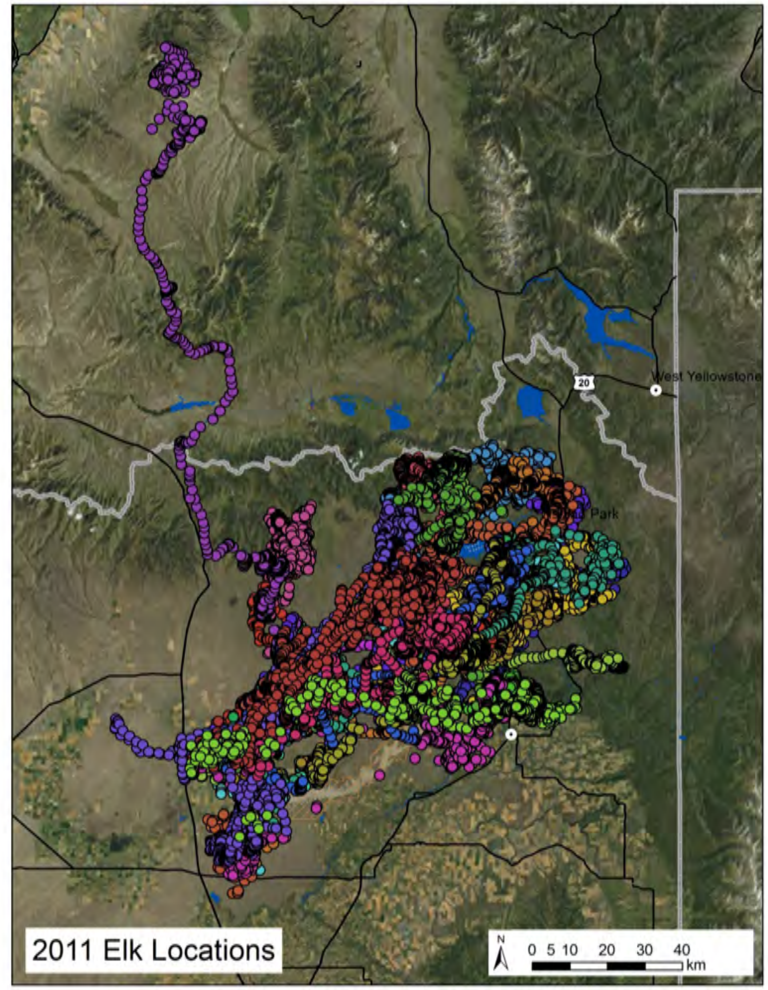

Figure 1.6. Locations of adult female elk fitted with GPS collars (n = 27) in 2011 in southeastern Idaho.

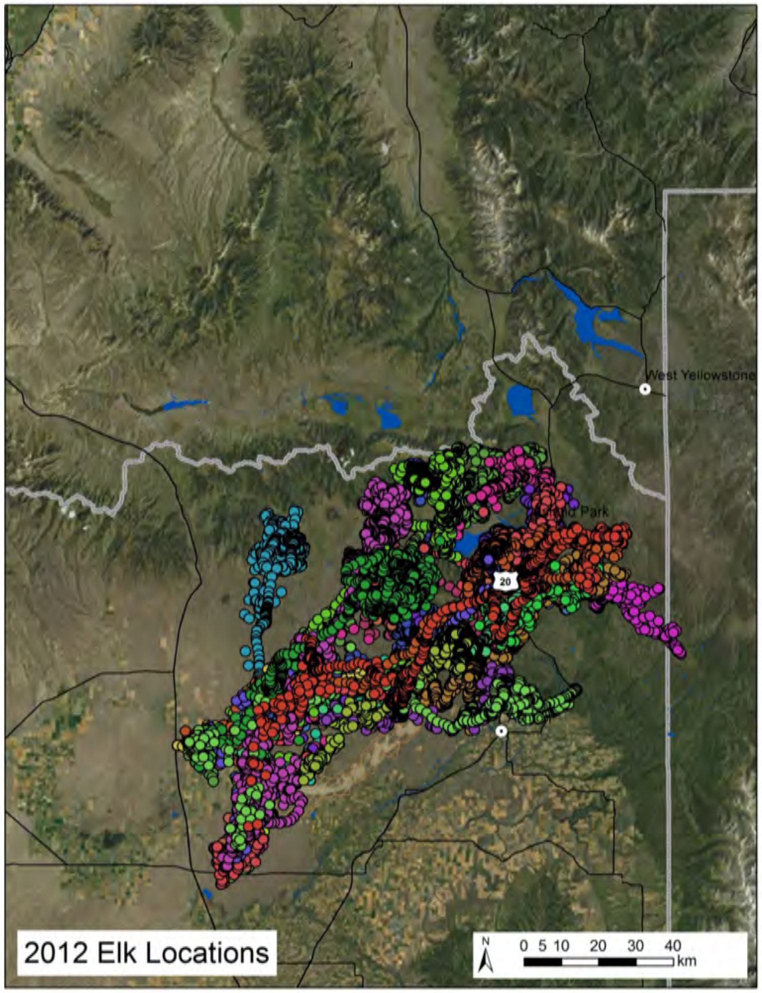

Figure 1.7. Locations of adult female elk fitted with GPS collars (n = 26) in southeastern Idaho in 2012.

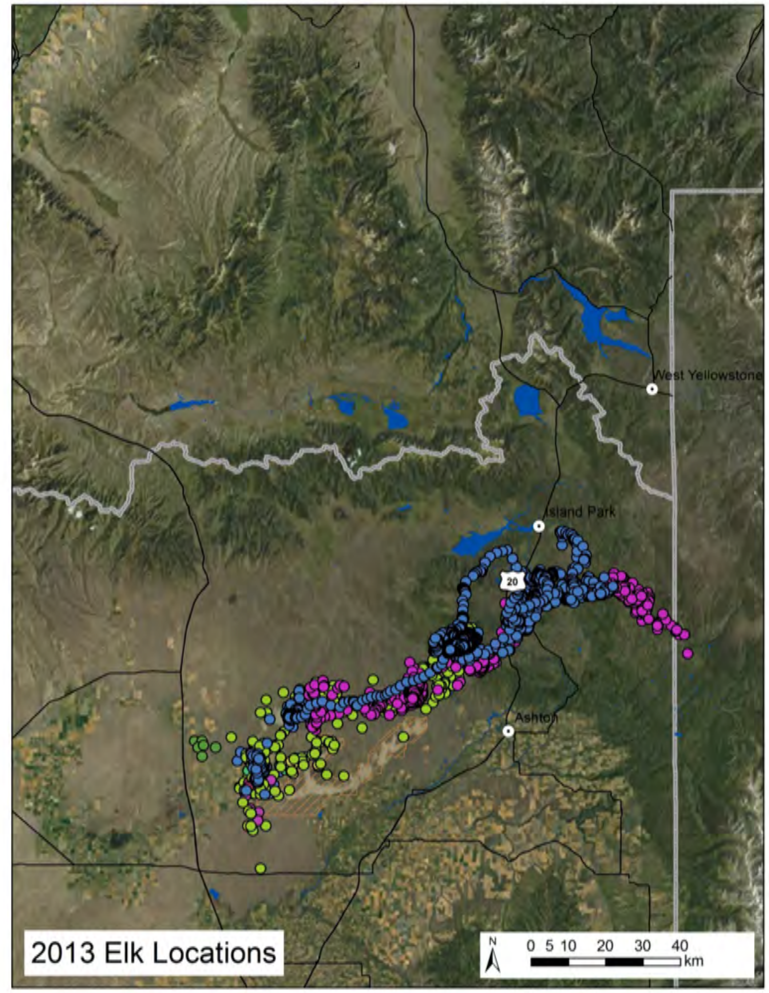

Figure 1.8. Locations of adult female elk fitted with GPS collars in southeastern Idaho in 2013.

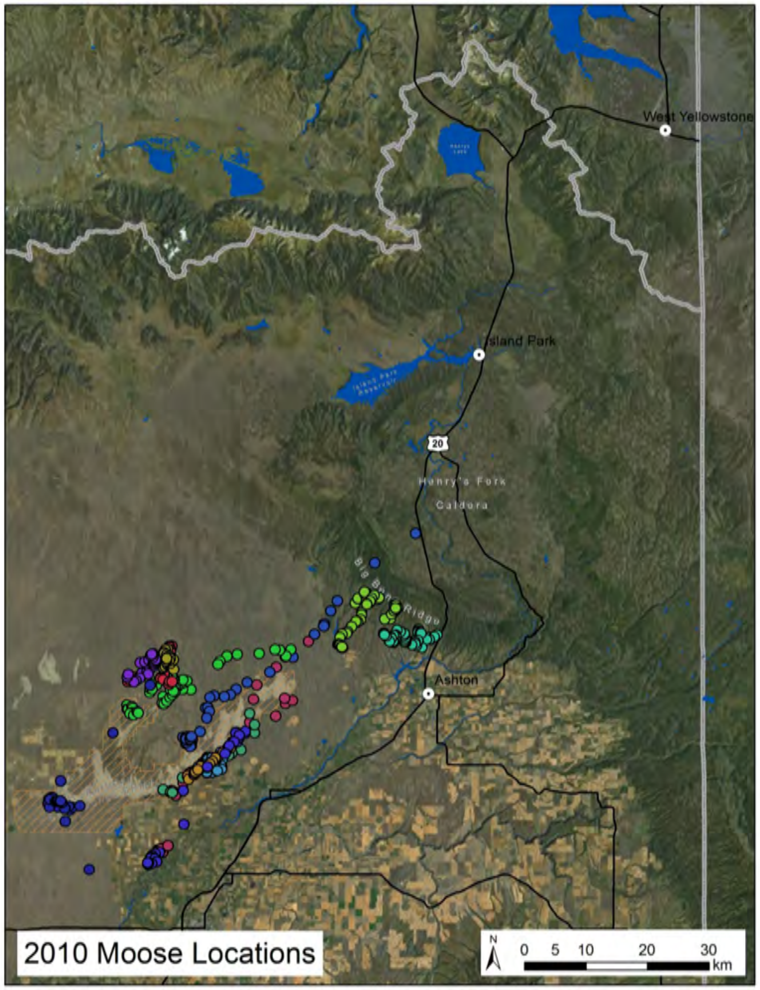

Figure 1.9. Locations of adult female moose fitted with GPS collars (n = 13) in southeastern Idaho in 2010.

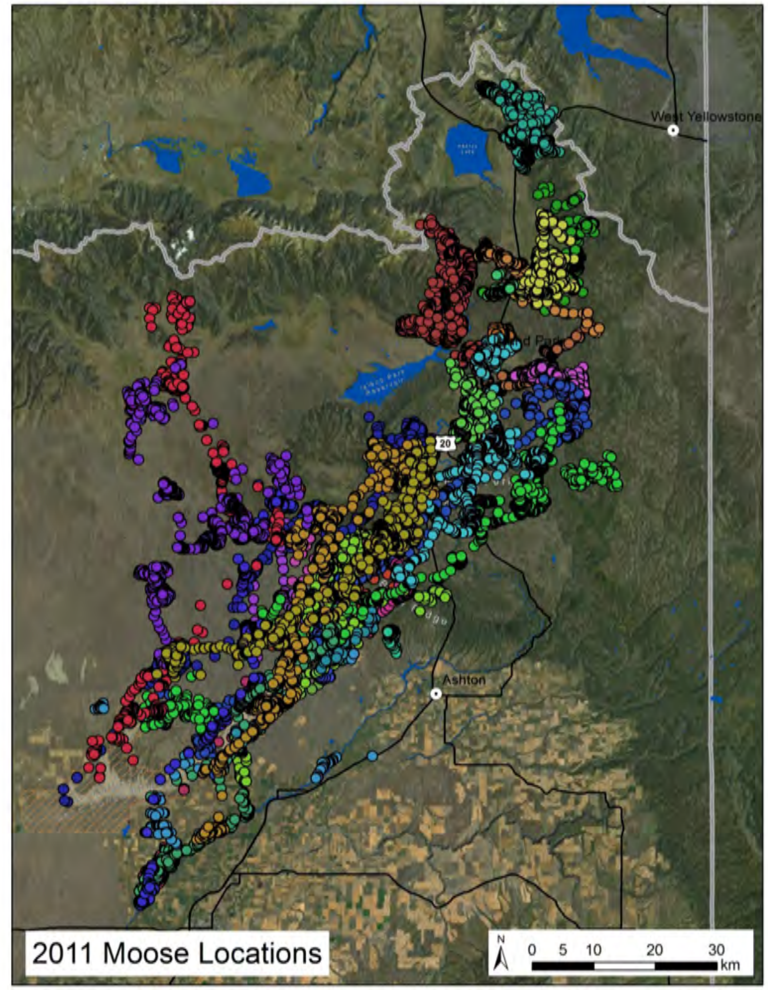

Figure 1.10. Locations of adult female moose fitted with GPS collars (n = 34) in southeastern Idaho in 2011.

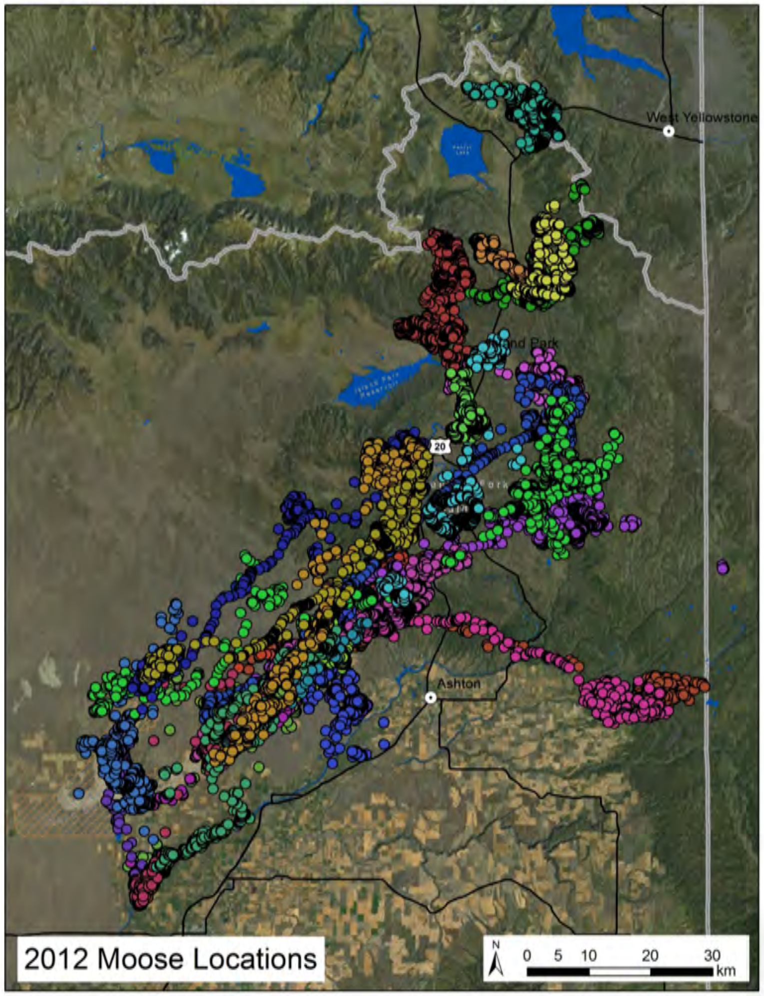

Figure 1.11. Locations of adult female moose fitted with GPS collars (n = 28) in southeastern Idaho in 2012 .

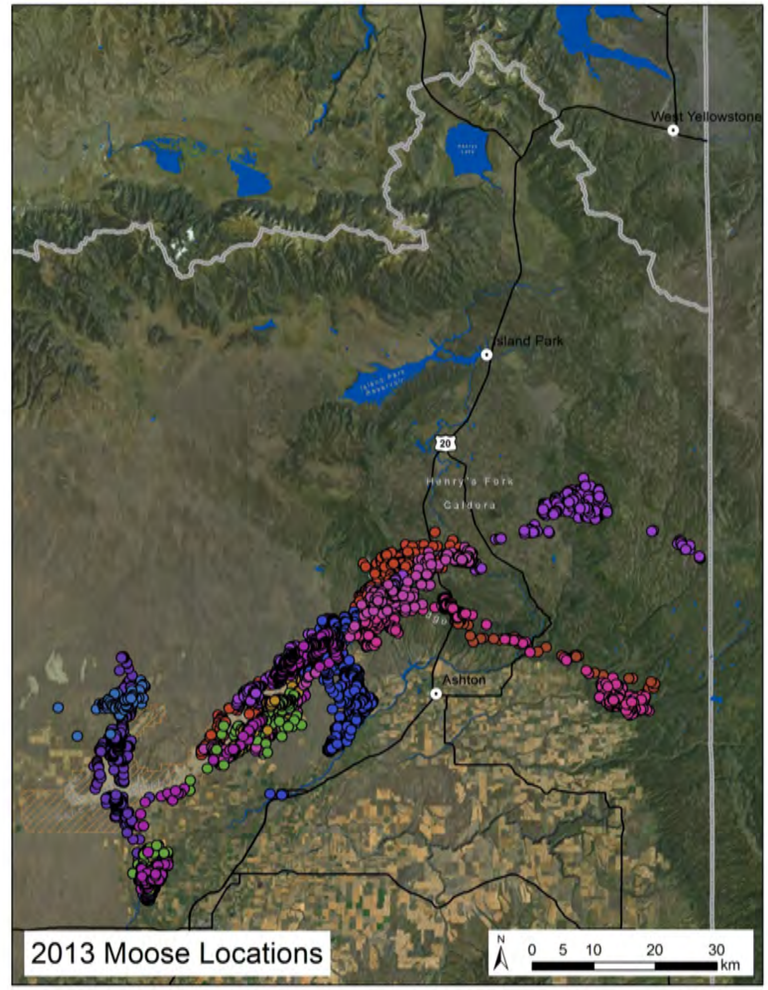

Figure 1.12. Locations of adult female moose fitted with GPS collars in southeastern Idaho in 2013 (n = 11).

summer points were combined across years for each individual. We used an *ad hoc* method to determine the bandwidth for each individual's seasonal range (Kie 2013). This method entails running multiple bandwidth kernel estimations for each set of points in order to determine the smallest bandwidth that produces a single polygon. We used a fixed kernel and calculated the standard sextante biweight using the HoRAE toolbox in OpenJUMP GIS 1.6ORC1 which estimates the 99.5% isopleth (Olaya 2008, Steiniger and Hunter 2012). We then converted these estimates to the 95% and 50% isopleth to display seasonal and core seasonal areas.

For non-migratory moose, we used all GPS points for each individual to create minimum convex polygons (MCPs) of their annual home ranges. Since GPS points were collected at 2 different time intervals, we used MCPs to avoid overweighting the kernel density estimator with 30-minute interval data.

Migration: Brownian bridge movement models

We created migration routes only for those migratory elk and moose which crossed US 20. We only used GPS points which were collected during the 30-minute interval schedule to run Brownian bridge movement models (BBMM, see *Animal capture and telemetry methods* section above for dates; Horne et al. 2007, Sawyer et al. 2009). Because we did not cull points from the migration data sets on an individual basis, some migration routes may contain part of a winter or summer range.

We used Animal Space Use 1.3 (Horne et al. 2009) to create probability of occurrence grids. We allowed the software to calculate Brownian motion variance from the GPS points for each individual and limited time intervals to 180 minutes. Extents were automatically calculated and output grid points were set at 100 m distances. We then converted the grid points to 100 m raster cells in ArcGIS 10.1. Individual utilization distributions were averaged using the Average Rasters Tool in ArcGIS to create population-level migration models. We used 23 individual models to create an elk spring population-level utilization distribution and 9 individual models to create the fall migration model. Sample sizes were too small to create population-level migration models for moose.

Track surveys

During 2010-2012, volunteers from the Idaho Master Naturalists and study team biologists conducted surveys for elk and moose tracks crossing US 20. Surveys were conducted twice during each spring (April, May, or June, 2011-12, depending on seasonal snow cycles) and fall (November, 2010-12) migration. Volunteers received 12 hours of training in elk and moose track identification and survey protocol taught by a professional tracker certified by CyberTracker Conservation (cybertracker.org). Refresher training was provided each fall prior to surveys. Volunteers typically worked in teams of 2, although some worked alone. Each volunteer or team was randomly assigned 1.6-3.2 km (1 -2 miles) adjacent to US 20. For each survey period, the entire study area stretch of US 20 was assessed. Surveyors walked one side of the highway, documented tracks with a handheld GPS unit, and recorded supporting data (e.g. direction of travel, track quality, GPS accuracy). Upon finding tracks entering or exiting the road surface, surveyors searched the opposite side of the road for tracks of the same animal, indicating it had crossed the road. Because elk and moose tracks can look similar in difficult tracking substrate, but are clearly elk or moose and no other species, surveyors identified tracks as "elk", "moose", or "either." Only tracks identified to species were used in all analyses.

Road mortality

Locations of elk and moose WVCs were documented through roadkill and traffic accident data collected during this study. Additionally, ITD and IDFG provided data for elk and moose road-mortality on US 20 and Highway 87 within the study area from 1982-2009 (ITD) and 1982-2005 (IDFG). ITD road-mortality data were measured to the nearest 0.16 km (0.1 mile). Most IDFG road-mortality data were attributed to the nearest mile marker; however a few records were assigned to the nearest 0.1 mile. Road mortality data from IDFG were accurate with respect to species for all instances (n = 164), but were not very precise spatially (i.e. only 19.5% [n = 32] were recorded to the nearest 0.16 km). In contrast, road mortality data from ITD were more spatially precise compared to IDFG data, but road mortality incidents only documented the species involved sporadically (only 48 of 221 [21.7%] WVCs from ITD data recorded the wildlife species [32 elk and 16 moose] involved from 1982-2009). Therefore, we elected to map only those road mortality data points for which both location (i.e., within 0.16 km) and species were accurately and precisely recorded across all datasets. Roadkill data for the GPS-collar study period from 2010 to 2012 were retrieved from The Idaho Fish and Wildlife Information System (IFWIS; https://fishandgame.idaho.gov/ifwis/portal/). These data were sourced from ITD and IDFG reports and accurate to the nearest 0.16 km or documented by GPS.

RESULTS

Elk

Winter and summer range

Elk summer and winter ranges overlapped somewhat along the edge of the caldera, south of the Ashton Reservoir, and near Kilgore, Idaho, but otherwise were fairly distinct (Figure 1.13). Winter ranges were primarily associated with lower elevations on and near the St. Anthony Sand Dunes (Figure 1.14). Summer ranges were along Big Bend Ridge and the Henry's Fork Caldera (Figure 1.15). One elk summered on the southern end of the Ruby Range in southwestern Montana. One elk spent part of her summer just over the Montana border on the northeastern edge of the Centennial Range and one spent part of her summer in north Bechler Meadows, Yellowstone National Park (YNP).

Seasonal and daily movements in relation to US 20

Elk utilize much of the Henry's Fork Caldera during fall migration, utilizing stopovers along Thurman's Ridge, the foothills, forests and meadows south of Harriman State Park, the forests and meadows east of Harriman State Park and Osborne Peak, as well as stopovers which appear to be associated with US 20 (Figure 1.16). Spring migration models appeared to capture some of elk summer range on the caldera and show that elk have high areas of utilization south of Island Park on either side of US 20 (Figure 1.17). Elk utilize many different routes to travel from winter and summer range. Travel routes into Montana were not included in the BBMM analysis because these animals did not cross US 20.

We analyzed US 20 crossings by month separately for 30-minute and 12-hour intervals, since one interval was exclusive of the other (i.e., number of crossings would be biased by 30-minute data for crossings in May, June, November, and December). Thirty-minute crossings showed elk crossed US 20 more often in May than in November (Figure 1.18). Twelve-hour crossings suggest that the majority of elk migrating in the fall crossed US 20 in October (Figure 1.18). Elk were crepuscular and nocturnal when crossing US 20

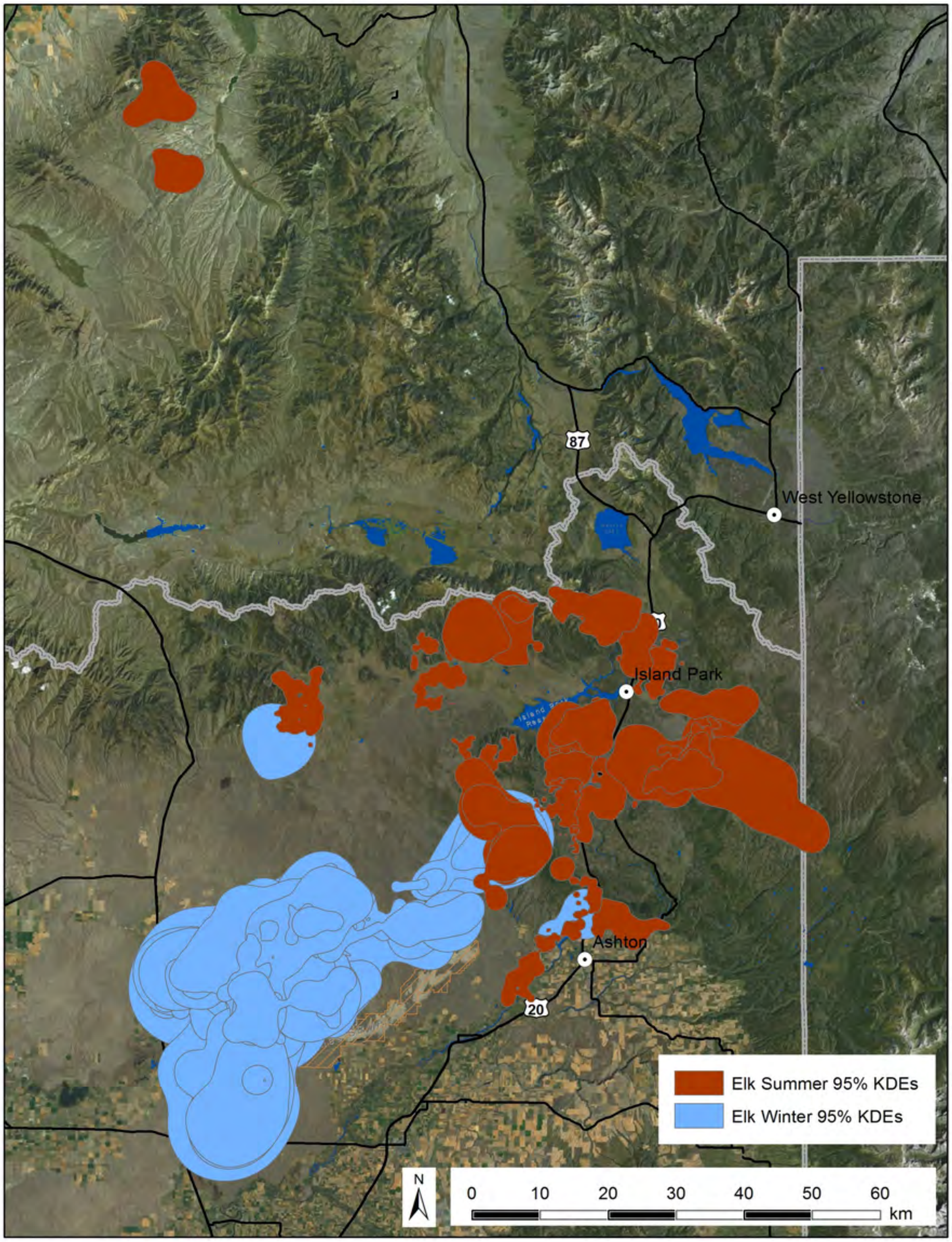

Figure 1.13. Elk summer and winter ranges were developed using a fixed kernel density estimator and an *ad hoc* bandwidth. We calculated 95% contours for all collared elk with sufficient data. Kernel estimates include all years' data for each individual. Winter range 12-hour data was used from the time period 1 January - 31 March. Summer range 12-hour data was used from the time period 1 July - 30 September.

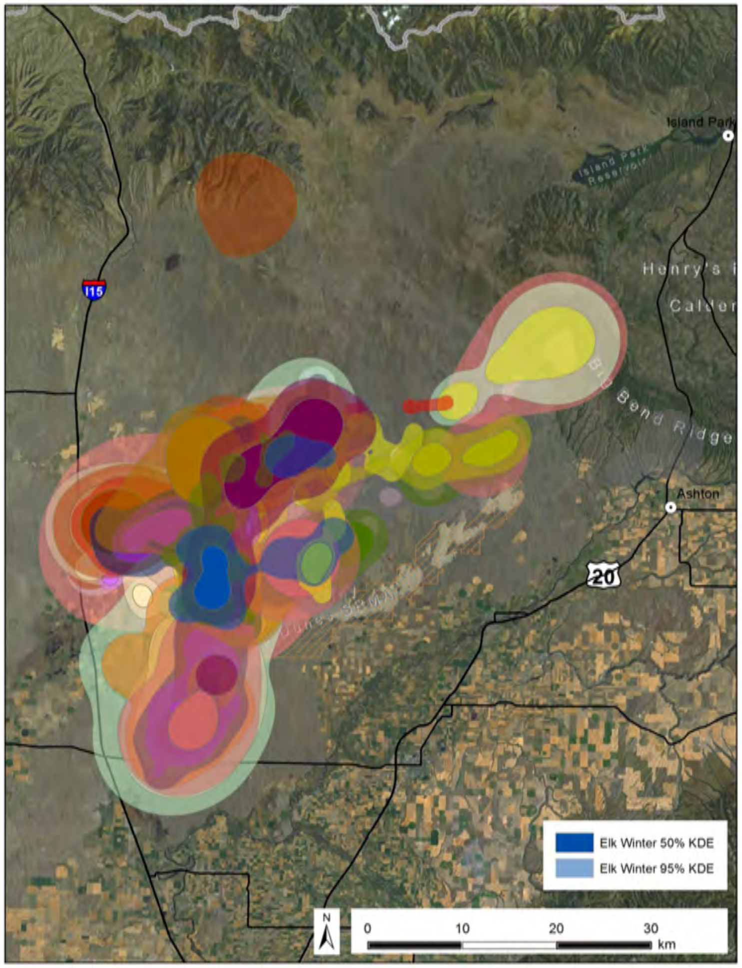

Figure 1.14. Elk winter ranges were primarily located southwest of the Henry's Fork Caldera near the St. Anthony Sand Dunes. Polygons representing the 95% and 50% kernel are shown.

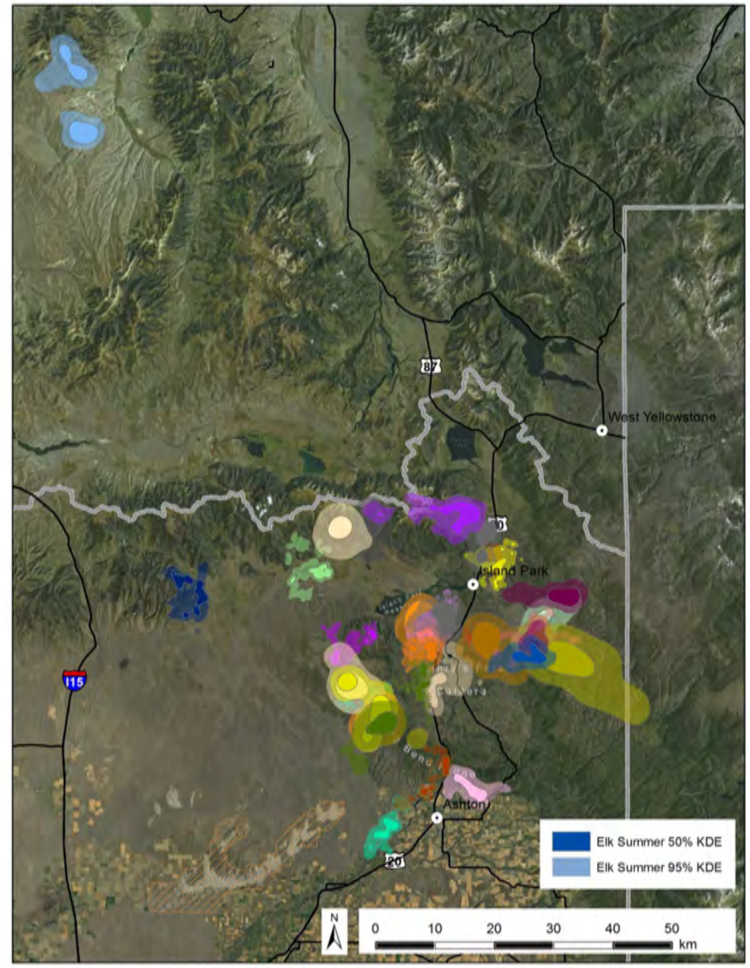

Figure 1.15. Elk summer ranges were dispersed on the caldera, Big Bend Ridge, and the Centennial Mountains. Polygons representing the 95% and 50% kernel are shown.

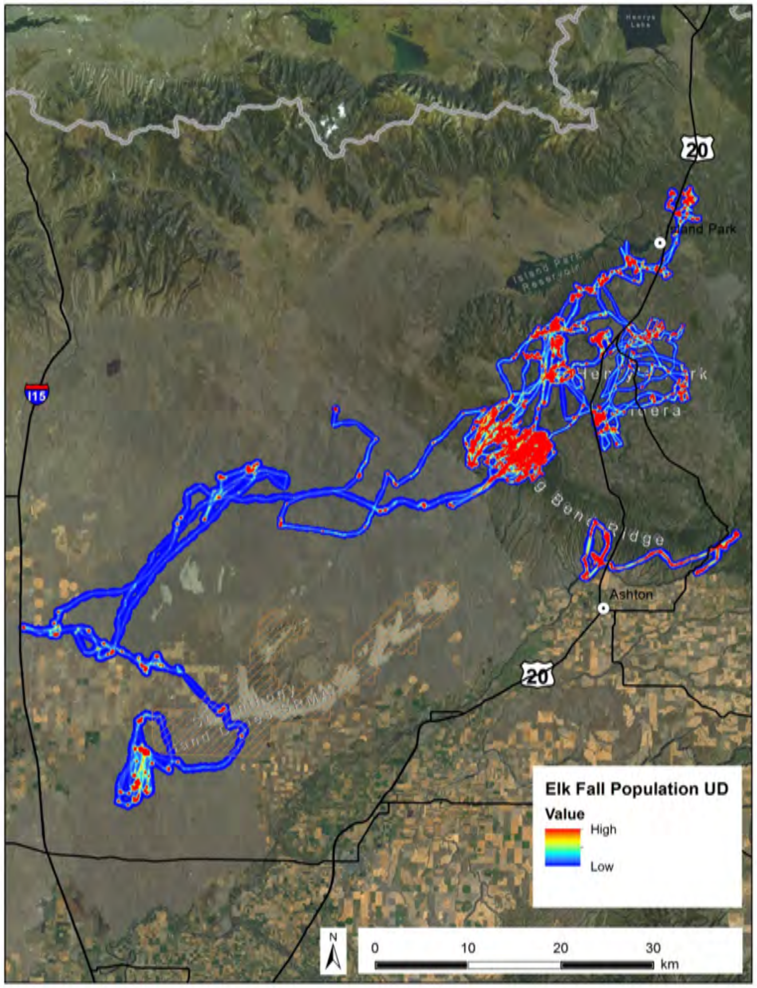

Figure 1.16. Population-level fall Brownian bridge movement models for elk show variant use of the landscape to travel from summer to winter range. Population-level models were created using 9 individual models.

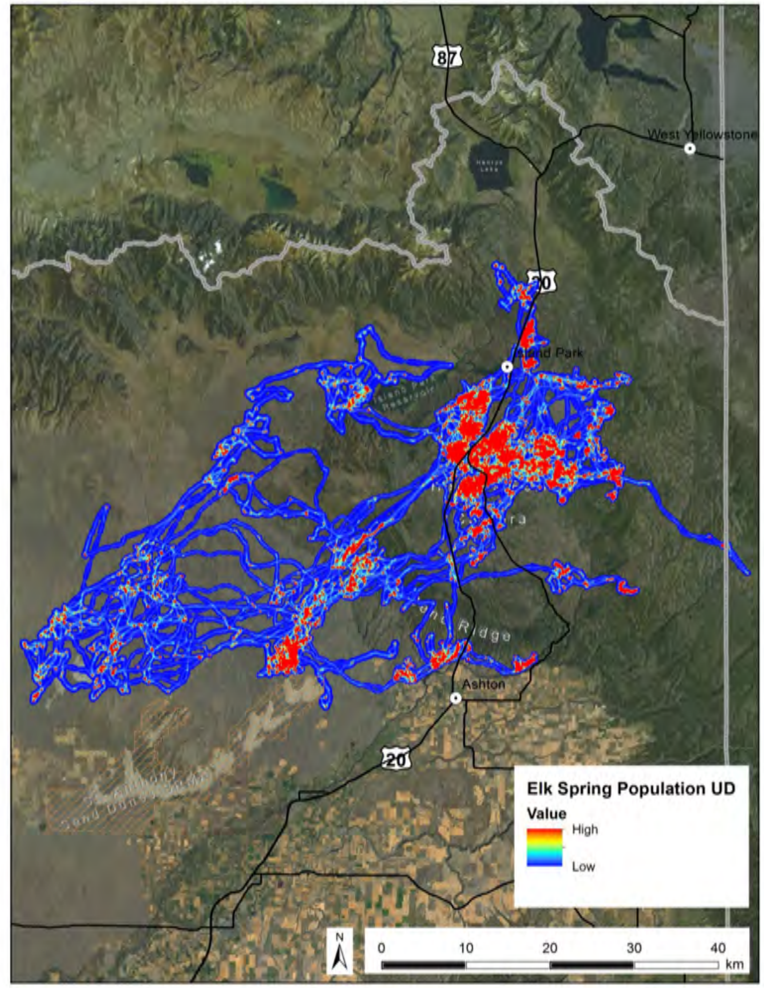

Figure 1.17. Population-level spring Brownian bridge movement models for elk show variant use of the landscape to travel from winter to summer range. Population-level models were created using 23 individual models.

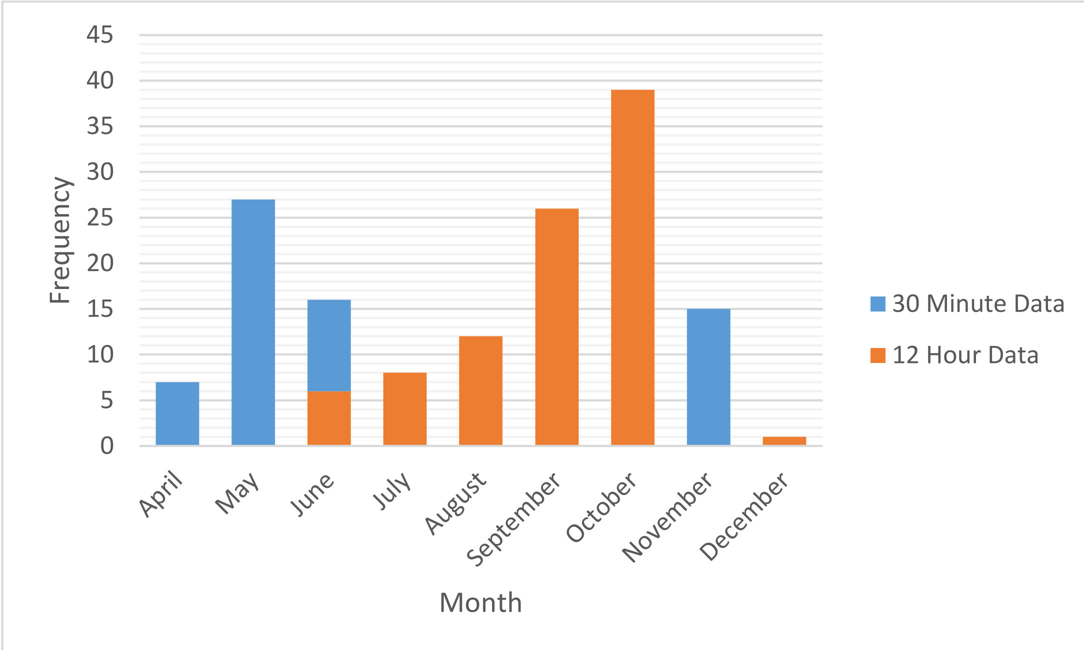

Figure 1.18. Monthly frequency of US 20 crossings (*n* = 118) by collared elk. Data are from 30-minute and 12-hour data collection intervals, as specified. Thirty-minute data were collected primarily in May and November; 12-hour data were collected primarily in June-October and December-March. Data were collected from 2010-2013.

(Figure 1.19). This pattern was stronger in May than in November (Figure 1.20).

Track surveys

Volunteers counted 431 elk tracks crossing US 20 between November 2010 – November 2012. Tracks were found along the length of the highway except very few elk crossings were detected between the junction of Highway 87 - US 20 and Macks Inn (mileposts [MP] 393-402). We detected elk tracks crossing both Highway 87 and US 20 north of its junction with Highway 87 (MP 402). Crossings along Highway 87 may be daily crossings made during summer foraging bouts in addition to migratory crossings. Crossings were more widely dispersed spatially in spring than in fall along the highway. Temporally, more crossings were detected in the spring (n = 337 across all springs; Figure 1.21).

Road mortality

Thirteen collared elk died during the study. Two of those were harvested, one removed for depredation, and 10 died due to unknown causes (Figure 1.22). The 2010-2012 Idaho Fish and Wildlife Information System dataset included 8 elk WVCs (Figure 1.22). Elk road mortalities were clustered north of Osborne Bridge to Island Park (MP 379-387) and near the junction of Highway 87 – US 20 (between MP 1-2 on Highway 87 and near MP 403 on US 20). Between 1982 - 2012, elk wildlife-vehicle collisions occurred primarily in May, June, July, September, and October (Figure 1.23).

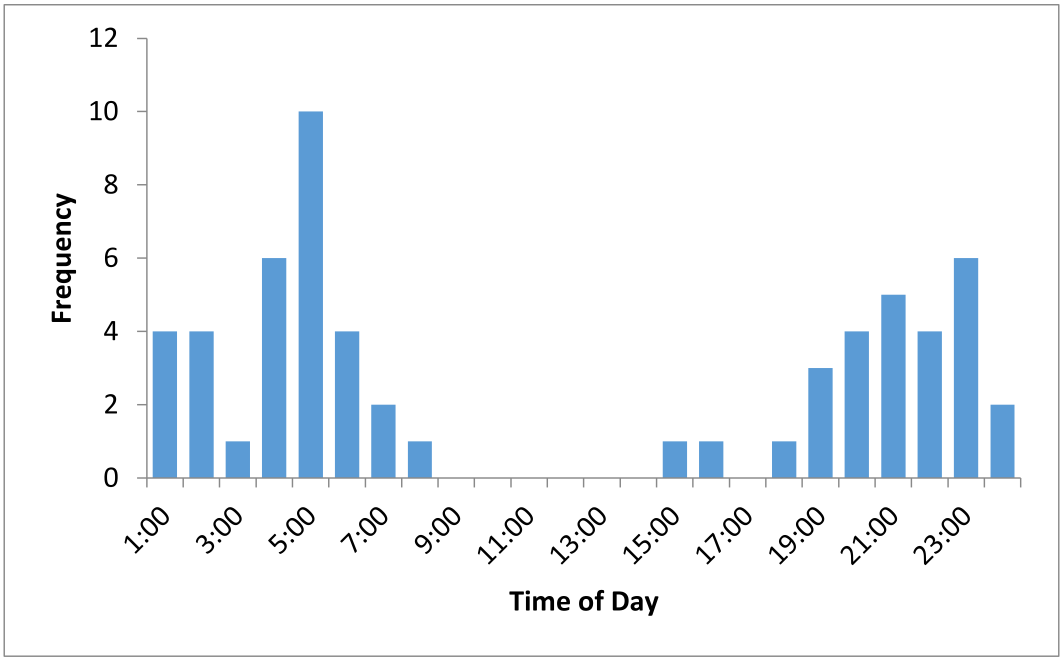

Figure 1.19. Frequency of US 20 crossings by collared elk (n = 59) by time of day. Data are from 30-minute data collection intervals only. Data collected in southeastern Idaho, 2010-2013.

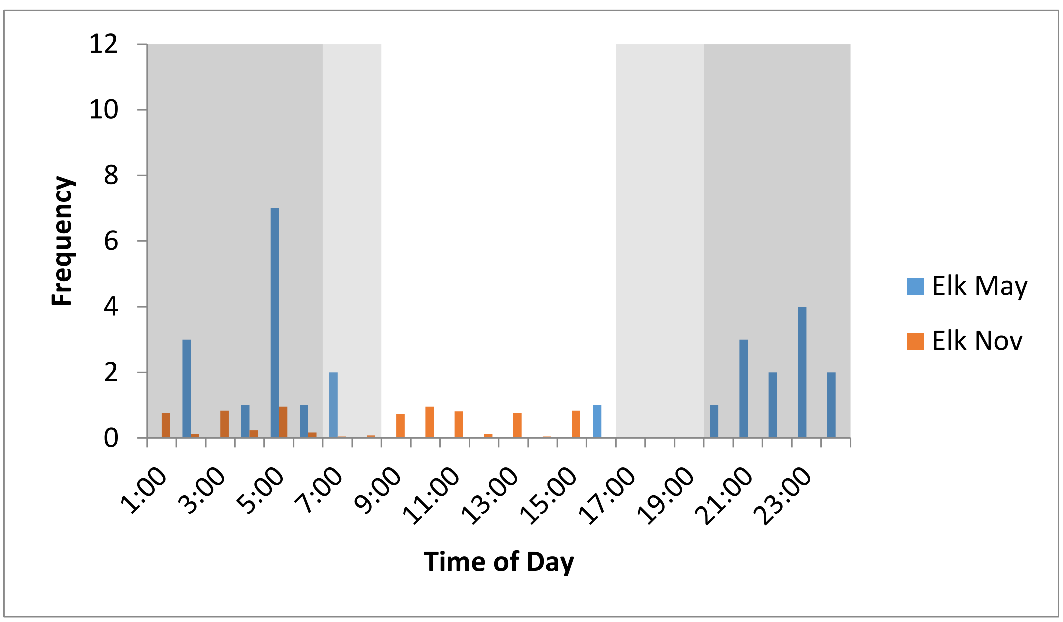

Figure 1.20. Frequency of US 20 crossings by collared elk in May (n = 27) and November (n = 15). Light grey shading represents approximate dark hours in November; darker grey shading represents approximate dark hours in May. Data are from 30-minute data collection intervals only. Data were collected from 2010-2013.

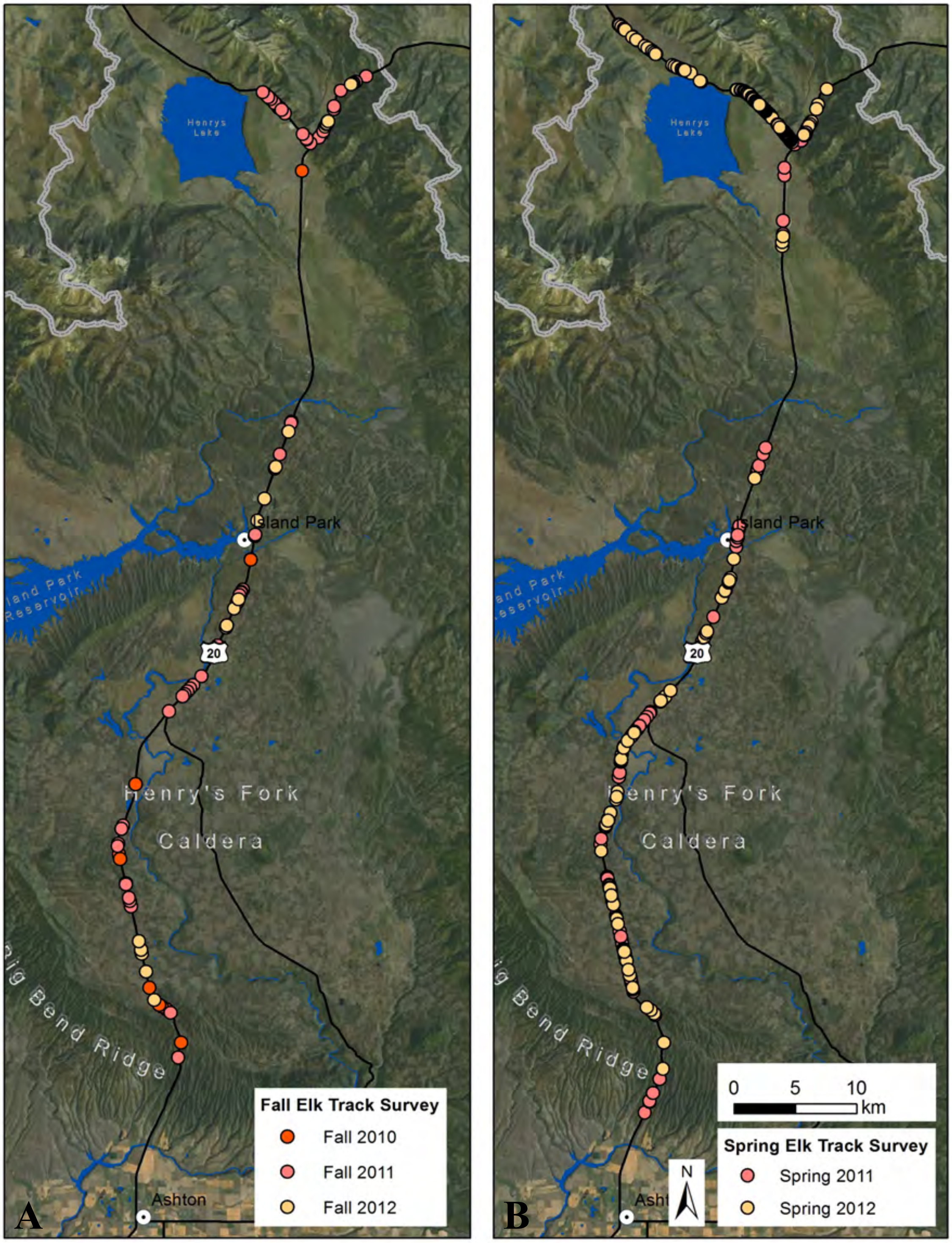

Figure 1.21. Data collected during track surveys showed that elk crossed US 20 and Highway 87 across most of its length, except along the stretch between Macks Inn and the Henry's Lake outlet. Fall (A) and spring (B) elk track surveys were conducted from 2010-2012. Track crossings are combined across years.

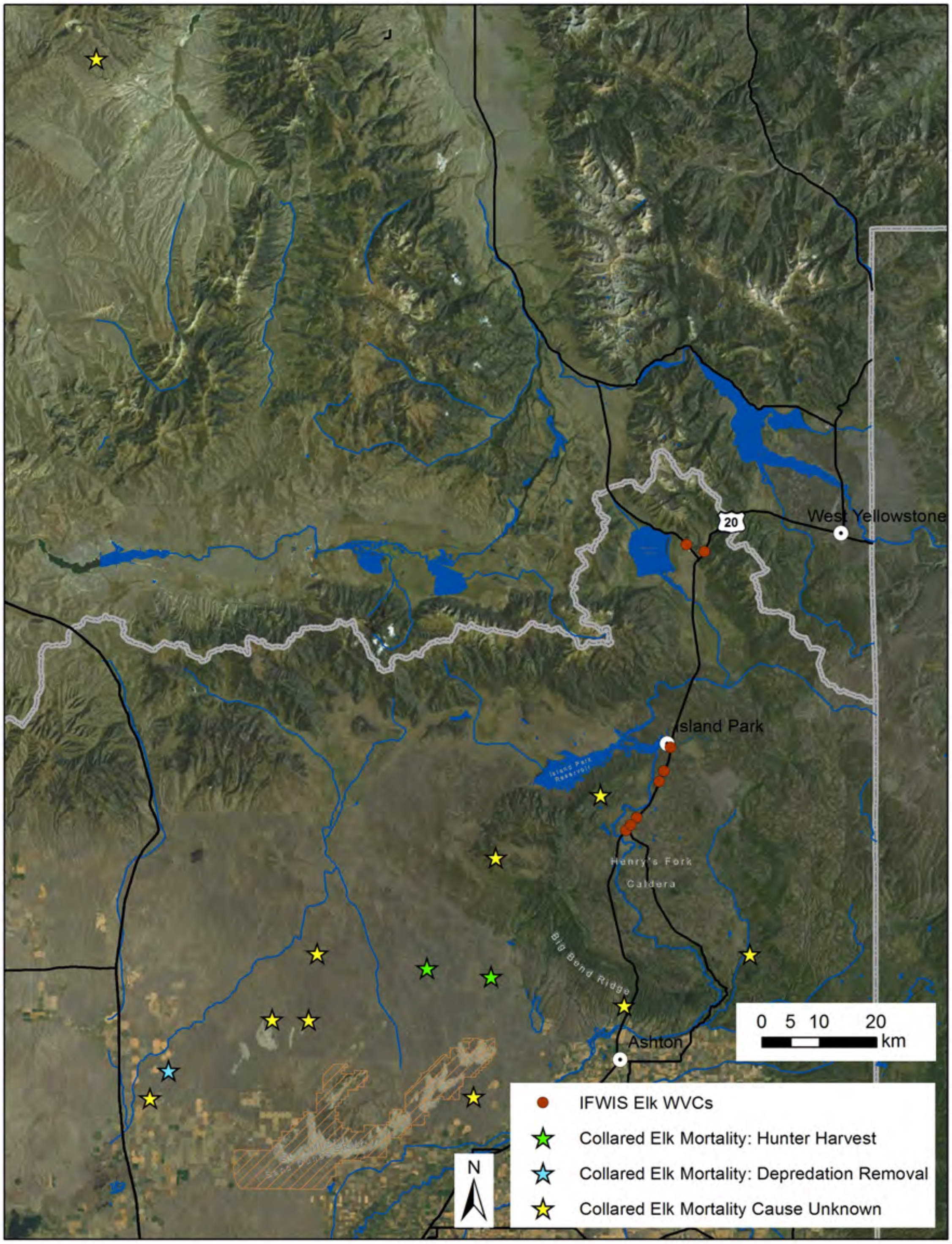

Figure 1.22. Eight elk died in documented WVCs along US 20 between 2010 - 2012. Two collared elk died during the fall hunt, one died in a depredation management removal, and 10 died due to unknown causes during the course of the study.

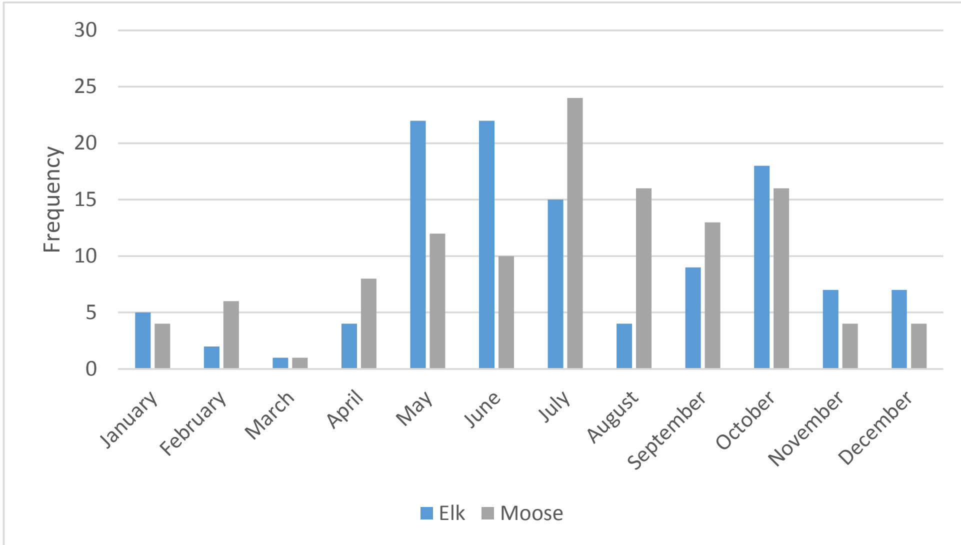

Figure 1.23. Wildlife vehicle collisions along US 20 in southeastern Idaho, between Highway 87 and Ashton, Idaho. Data are from Idaho Transportation Department, Idaho Department of Fish and Game, and the Idaho Fish and Wildlife Information System, 1982-2012.

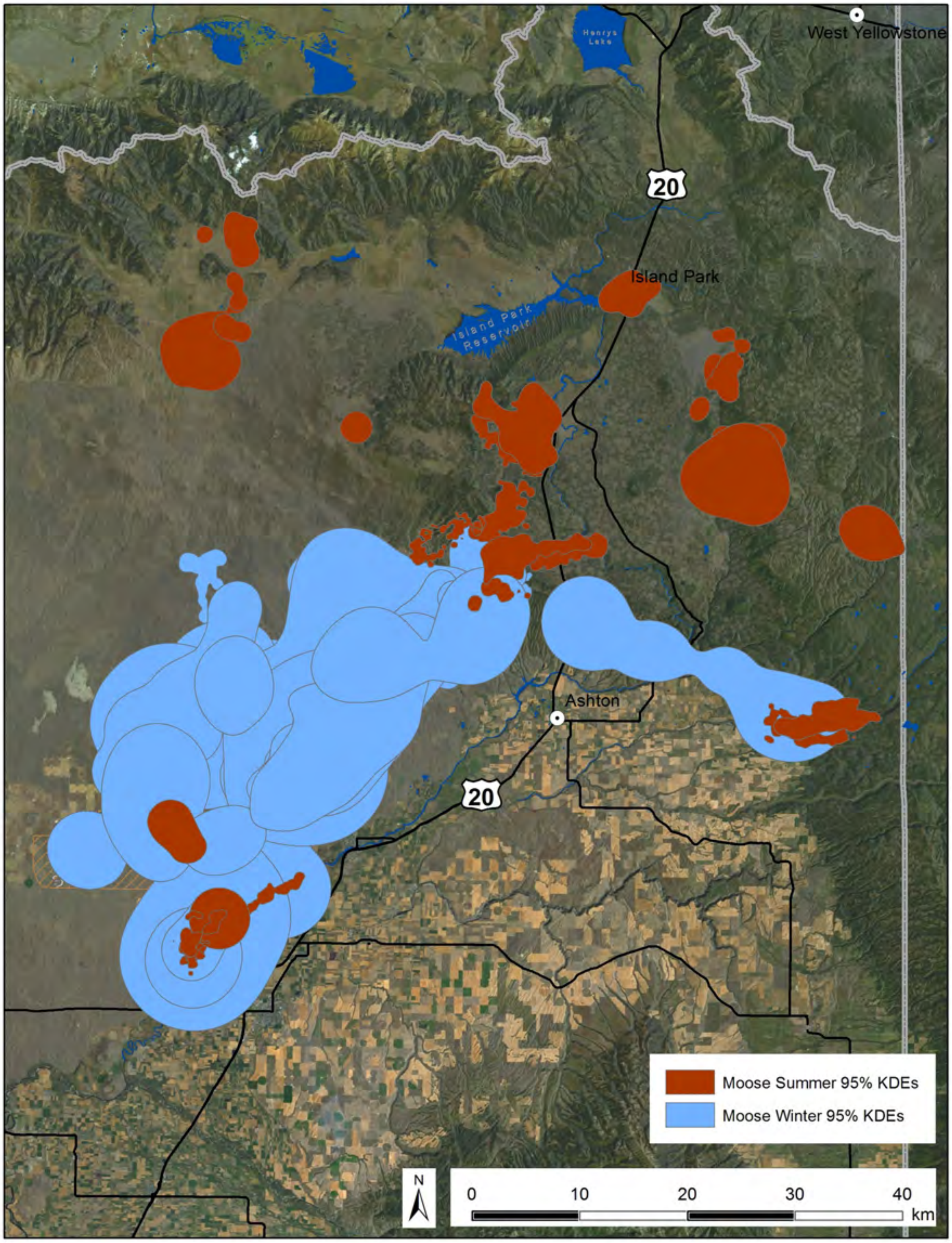

Figure 1.24. Migratory moose wintered southwest of the caldera, predominantly west of US 20. Most summer ranges were on the caldera. Moose summer and winter ranges were developed using a fixed kernel density estimator and an *ad hoc* bandwidth. We calculated 95% contours for all collared migratory moose with sufficient data. Kernel estimates include all years' data for each individual. Winter range 12-hour data was used from the time period 1 January - 31 March. Summer range 12-hour data was used from the time period 1 July - 30 September.

Moose

Winter and summer range

Not all migratory moose summered on the caldera (Figure 1.24). Migratory moose wintered off the caldera in and around the St Anthony Sand Dunes and on the south-facing slopes of Big Bend Ridge (Figure 1.25). Migratory moose summer ranges were often associated with water (Camas Creek, Spring Creek, Island Park Reservoir, Buffalo Fork River, Henry's Fork River—both on the caldera and south of Ashton—Warm River, Robinson Creek, Falls River, Blue Creek Reservoir, and Sand Creek Reservoir; Figure 1.26). In the summer and fall, 2012, one moose traveled into Montana north of Henry's Lake (Figure 1.11). One moose forayed into Bechler Meadows, Yellowstone National Park, for <3 days in July, 2012 (Figure 1.11). Collared non-migratory moose home ranges centered around Island Park, Macks Inn, and the junction of Highway 87 - US 20 and were associated with perennial water sources (Figure 1.27).

Seasonal and daily movements in relation to US 20

Brownian bridge movement models for migratory moose that crossed US 20 were limited to 5 individual models in the spring and 4 in the fall because we only used data that were collected during the collar's preprogrammed 30- minute interval schedule. Due to the small sample size, population level models were not created from migratory moose utilization distributions; maps display individual models only (Figures 1.28, 1.29).

Moose migrated (straight-line distance) 10-38 km between seasonal ranges (Figures 1.28, 1.29). In the spring, we were able to detect areas of higher use (i.e., a migratory stopover) approaching US 20 in only one instance (Figure 1.28). We were not able to detect any stopovers adjacent to the highway in fall, suggesting that moose may

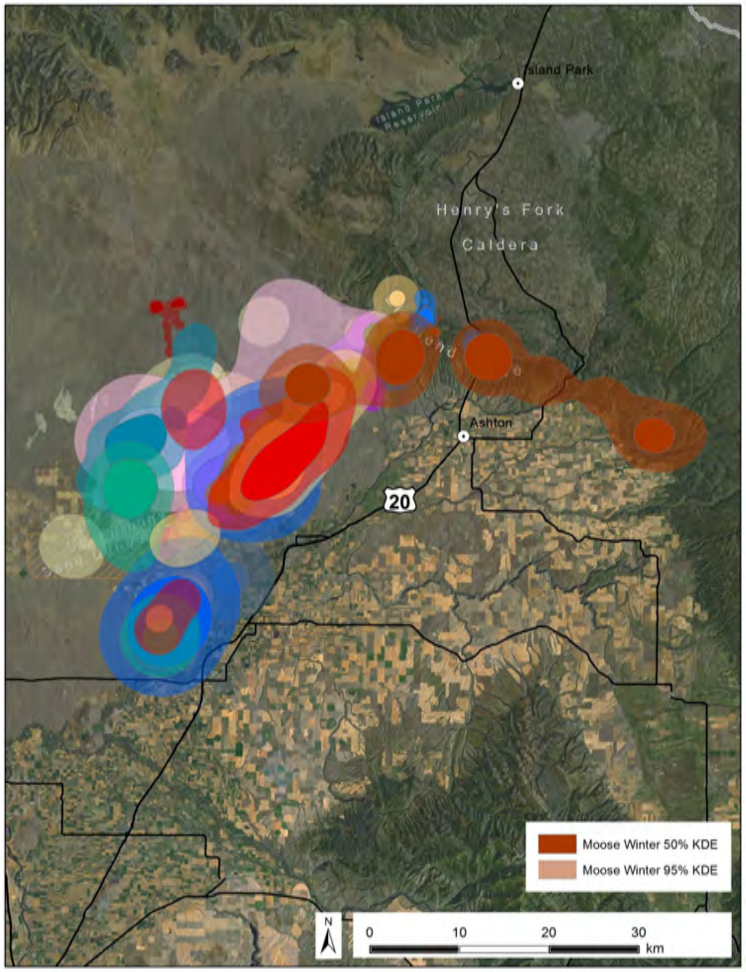

Figure 1.25. Migratory moose winter ranges were confined to lower elevations southwest of the Henry's Fork Caldera near the St. Anthony Sand Dunes and along Big Bend Ridge. Polygons representing the 95% and 50% kernel are shown.

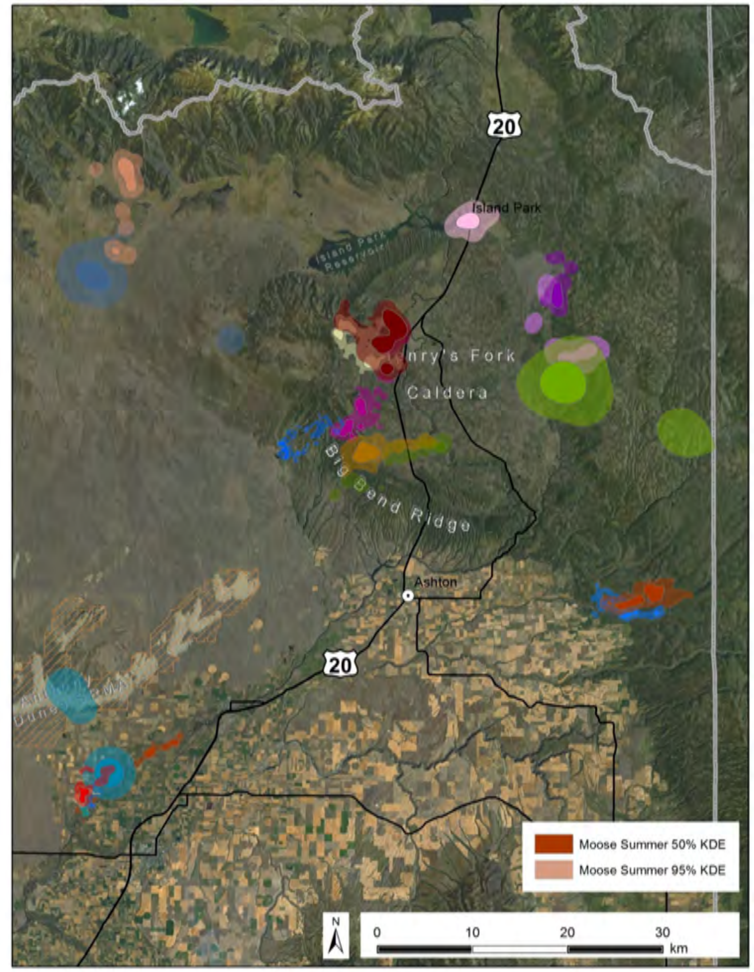

Figure 1.26. Migratory moose summer ranges were located around the edges of the caldera, near Camas Creek, near Bechler Meadows in Yellowstone National Park, and southeast of the St. Anthony Sand Dunes along the Henry's Fork River. Polygons representing the 95% and 50% kernel are shown.

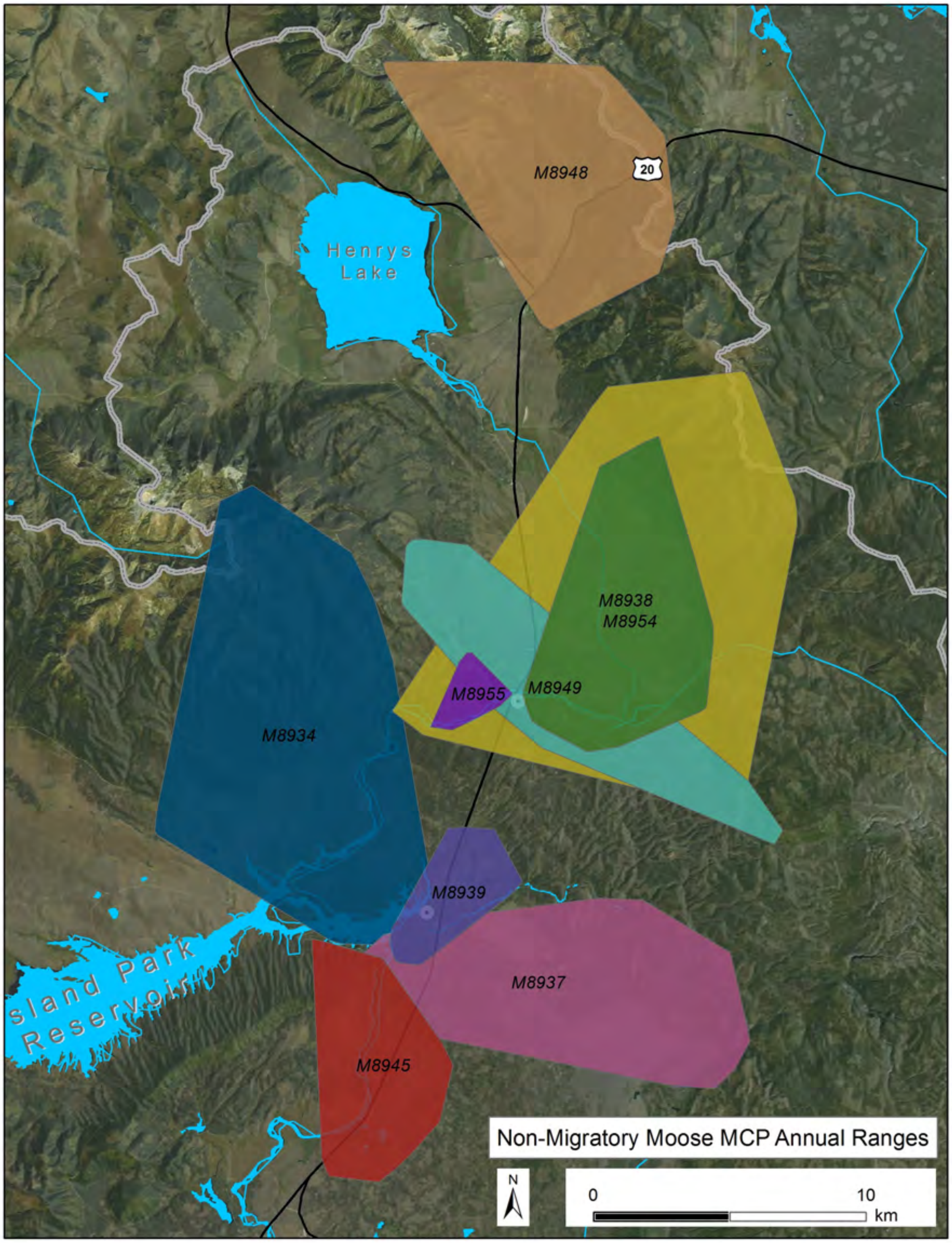

Figure 1.27. Non-migratory moose annual home ranges were located on the northern end of the Henry's Fork Caldera or north of the caldera and were associated with perennial water sources. Moose M8955 died < 4 months after capture and M8939 died < 8 months after capture, likely contributing to their home ranges being relatively small.

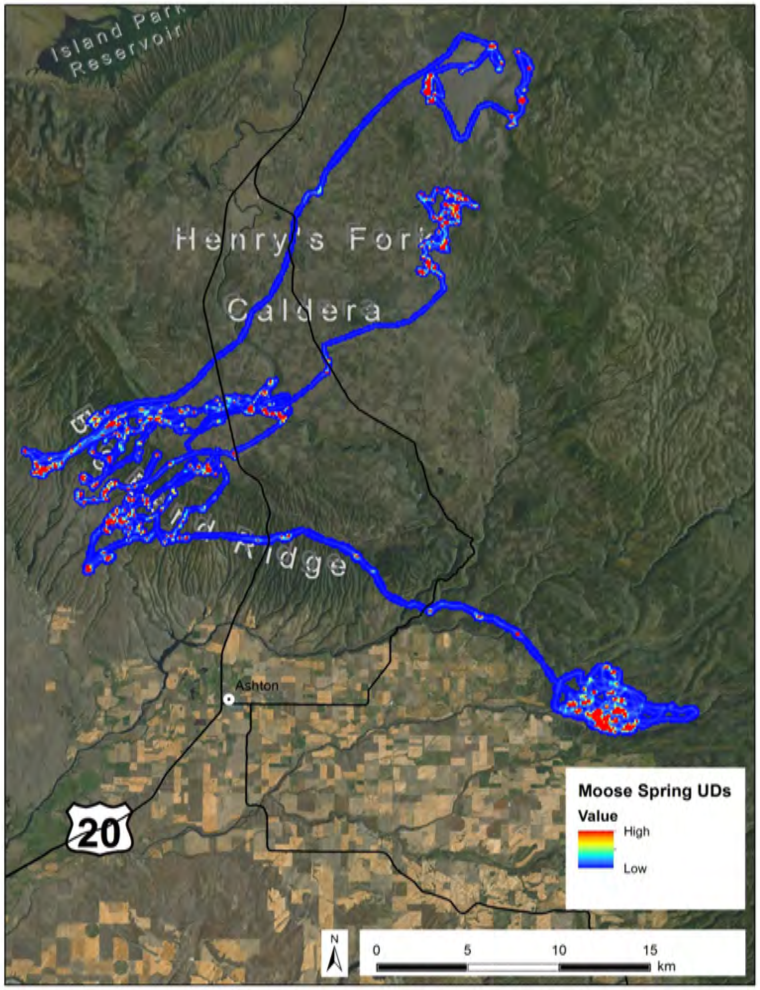

Figure 1.28. Spring Brownian bridge movement models suggest that migratory moose (n = 5) cross US 20 shortly after ascending Big Bend Ridge.

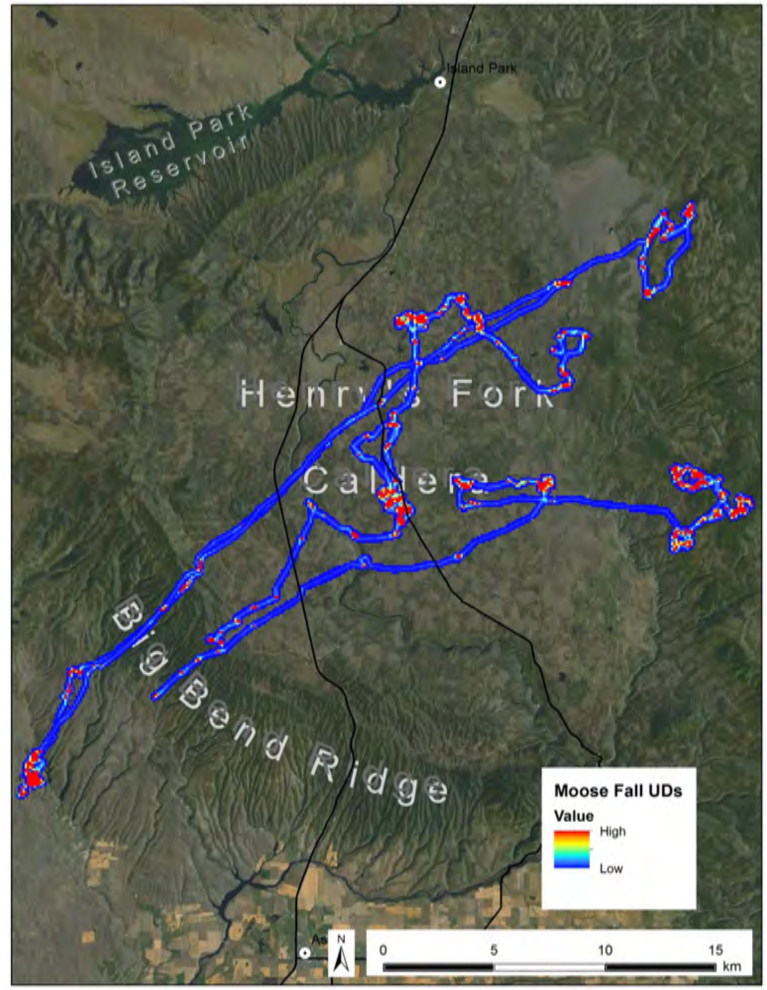

Figure 1.29. Fall Brownian bridge movement models show an invariant path for one migratory moose over 2 consecutive years (uppermost 2 utilization distributions) and 2 paths which are similar to spring moose migrations across US 20.

not view US 20 as a significant impediment (Seidler et al. 2014; Figure 1.29). Various stopovers were utilized along both the spring and fall migrations that were not associated with highways. One moose utilized an invariant path over 2 consecutive years during the fall (Figure 1.29).

We analyzed moose US 20 crossings by month separately for 30-minute and 12-hour intervals as we did with elk, since one interval was exclusive of the other. The majority of collared moose US 20 crossings occurred in the summer and fall (Figure 1.30). Moose daily crossing patterns are not as defined as those for elk, but are still centered on the crepuscular and nocturnal hours (Figure 1.31). In May, the majority of US 20 crossings by moose occurred between 24:00 and 1:00 and between 19:00 - 20:00 (Figure 1.32). In November, the majority of crossings occurred between 7:00 - 8:00 and between 17:00 - 18:00 (Figure 1.32).

Track surveys

Two-hundred moose tracks crossing US 20 were counted by volunteers from November 2010 - November 2012. Most US 20 moose track crossings were detected between Big Bend Ridge and Island Park (between MP 365 and 389) and north of the US 20 junction with State Highway 87 (MP 402-405; Figure 1.33). Spring crossings were also noted on Highway 87 north of Henry's Lake (MP 3-5). Similar to elk, few tracks were recorded between the junction of Highway 87 - US 20 and Macks Inn (MP 393-401). This section of highway and the importance of the lack of tracks is discussed in Chapter 2.

Road mortality

Of the captured moose, 15 died over the study period; 2 were known to have been

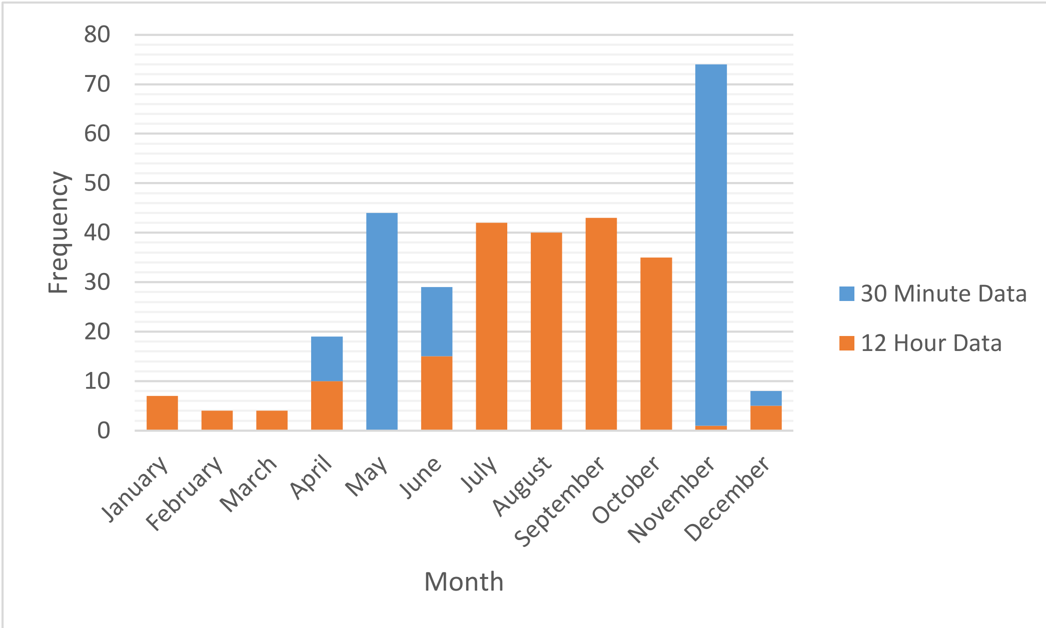

Figure 1.30. Monthly frequency of US 20 crossings (n = 350) by collared moose. Data are from 30-minute and 12-hour data collection intervals, as specified. Thirty-minute data were collected primarily in May and November; 12-hour data were collected primarily in June-October and December-March. Data were collected from 2010-2013.

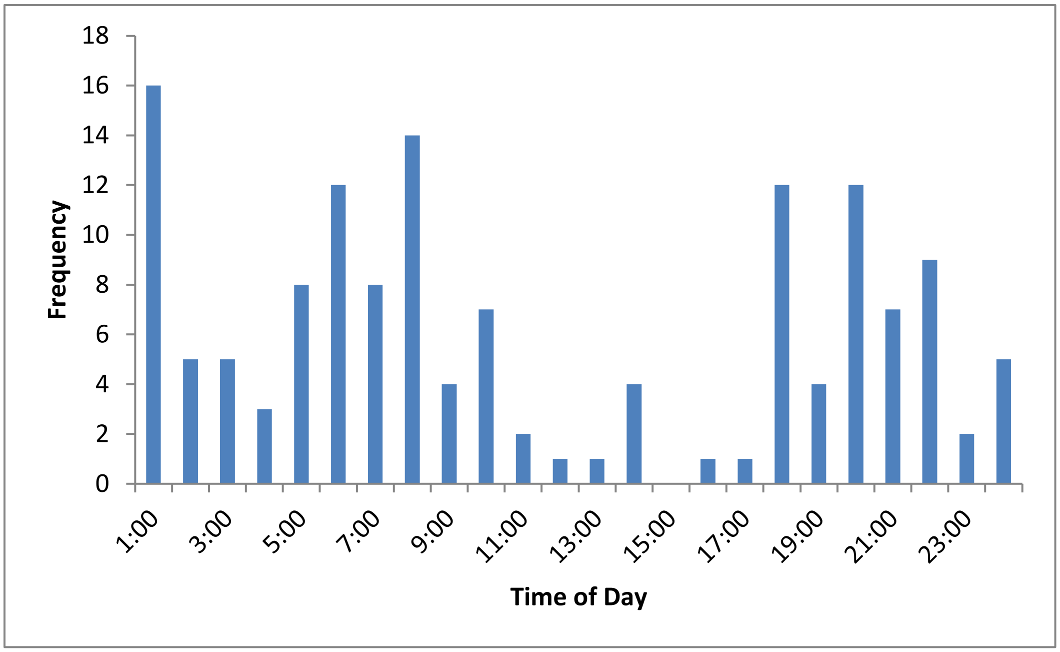

Figure 1.31. Frequency of US 20 crossings by collared moose (n = 144) by time of day. Data are from 30-minute data collection intervals only. Data collected in southeastern Idaho, 2010-2013.

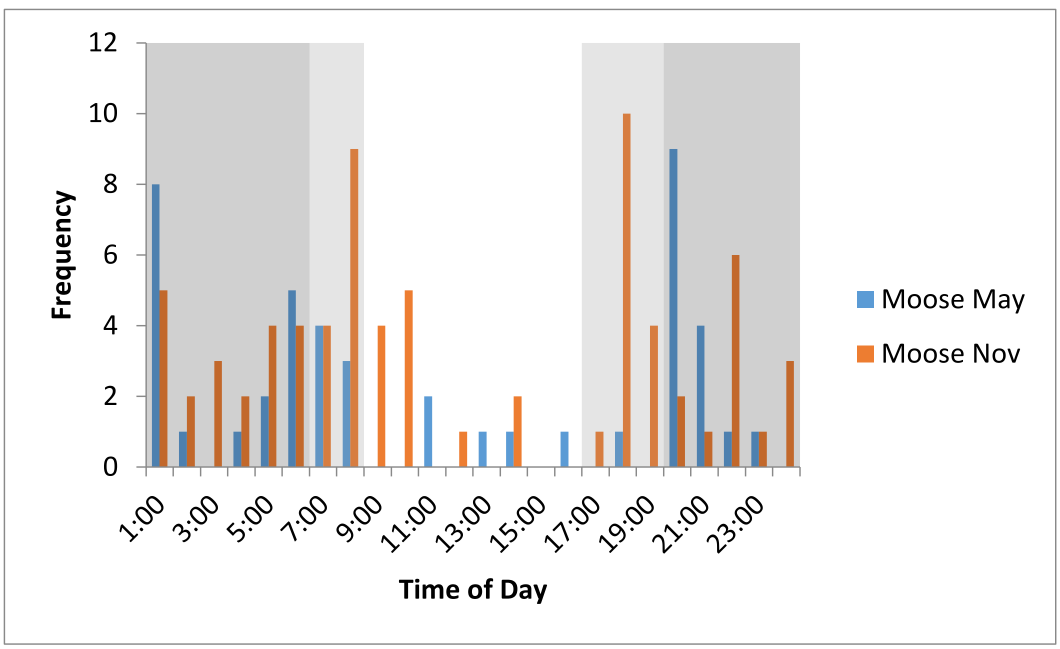

Figure 1.32. Frequency of US 20 crossings by collared moose in May (n = 45) and November (n = 57) by time of day. Light grey shading represents approximate dark hours in November; darker grey shading represents approximate dark hours in May. Data are from 30-minute data collection intervals only. Data were collected from 2010-2013.

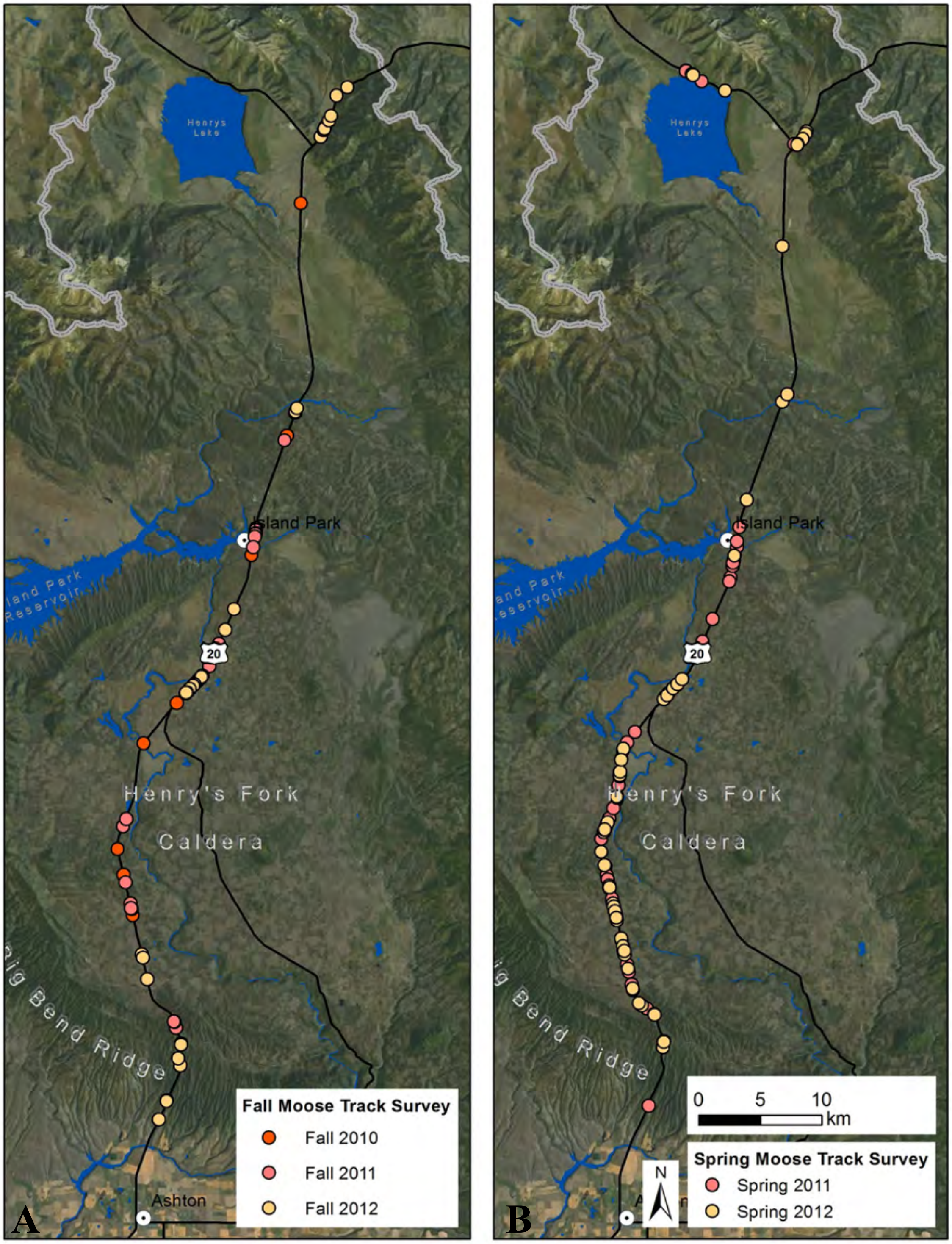

Figure 1.33. Moose track surveys in the fall (A) and spring (B) suggest that most moose cross US 20 between Island Park and Big Bend Ridge.

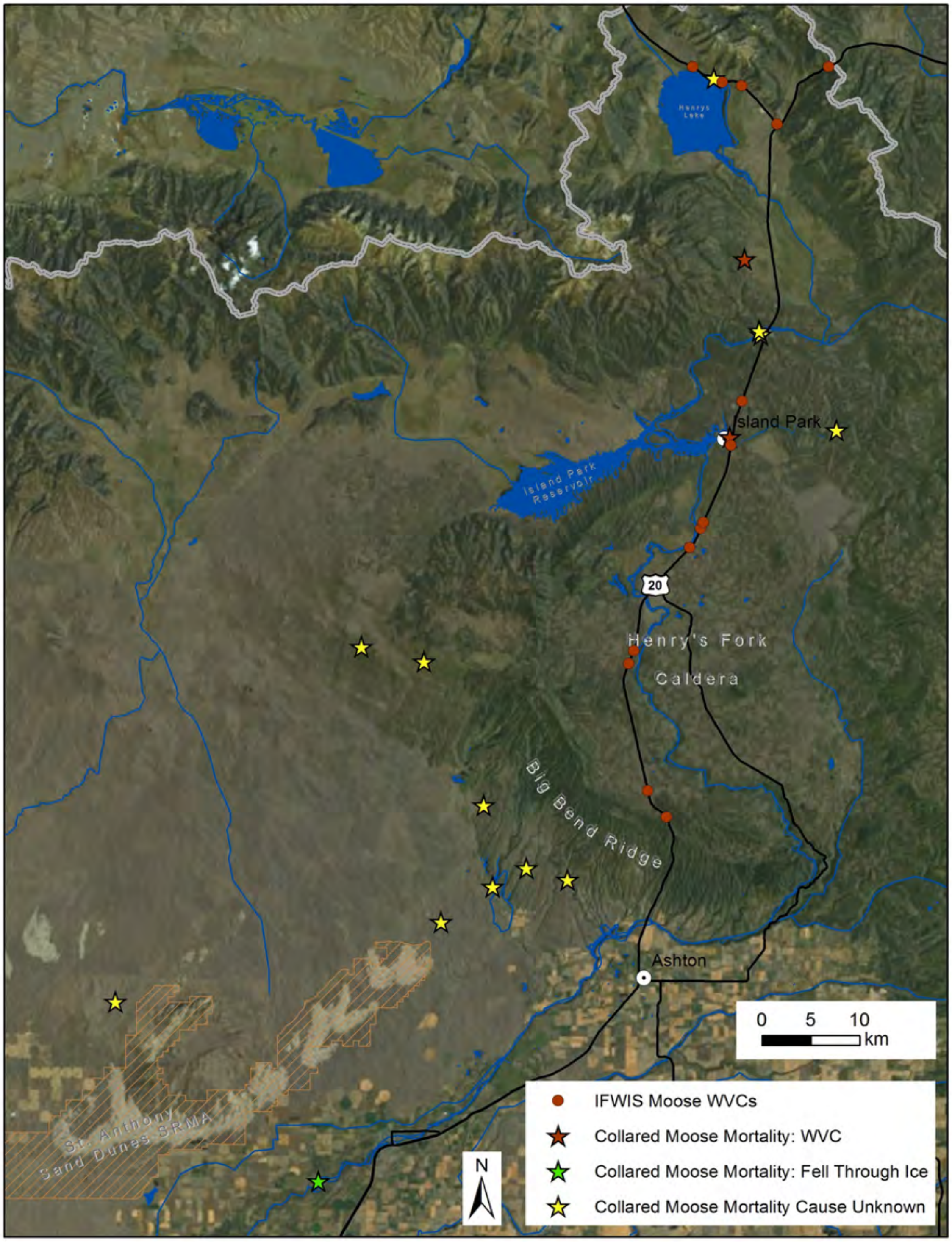

Figure 1.34. Sixteen wildlife vehicular collisions with moose on US 20 in the study site were reported to the Idaho Fish and Wildlife Information System between 2010 - 2012. Two collared moose were hit by vehicles, one was euthanized after falling through ice, and 12 collared moose died of unknown causes. Six of the 15 collared moose mortalities were non-migratory moose and included the 2 vehicular collision mortalities.

hit by vehicles, one died after falling through ice, and 12 died of unknown causes (Figure 1.34). Six of the 15 moose were Island Park residents, including the 2 killed by vehicles. Another non-migratory moose died just after making its only documented crossing of US 20, suggesting a possible WVC. The 2010-2012 IFWIS dataset consisted of 16 moose WVCs. These collisions occurred at the top of Big Bend Ridge (near MP 369-370), south of the Osborne Bridge (near MP 376-377), near Last Chance (near MP 382-384) and Island Park (near MP 387 and 389), at the Highway 87 – US 20 junction (near MP 0 on Highway 87), north of this junction on US 20 (near MP 406), and along Highway 87 near Henry's Lake (MP 2-5; Figure 1.34). Most documented moose wildlife-vehicle collisions occurred primarily in July, August, September, and October (Figure 1.23).

DISCUSSION

Elk and moose that winter in the lower elevations below Big Bend Ridge near the St. Anthony Sand Dunes are predominantly migratory. Collared elk in this study all migrated to summer range at higher elevations north of their winter range. Moose collared at lower elevations were also migratory, but some migratory moose moved to similar or lower elevations in the summer apparently pursuing perennial water sources, such as the Henry's Fork River. Most collared migratory moose, however, summered on the caldera, where higher elevations and forest stands provide cooler temperatures and thermal cover (Haase and Underwood 2013, Melin et al. 2014).

Migration routes to and from summer range follow various routes for both elk and moose and delineating consistent crossing points on US 20 would prove difficult without the use of resource selection and predictive models (see chapter 2) as well as other sources of data, such as track surveys and WVC databases. Track surveys did not suggest a consistent number of crossings among seasons, potentially due to easier tracking substrate in spring. However, track surveys otherwise demonstrated fairly consistent patterns for elk and for moose; hence these data are suitable for validating resource selection (RSF) models along US 20 (see chapter 2).

Wildlife-vehicle collision data may also be applicable for validating RSF models, although it has been suggested that WVCs occur in different locations than successful road crossings (see chapter 2). Wildlife-vehicle collisions with large ungulates (i.e., elk and moose) along US 20 are more prevalent in the summer and fall months (May – October), due in part to the fact that most of these animals winter off of the Henry's Fork Caldera and away from US 20 (Figures 1.14, 1.23, 1.25). Generally, elk and moose were less likely to cross US 20 during the midday and afternoon hours (8:00-18:00 for elk, 10:00-17:00 for moose; Figures 1.19, 1.31). Elk crossed US 20 most often between 4:00 and 5:00 (Figure 1.19). Moose most often crossed US 20 between 24:00 and 1:00 (Figure 1.31).

Here we offered an overview of the movement ecology of elk and moose between the Henry's Fork Caldera summer range and the Snake River Plain winter range in order to set the stage and lend additional perspective for examining and discussing the potential impacts of US 20 on long-distance ungulate migration. In subsequent chapters of this report, we examine selection for the habitat parameters (e.g., habitat type, terrain roughness, amount of horizontal concealment cover, distance to water) and features associated with roads (e.g., number of lanes, speed limit, road width) that elk and moose select when crossing US 20. These models and other data and analyses throughout this report allowed us to highlight the sections of US 20 and Idaho State Highway 87 that have the highest probability of crossing by these 2 species. With this information we were able to offer recommendations on locations and ways to potentially mitigate the impacts of US 20 and Highway 87 on elk, and non-migratory and migratory moose in this part of the GYE (see chapter 3).

CHAPTER 2

IMPACT OF ROAD AND ENVIRONMENTAL FACTORS ON ROAD CROSSING LOCATIONS BY ELK AND MOOSE IN THE GREATER YELLOWSTONE ECOSYSTEM

INTRODUCTION

US Highway 20 in the GYE near Island Park, Idaho represents a potential barrier to seasonal migratory movements for elk and moose as they move from summer range on the Henry's Fork Caldera to winter range in the Upper Snake River Plain (Figure 2.1). Wildlife-vehicle collisions (WVCs) represent a source of mortality for elk and moose along this road and WVCs are a threat to the traveling public's safety. In fact, from 1982-2012 Idaho Transportation Department (ITD) and Idaho Department of Fish and Game (IDFG) recorded 409 WVCs involving ungulates along a 42-mile stretch of the highway (US 20 mile post 364-406). This is an average of 13.6 WVCs per year that were recorded, with an unknown level of unreported or undetected WVCs. Elk represented 49.6% (*n* = 117) of those 236 WVC incidences for which the ungulate species was recorded, with moose (*Alces alces*) representing the other 50.4% (*n* = 119) of species-identified WVCs.

As a result, in 2009-10 we initiated this study with the goal of modeling the habitat parameters (e.g., habitat type, terrain roughness, amount of horizontal concealment cover, distance to water) and features associated with roads (e.g., number of lanes, speed limit, road width) that elk and moose select when crossing US 20. Following Lewis et al. (2011) we used a 2-step process to identify habitat and highway characteristics potentially important to predict where elk and moose cross the highway. We first modeled the movement of elk and moose between successive GPS locations on either side of the road to estimate a probability distribution where the animal crossed the road using Brownian bridge

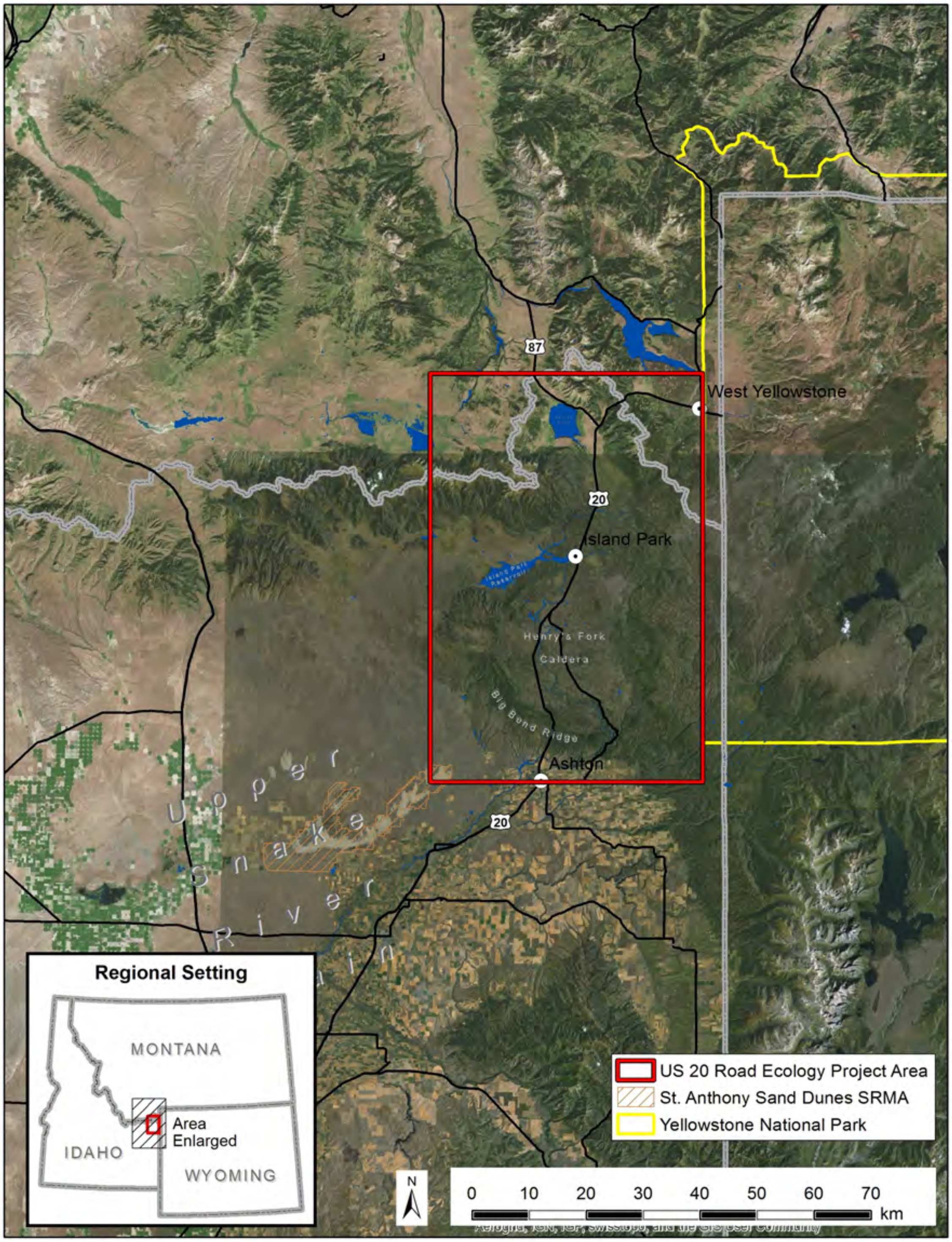

Figure 2.1. Study area and focal segment of US 20 where habitat selection by elk and moose at road crossing locations was evaluated in Fremont County, Idaho, USA 2010-2013.

movement models (BBMM; Horne et al. 2007). We then modeled resource selection of elk and moose at highway crossing locations using resource selection functions (RSFs; Manly et al. 2002). We used multimodel inference (Burnham and Anderson 2002) to select the best model, which was then mapped to illustrate the relative probability of highway crossings by elk and moose on US 20. We then validated the predictive ability of our model using 3 separate datasets: 1) a subset of withheld data 2) track survey data 3) WVC and traffic accident data. Ultimately these data and resulting models can inform decisions aimed at reducing WVCs with elk and moose and improve driver safety along US 20 in the GYE, mitigating the impact of US 20 on long-distance migrations of elk and moose in the region, and informing decisions and situations involving elk and moose crossing other highways in similar systems in the northern US Rockies.

METHODS

Model development

Data inclusion decisions

To minimize error associated with GPS locations in our RSF models, all 2-D GPS fixes were eliminated. We identified highway crossings as those crossings with at least 2 successive GPS locations on opposite sides of the highway. Two successive locations on opposite sides of the highway have been suggested to further minimize false crossings being identified by GPS location error (Lewis et al. 2011). We enumerated all highway crossings irrespective of GPS fix interval; however, only crossings during periods in which the programmed GPS interval was 30 minutes were used to model highway crossing locations. We did not include crossings that occurred within 12-hour intervals due to excessively large probability clouds resulting from such large time lags, sometimes in excess of 2 kilometers (Figure 2.2).

Development of 2-point Brownian bridge movement models

Brownian bridge movement models were used to estimate a probability distribution of where along the length of the highway an individual elk or moose crossed between 2 successive 30-minute interval GPS locations on either side. Brownian bridge models take into consideration 1) time lapse between points, 2) distance between successive locations, 3) positional error associated with locations, and 4) animal movement characteristics associated with the Brownian motion variance term (Horne et al. 2007, Sawyer et al. 2009). The term describing the Brownian motion variance contains information on how straight a movement path is as well as variation in speed and distance (Horne et al. 2007, Kranstauber et al. 2012). However, because the Brownian motion variance is calculated using a leave-one-out approach, a minimum of 3 locations is necessary for estimation. We therefore, calculated the Brownian motion variance for each crossing location using the entire track consisting of 30-minute location data specific for the individual and season for which the crossing was associated. We then incorporated the resulting Brownian motion variance to calculate the 2-point Brownian Bridge using the Animal Space Use program (Animal Space Use; Horne et al. 2009). We projected the probability distribution using a GIS and selected the pixel with the highest probability value that intersected the highway. The pixel with the highest probability value that intersected the highway was converted to a point and snapped to the road. This point then represented the location of the highest probability of crossing which was designated as our 'used' location (i.e. the crossing location) for subsequent predictive modeling.

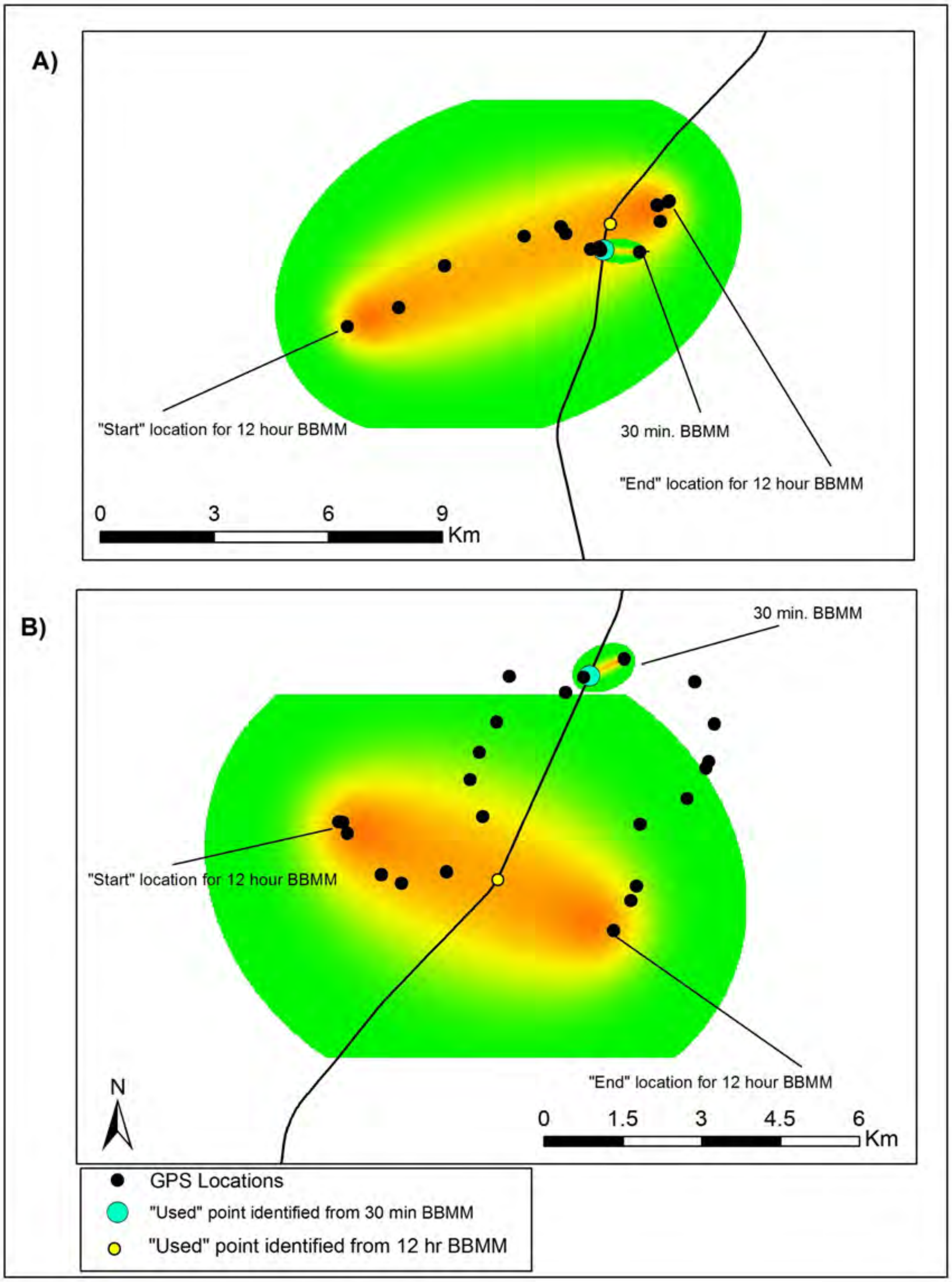

Figure 2.2. Comparison of road crossing locations estimated from crossings recorded during 12-hour GPS intervals and 30-minute intervals. In some instances, road crossings occurring within 12-hour GPS intervals may be estimated within several hundred meters from the more accurate 30-minute interval crossing location (A) when the path is a relatively straight line. However, the crossing location estimated from GPS locations taken at 12-hour intervals may be several kilometers from the 30-minute road crossing location if the animal did not travel in a straight line between the locations ($n = 25$; B).

Resource selection functions (RSF)

Defining the study area

We evaluated resource selection of highway crossings for a population of elk and a population of moose in which individual road crossings were identified as the unit of study under a use-availability design (Thomas and Taylor 1990, Manly et al. 2002). We defined the extent of the study area 'available' to moose as the most extreme northern and southern crossings occurring within 30-minute intervals buffered by the mean distance traveled by study animals within 30-minute intervals, plus 2 standard errors (i.e., 95% probability that the individual was in this area when crossing). This resulted in a buffer distance of 100 meters for moose. To assess the probability of road crossings at a similar extent for elk, we defined the area 'available' by the most northern and southern crossing occurring within a 30-minute interval or track recorded during track surveys along US 20 buffered by the mean distance traveled by study animals within 30-minute intervals, plus 2 standard errors (225m). Available locations were randomly selected from along the highway for comparison with used locations at a 3:1 ratio. Because all used and available locations were located directly on the highway, buffering locations was necessary to encompass potentially important habitat variables. We attempted to use a biologically relevant buffer size for elk and moose and therefore buffered each 'used' location, identified by BBMM, and 'available' location by the mean distance traveled by study animals within 30-minute intervals plus 2 standard errors (225 and 100 meters; see immediately above).

Development and incorporation of road and habitat variables

We obtained the percent habitat type (forest, riparian, shrub-grassland, and developed) on the landscape within buffers by re-categorizing the LANDFIRE 1.1.0 habitat model into 4 habitat types. The category ‘forest’ included all species of trees and ‘shrub-grass’ was a combination of all shrubland and grassland categories. Distance to water was derived using imagery from the National Hydrography Database and Near analysis in ArcMap 10.1 to obtain the Euclidean distance to the nearest water feature including rivers and streams as well as lakes and ponds.

We created a layer depicting terrain ruggedness (Vector Ruggedness Measure – VRM) from a digital elevation model using methods described by Sappington et al. (2007) that incorporate the heterogeneity in both slope and aspect while minimizing dependence of slope and aspect values. The VRM values are therefore low in areas that are flat and areas that are steep with little heterogeneity, but are greater in areas that are steep and rugged (Sappington et al., 2007).

In order to measure how an elk or moose might use vegetation as cover near a road, we generated 200 sampling points per species to estimate horizontal vegetative cover along US 20. To do this, we randomly selected 50 known crossing locations for each species based on all years’ track surveys and then randomly generated 150 points. In order to ensure relatively uniform sampling in proportion to track samples across the entire study area, we divided the highway into 5 equal segments and sampled the 150 points proportional to the number of tracks within each segment. In April 2013, we measured the distance to cover and disappearance distance of a cover board (1.83 x 0.91 m painted with 8 black and white 47.5 cm squares) at each sampling location on both sides of the road (Nudds 1977, Mysterud 1996). Distance to cover was measured as the distance from the edge of the pavement to the edge of horizontal cover (vegetation or otherwise) that a large ungulate could be obscured in. Disappearance distance meant complete obstruction of the cover board by horizontal cover. Distance to cover and disappearance distance values from the resulting 800 (elk and moose, east and west sides of road) sampled locations were then interpolated, separately for each side of the highway, across the landscape using the inverse distance weighted (IDW) tool in ArcMap 10.1. Because of recent horizontal cover vegetation thinning along US 20 which was completed in October 2010 in the southern end of the study area, we hypothesized that distance to cover would best account for this mitigation and used it as a variable in our models. Because these measures were larger in less dense cover, higher values represent more open areas on the landscape.

Road density was calculated as the mean linear kilometers of road per 1 square kilometer neighborhood in ArcGIS. GIS layers depicting other road variables associated with US 20, including the number of lanes (2 or 3) and speed limit (45 mph or 65 mph), were obtained from Idaho Transportation Department (ITD).

Point values of predictor variables were extracted to all 'used' and 'available' locations in ArcGIS for number of lanes, speed, road density, and distance to water. Mean values within the buffers were calculated using the Geospatial Modeling Environment (GME; Beyer 2012) for terrain ruggedness and horizontal cover. The GME was also used to calculate the proportion of each habitat type on the landscape within the buffers (Table 2.1 and 2.2).

We assessed multicollinearity of predictor variables ($r > 0.6$) separately for elk and moose datasets using Pearson's correlation matrix for continuous variables in program R (R Development Core Team 2013). We also used the R package Polychor for polyserial comparisons between continuous and categorical variables, and polychoric tests to

Table 2.1. Variables considered and those retained for inclusion into resource selection functions for elk road crossing locations on US 20 in eastern Idaho, USA between 2011 and 2013.

Variable	Variable Description	Method	Source	Type	Effect Category	Retained
Forest	Aspen, conifer, conifer-aspen mix	Percent within buffer	LANDFIRE 1.1.0	Continuous	Habitat	
Riparian	Riparian	Percent within buffer	LANDFIRE 1.1.0	Continuous	Habitat	x
ShrubGrass	Agriculture, shrub, herbaceous, sparse	Percent within buffer	LANDFIRE 1.1.0	Continuous	Habitat	
DistWater	Distance to water (rivers, streams, lakes, ponds)	Euclidean Distance	National Hydrography Database	Continuous	Water	
RuggedMN	Terrain ruggedness	Mean value within buffer	Developed following Sappington et al. (2007)	Continuous	Topography	
DisDistMN	Disappearance distance interpolated	Mean value within buffer	Data collected in field	Continuous	Vegetative cover	
DstCovMN*	Distance to cover interpolated	Mean value within buffer	Data collected in field	Continuous	Vegetative cover	x
RdDens	Road density	Point estimate	State of Idaho	Continuous	Road	x
Developed*	Developed	Percent within buffer	LANDFIRE 1.1.0	Continuous	Anthropogenic	
Speed (45 or 65)	Speed limit	Point estimate	ITD	Categorical	Road	
Nlanes (2 or 3)	Number of lanes	Point estimate	ITD	Categorical	Road	

*Variables demonstrated instability in models by flipping between positive and negative coefficent values when included with other habitat covariates.

Table 2.2. Variables considered and those retained for inclusion into resource selection functions for non-migratory and migratory moose road crossing locations on US 20 in eastern Idaho, USA between 2011 and 2013.

Variable	Variable Description	Method	Source	Type	Effect Category	Non-migratory Retained	Migratory Retained
Forest	Aspen, conifer, conifer-aspen mix	Percent within buffer	LANDFIRE 1.1.0	Continuous	Habitat		
Riparian	Riparian	Percent within buffer	LANDFIRE 1.1.0	Continuous	Habitat	x	x
ShrubGrass	Agriculture, shrub, herbaceous, sparse	Percent within buffer	LANDFIRE 1.1.0	Continuous	Habitat		
DistWater	Distance to water (rivers, streams, lakes, ponds)	Euclidean Distance	National Hydrography Database	Continuous	Water		
RuggedMN	Terrain ruggedness	Mean value within buffer	Developed following Sappington et al. (2007)	Continuous	Topography	x	
DisDistMN	Disappearance distance interpolated	Mean value within buffer	Data collected in field	Continuous	Vegetative cover		
DstCovMN	Distance to cover interpolated	Mean value within buffer	Data collected in field	Continuous	Vegetative cover	x	x
RdDens	Road density	Point estimate	State of Idaho	Continuous	Road		x
Developed*	Developed	Percent within buffer	LANDFIRE 1.1.0	Continuous	Anthropogenic		x
Speed (45 or 65)	Speed limit	Point estimate	ITD	Categorical	Road	x	
Nlanes (2 or 3)	Number of lanes	Point estimate	ITD	Categorical	Road		

*Variables demonstrated instability in models by flipping between positive and negative coefficent values when included with other habitat covariates.

compare categorical variables (Fox 2013). Prior to model building, we examined explanatory ability of each potential predictor variable by running univariate logistic regression models. Thus, when removing correlated or redundant variables, we attempted to maintain the most biologically and statistically explanatory variables while also maintaining variables associated with the highway (see Appendix B for univariate results).

RSF model development

For elk, we randomly removed 20 crossings from the full dataset collected between December 2010 and December 2013 prior to model development to use as an independent validation of the final model and used the remaining 37 crossings as a training dataset to develop the model (see Figure 2.3A). The number of predictor variables was reduced considerably after selecting the most explanatory variables based on results from univariate models and removing correlated and redundant variables. We used the remaining variables to construct 4 *a priori* models representing hypothesized combinations of habitat and road variables important to where elk choose to cross the highway (Table 2.3). We used logistic regression to fit the data to these 4 models in addition to the 3 main effects models (models with single covariates) assessing each variable independently (Table 2.3). We tested for potential confounding effects of differential selection of variables between years by testing each of the 7 models with an interaction term for year. We repeated these steps to test for confounding effects of season. We used AIC corrected for small sample size (AICc; Burnham and Anderson 2002) to select the models that best explained the habitat and road variables associated with highway crossings. To assess potential importance of season and year on habitat selection at road crossing locations for elk, we examined model output for significance of coefficients resulting from inclusion of interac-

Table 2.3. *A priori* models representing hypothesized combinations of habitat and road variables important to where elk choose to cross the highway along US 20 in eastern Idaho, USA 2011-2013. Variables were grouped into models to evaluate how elk select for characteristics associated with natural habitat and highway characteristics.

Model#	Model	K
1	Riparian	2
2	DstCovMN	2
3	RdDens	2
4	Riparian+DstCovMN	3
5	Riparian+RdDens	3
6	RdDens+DstCovMN	3
7	DstCovMN+RdDens+Riparian	4

tion terms in addition to AICc model rankings. We averaged parameter estimates across models that were within Δ 4 AICc points using 'shrinkage' estimates (Burnham and Anderson 2002). We quantified the relative importance of each explanatory variable by summing Akaike weights over the subset of all models in which the variable appeared (Burnham and Anderson 2002). We used the averaged coefficients obtained from logistic regression to fit the RSF:

$$w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k)$$

where $w(x)$ represents a resource selection function for the predictor variables, x_i, and associated coefficients (β_i).

Because early analysis indicated that non-migratory and migratory moose select habitat differently at road crossing locations, we created separate models for non-migratory and migratory moose and validated those models independently. For the non-migratory moose model, we *a priori* randomly removed 30 moose crossings from the full non-migratory moose dataset collected between December 2010 and December 2013 to use as an independent validation of the final model (see Figure 2.7A). The remaining crossings were used as a training dataset to create the model for non-migratory moose. We created 10 *a priori* models representing hypothesized combinations of habitat and road variables potentially important to predicting where moose highway crossings occur based on expert opinion from WCS and IDFG biologists (Table 2.4). We used logistic regression to fit the data to these 10 models in addition to all 4 main effects models (models with single covariates) assessing each variable independently. Confounding effects, model selection, and the logistic regression model were treated the same for non-migratory moose as for elk. We repeated the same steps for migratory moose crossings,

Table 2.4. *A priori* models representing hypothesized combinations of habitat and road variables important to where non-migratory moose choose to cross the highway along US 20 in the eastern Idaho, USA 2011-2013. Variables were grouped into models to evaluate how non-migratory moose select for characteristics associated with natural habitat and highway characteristics.

Model#	Model	K
1	Riparian	2
2	RuggedMN	2
3	DstCovMN	2
4	Speed	2
5	Riparian+DstCovMN	3
6	DstCovMN+RuggedMN	3
7	Riparian+DstCovMN+RuggedMN	4
8	Riparian+DstCovMN+Speed	4
9	DstCovMN+Speed	3
10	Riparian+Speed	3
11	Riparian+Speed+RuggedMN	4
12	Speed+RuggedMN	3
13	Riparian+DstCovMN+Speed+RuggedMN	5
14	Riparian+RuggedMN	3

Table 2.5. *A priori* models representing hypothesized combinations of habitat and road variables important to where migratory moose choose to cross the highway along US 20 in the eastern Idaho, USA 2011-2013. Variables were grouped into models to evaluate how migratory moose select for characteristics associated with natural habitat and highway characteristics.

Model#	Model	K
1	Riparian	2
2	DstCovMN	2
3	RdDens	2
4	Developed	2
5	Riparian+DstCovMN	3
6	DstCovMN+RdDens	3
7	Riparian+RdDens	3
8	Riparian+Developed	3
9	DstCovMN+Developed	3

however due to small sample sizes of road crossings, we limited the number of variables per *a priori* model to 2, resulting in a total of 9 models for migratory moose (Table 2.5). In addition, we did not remove crossings from the migratory moose dataset for validation because of limited sample sizes (see Figure 2.12A).

RSF Model Validation

In order to examine model predictive ability, we conducted tests of model validation using 3 independent datasets assessed with a Spearman rank correlation and linear regression (see Boyce et al. 2002). The validation datasets consisted of 1) a random subset of elk or non-migratory moose crossings withheld *a priori* from the full dataset (n = 20 for elk, n = 30 for non-migratory moose), 2) elk and moose road crossing data obtained from our track surveys (n = 432 for elk, n = 200 for moose), and 3) data from WVC locations for elk (n = 55) and moose (n = 49). Only locations of WVCs involving elk or moose that were measured to the nearest 0.16 km (0.1 mile) or documented by GPS were used in model validation.

Within a spreadsheet (Microsoft Excel), we fit the random "available" locations sampled on the landscape (n = 111 for elk, and n = 270 for non-migratory moose) with the final RSF to represent the range of habitat selection within the extent that the model was developed (Anderson et al. 2005). The RSF values for the available locations were then sorted from lowest to highest and grouped into 5 rank bins representing relative probability of use (low to high), with approximately equal number of random locations in each (n = 22 for elk, n = 54 for moose). Resource selection functions were then fit to the held out test data (n = 20; 30). The number of test locations with RSF values falling into each bin was recorded. A Spearman rank correlation coefficient (r_s) and coefficient of determination (R^2) were calculated to compare bin rank and the frequency of withheld data within each bin. Models with good predictive ability would be those with strong positive correlation (i.e., $r_s > 0.6$) with increasing frequency of locations falling into successively higher bin ranks (i.e., Boyce et al. 2002; Anderson et al. 2005).

In order to assess predictive ability of RSF models, we tested model predictions against distinct datasets consisting of road crossings recorded by track surveys and unsuccessful road crossings recorded by WVCs (Boyce et al. 2002; Howlin et al. 2004; see Figures 2.4B, 2.8B, and 2.13B for track surveys and 2.4C, 2.8C, and 2.13C for WVCs). Using these datasets as more stringent tests of the predictive ability of the model, we projected the RSF models for elk, non-migratory moose, and migratory moose in GIS using covariates associated with location points on the highway at 30-meter intervals extended as far north and south as the most northern and southern crossings recorded by 30-minute crossings or track surveys. We sorted the resulting RSF scores into bins ranked 1 – 10, with equal numbers of locations in each, representing low to high relative probability of crossing. This resulted in the road having equal representation in each category of relative probability (i.e., 1/10 of the road = lowest probability of crossing, 1/10 = highest relative probability of crossing). We overlaid the crossing locations obtained from the track surveys and WVCs on the RSF in GIS and recorded the number of locations (from track surveys and WVCs separately) falling within each bin. A Spearman rank correlation coefficient (r_s) and coefficient of determination (R^2) were calculated to compare bin rank and the frequency of track and WVC locations within each bin (for each dataset separately). We again expected that models with good predictive ability for successful crossings (track data) and unsuccessful crossings (WVC data) would be those with positive correlation (i.e., $r_s > 0.6$) with increasing frequency of locations falling into successively higher bin ranks (i.e., Boyce et al. 2002; Anderson et al. 2005).

RESULTS

Thirty-seven female elk were fitted with GPS collars and movements of 32 elk that remained on the air long enough to migrate were evaluated. Four individuals died shortly after being captured and did not cross the road and data from 1 individual was not obtained due to collar failure. We recorded 152 total elk crossings made by 14 individuals between December 2010 and December 2013. Of these crossings, 91 occurred during 12-hour interval collar schedules and 61 crossings during the 30-minute collar data collection intervals. We removed 4 of the 30-minute crossings that did not meet the criteria of > 1 location on both sides of the highway. Given the requirements for inclusion as an accurately identified crossing location, we retained a total of 57 road crossings made by 14 elk which occurred during 30-minute data collection intervals and had > 1 location on both sides of US 20. These 57 points were analyzed using the 2-point Brownian bridge movement model process (see above) to determine the 'used' locations to evaluate selection by elk at road crossings using the subsequent RSF models (see Figure 2.3A). The number of 30 minute crossings made by individual elk ranged from 1 to 19, with a median of 3. All crossings evaluated were during migration movements between seasonal ranges for elk.

Forty-two adult, female moose were fitted with GPS collars of which 36 moose that remained on the air long enough to examine movements were evaluated. Of the 6 moose that were not evaluated, 4 died within a month of capture and 2 had collar failure. Ten moose were identified as non-migratory and twenty moose were migratory (see Figure 1.3). One moose had a mixed strategy and was non-migratory one year and migratory the second year. However, she only contributed one road crossing during migration movements so we categorized her as non-migratory. Five moose were not monitored long enough to determine migration strategy. We recorded 354 total road crossings by moose made by 15 individuals between December 2010 and December 2013. Of these crossings, 208 occurred during 12-hour intervals and 146 occurred during 30-minute intervals. Thirteen crossings were made by 6 moose classified as migratory within 30-minute intervals and 120 crossings were made by 6 non-migratory moose within 30-minute intervals. We removed thirteen 30-minute crossings that did not meet the criteria of > 1 location on both sides of the highway. We retained a total of 120 road crossings made by 6 non-migratory moose and 13 crossings made by migratory moose which occurred during 30-minute intervals to evaluate habitat selection of migratory and non-migratory moose at road crossing locations (see Figures 2.7A and 2.12A). The number of 30-minute crossings used in the analysis made by individual non-migratory moose ranged from 1 to 85 (median = 7.5 crossings). The number of 30-minute crossings made by individual migratory moose ranged from 1 to 6 (median = 1 crossing).

Elk selection of crossing locations along US 20

We eliminated the variable representing the percentage of forest on the landscape from further analysis due to correlation with the amount of horizontal cover (disappearance distance and distance to cover) on the landscape (r = -0.80). We also eliminated speed (r = -0.59) and number of lanes (r = -0.59) due to correlation and redundancy with road density which was the better predictor of elk selection behavior at road crossing locations (Appendix B-1;Table 2.6). Terrain ruggedness, distance to water, and shrub grasslands, were also dropped due to instability when included in models with other vari-

Table 2.6 A) Pearson's correlation for all continuous variables (top table) and B) polychoric/polyserial correlations for categorical variables (bottom table) assessed for inclusion into resource selection functions for elk road crossing locations on US 20 in eastern Idaho, USA between 2011 and 2013.

A.	Forest	ShrubGrass	Riparian	DistWater	Developed	RdDens	RuggedMN	DisDistMN	DstCovMN
Forest	1.000	-0.682	-0.541	0.269	-0.147	-0.177	0.483	-0.807	-0.808
ShrubGrass	-0.682	1.000	-0.173	-0.016	-0.224	0.097	-0.327	0.572	0.573
Riparian	-0.541	-0.173	1.000	-0.309	0.148	-0.038	-0.230	0.481	0.468
DistWater	0.269	-0.016	-0.309	1.000	-0.178	-0.236	-0.345	-0.363	-0.343
Developed	-0.147	-0.224	0.148	-0.178	1.000	0.264	-0.144	-0.020	-0.025
RdDens	-0.177	0.097	-0.038	-0.236	0.264	1.000	-0.289	0.095	0.148
RuggedMN	0.483	-0.327	-0.230	-0.345	-0.144	-0.289	1.000	-0.324	-0.301
DisDistMN	-0.807	0.572	0.481	-0.363	-0.020	0.095	-0.324	1.000	0.953
DstCovMN	-0.808	0.573	0.468	-0.343	-0.025	0.148	-0.301	0.953	1.000

B.	Speed	Nlanes	Forest	ShrubGrass	Riparian	DistWater	RdDens	RuggedMN	DisDistMN	DstCovMN
Speed	1.000	1.000	0.176	0.382	-0.132	0.407	-0.590	0.490	0.075	0.063
Nlanes	1.000	1.000	0.176	0.382	-0.132	0.407	-0.590	0.490	0.075	0.063
Forest	0.176	0.176	1.000	-0.630	-0.516	0.311	-0.194	0.532	-0.793	-0.801
ShrubGrass	0.382	0.382	-0.630	1.000	-0.134	0.048	0.072	-0.253	0.593	0.584
Riparian	-0.132	-0.132	-0.516	-0.134	1.000	-0.278	-0.050	-0.193	0.491	0.474
DistWater	0.407	0.407	0.311	0.048	-0.278	1.000	-0.256	-0.285	-0.346	-0.334
RdDens	-0.590	-0.590	-0.194	0.072	-0.050	-0.256	1.000	-0.313	0.088	0.145
RuggedMN	0.490	0.490	0.532	-0.253	-0.193	-0.285	-0.313	1.000	-0.304	-0.290
DisDistMN	0.075	0.075	-0.793	0.593	0.491	-0.346	0.088	-0.304	1.000	0.956
DstCovMN	0.063	0.063	-0.801	0.584	0.474	-0.334	0.145	-0.290	0.956	1.000

ables (flipping of coefficient signs).

Model selection results and interaction terms suggested that there was no detectable difference in habitat selection at road crossings for elk among seasons or years (Δ AICc > 4.0, $P > 0.05$). Relative importance of predictor variables calculated by summing Akaike weights across all models the variable appeared in indicated that road density (0.99), was the most important variable followed by distance to cover (0.56), and riparian (0.53) .

There was uncertainty as to the best model in our set of candidate models with the first through fourth models having Akaike weights of 0.37, 0.29, and 0.19 and 0.16 respectively (Table 2.7). Average parameter estimates suggest elk select for areas on the landscape that have relatively low average density of roads (95% confidence intervals do not overlap 0 for this variable; Table 2.8). Parameter coefficients from the final averaged model indicate that elk select areas to cross the highway where there is less distance between the edge of the road and horizontal vegetative cover and more riparian habitat on the landscape. However, 95% confidence intervals overlap zero for these variables (Table 2.8).

In terms of specific locations, the highest probability of crossing locations for elk were: 1) along Highway 87 at mile post 2 (Figures 2.3, 2.4, 2.5); 2) near the Montana border between mile post 405-406 (Figures 2.3, 2.4, 2.5); 3) south of Macks Inn near mile post 391 (Figures 2.3, 2.4, 2.6A); 4) near Osborne Bridge and the junction of US 20 and the Mesa Falls Road between mile posts 377-382 (Figures 2.3, 2.4, 2.6B); and 5) south of Swan Lake to the bridge north of Ashton between mile posts 365-376 (Figures 2.3, 2.4, 2.6C).

Table 2.7. Model selection results used to assess variables selected by elk at 37 crossing locations along US 20 in the eastern Idaho, USA 2011-2013. Variables were grouped into models to evaluate how elk select for characteristics associated with natural habitat and highway characteristics.

Model#	Model	K	AICc	Δ AICc	AICc w_i
7	DstCovMN+RdDens+Riparian	4	153.2400	0	0.3700
3	RdDens	2	153.7600	0.5200	0.2900
6	RdDens+DstCovMN	3	154.5800	1.3400	0.1900
5	Riparian+RdDens	3	154.9800	1.7400	0.1600
4	Riparian+DstCovMN	3	164.7700	11.5300	0
2	DstCovMN	2	167.5000	14.2600	0
1	Riparian	2	169.5000	16.2600	0

Table 2.8. Parameter estimates and standard errors of variables from the top models (Δ AIC < 4), model averaged parameter estimates (shrinkage estimates) with standard errors, and 95% confidence intervals for parameter estimates for habitat selection of crossing locations by elk along US 20 in eastern Idaho, USA, 2011-2013.

Model #	AICc w_i	DstCovMN	RdDens	Riparian
7	0.37	-0.0072 (0.0039)	-0.7411 (0.2288)	2.1715 (1.1839)
3	0.29		-0.8048 (0.2264)	
6	0.19	-0.0033 (0.0030)	-0.7693 (0.2282)	
5	0.16		-0.8037 (0.2267)	0.8746 (0.9351)
Averaged		-0.0033 (0.0041)	-0.7743 (0.2313)	0.9393 (1.2717)
95% CI		-0.0140 ; 0.0021	-1.2278 ; -0.3209	-0.7042 ; 4.2806

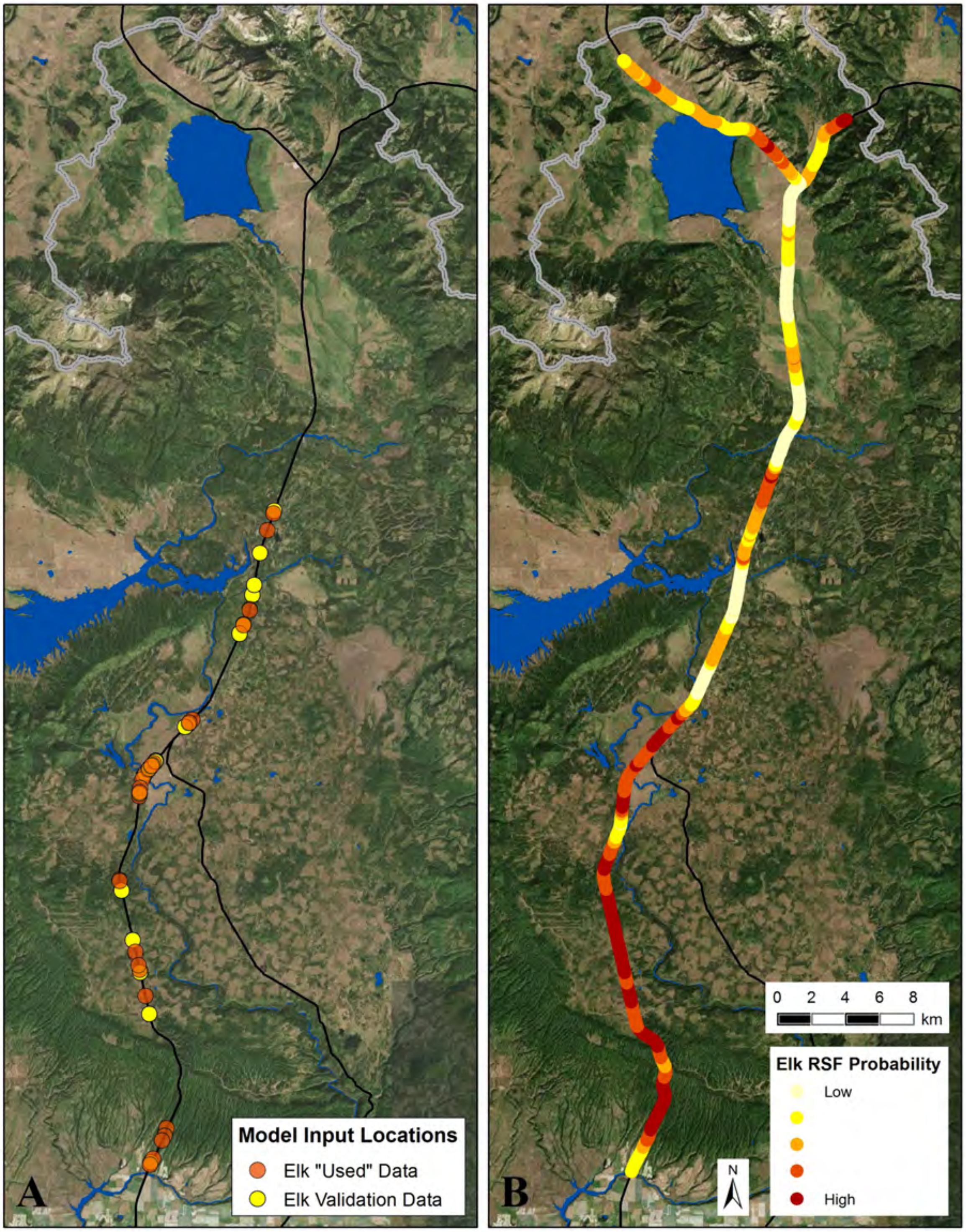

Figure 2.3. A) Crossing locations used in training dataset to model resource selection of elk at road crossing locations (n = 37; "used" locations) and validation dataset (n = 20) and B) resource selection function for elk showing relative probability of crossing areas along US 20, Idaho, USA 2010-2013.

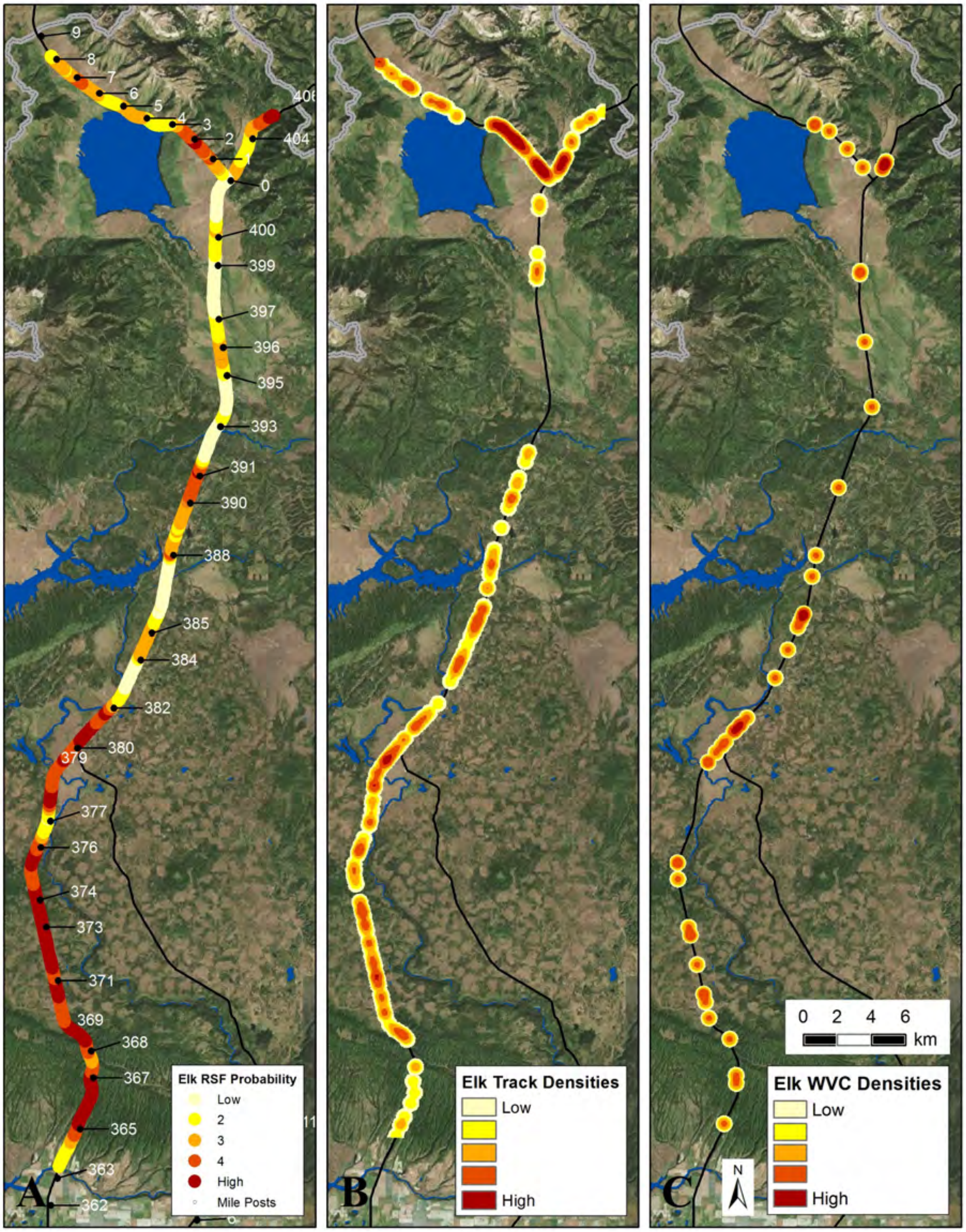

Figure 2.4. A) Resource selection function for elk showing relative probability of crossing areas, 2010-2013, B) relative density of road crossing locations of elk recorded during track surveys 2010-2013, and C) elk-vehicle collisions reported along US 20, Idaho, USA from 1982-2012. Note that track survey data were only collected as far south as displayed in the map (i.e., the extent of the track densities represents the extent of the surveys).

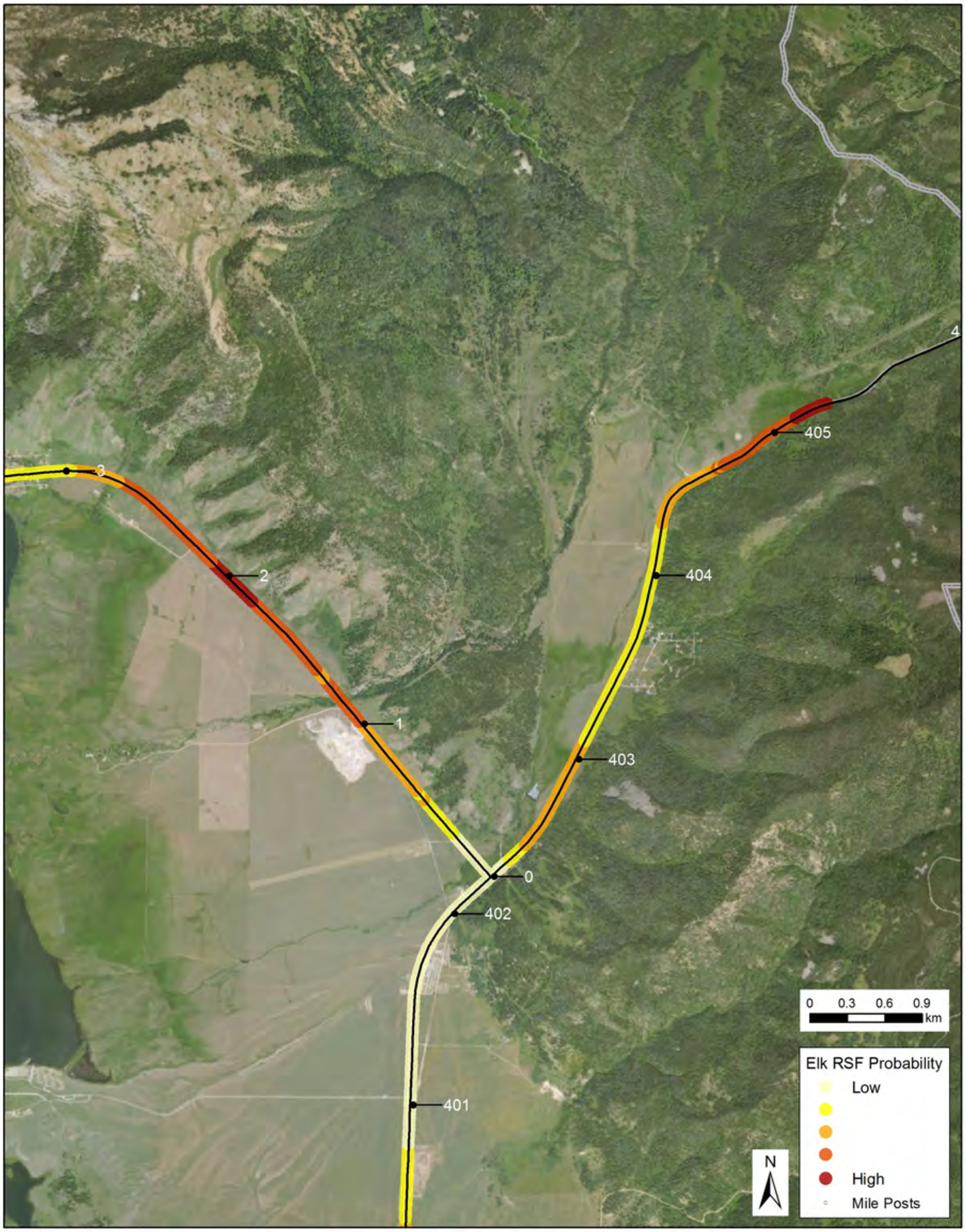

Figure 2.5. High probability of road crossing for elk along Highway 87 at mile post 2 and on US 20 near the Montana border between mile post 405-406 in Fremont County, Idaho, USA 2010-2013.

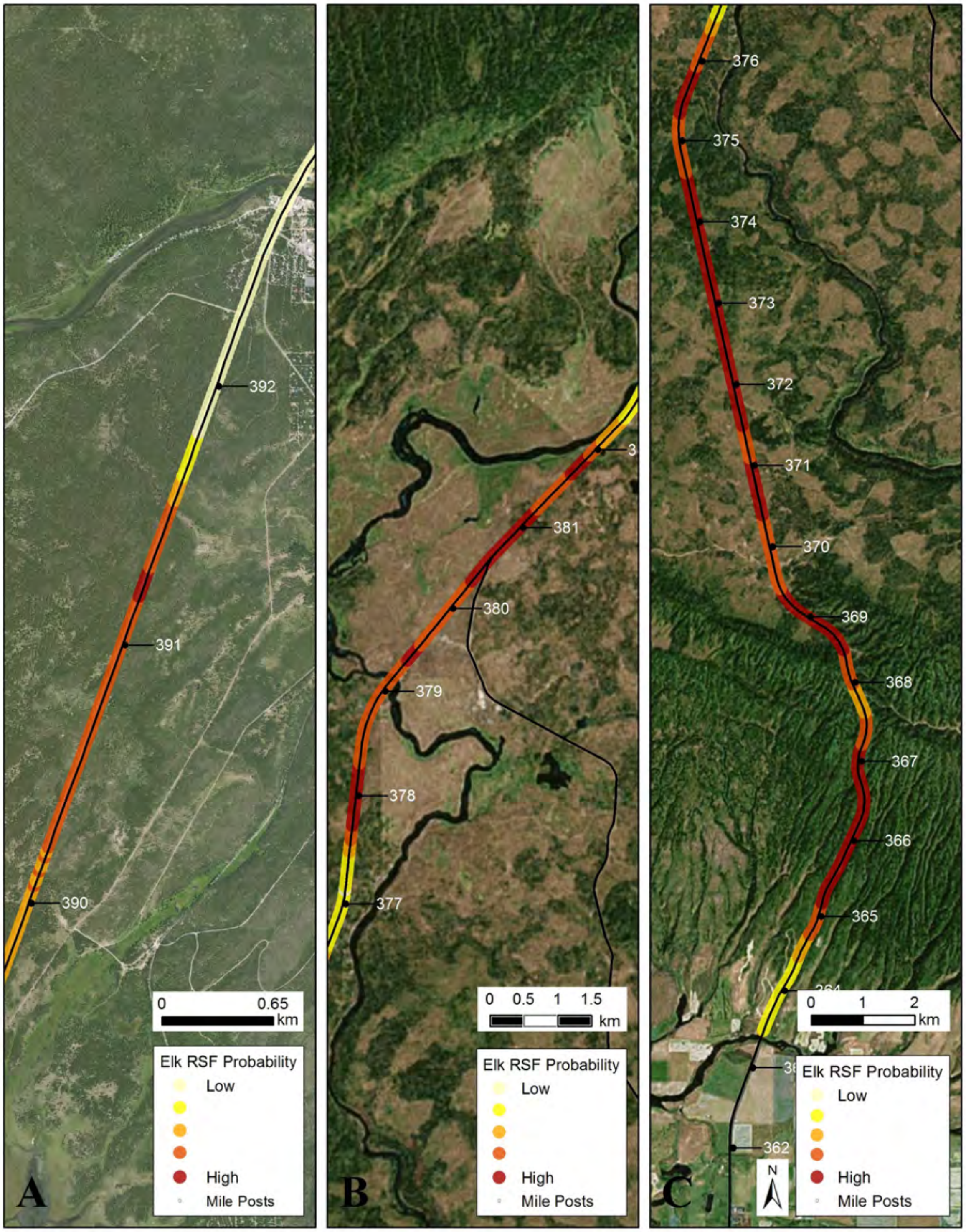

Figure 2.6. High probability of road crossing for elk A) south of Macks Inn near mile post 391, B) near Osborne Bridge and the junction of US 20 and the Mesa Falls Road between mile posts 377-382, and C) south of Swan Lake to the bridge north of Ashton between mile posts 365-376 along US 20 in Fremont County, Idaho, USA 2010-2013.

Non-migratory moose selection of crossing locations along US 20

Percent forest on the landscape was correlated with distance to cover (r = -0.68). As we were interested in accounting for horizontal cover vegetation thinning conducted by ITD in 2010, we retained distance to cover as the more explanatory variable over forest. We also eliminated distance to water (r = 0.74), road density (r = -0.69) and number of lanes (r = 1.0) due to correlation with speed, as speed was the better predictor of moose selection behavior at road crossing locations (Appendix B-2; Table 2.9).The top model (percent riparian habitat, distance to cover, speed limit, and terrain ruggedness) carried over 99% of the AICc weight, indicating that these were the most important combination of variables associated with non-migratory moose highway crossings (Table 2.10). Parameter estimates from this top model suggest non-migratory moose select for areas on the landscape that have more riparian habitat, have relatively more horizontal cover, are in 45 mph speed limit zones and are relatively less rugged. For each of these factors, the 95% confidence intervals did not overlap 0 (Table 2.11). Parameter estimates for interaction terms for year and season indicated that there may be slight differences in the way that non-migratory moose select for riparian habitat at road crossings between spring and fall (P = 0.035). However, after Bonferroni correction for multiple samples, this difference is not statistically significant. Further, model selection results suggested that including the interaction did not improve the model (Δ AICc > 4.0) and limited sample sizes precluded modeling habitat selection at road crossing locations for season or year separately.

In terms of specific locations, the highest probability of non-migratory moose crossing locations were: 1) near Henry's Lake along Highway 87 from mile post 3-5

Table 2.9. A) Pearson's correlation for all continuous variables (top table) and B) polychoric/polyserial correlations for categorical variables (bottom table) assessed for inclusion into resource selection functions for moose road crossing locations on US 20 in eastern Idaho, USA between 2011 and 2013.

A.	Forest	ShrubGrass	Riparian	DistWater	Developed	RdDens	RuggedMN	DisDistMN	DstCovMN
Forest	1.000	-0.644	-0.477	0.457	-0.273	-0.250	0.269	-0.702	-0.677
ShrubGrass	-0.644	1.000	-0.209	-0.031	-0.152	-0.102	-0.181	0.524	0.549
Riparian	-0.477	-0.209	1.000	-0.470	0.158	0.246	-0.135	0.326	0.259
DistWater	0.457	-0.031	-0.470	1.000	-0.203	-0.440	-0.160	-0.367	-0.338
Developed	-0.273	-0.152	0.158	-0.203	1.000	0.305	-0.082	0.095	0.077
RdDens	-0.250	-0.102	0.246	-0.440	0.305	1.000	-0.177	0.137	0.112
RuggedMN	0.269	-0.181	-0.135	-0.160	-0.082	-0.177	1.000	-0.182	-0.133
DisDistMN	-0.702	0.524	0.326	-0.367	0.095	0.137	-0.182	1.000	0.950
DstCovMN	-0.677	0.549	0.259	-0.338	0.077	0.112	-0.133	0.950	1.000

B.	Speed	Nlanes	Forest	ShrubGrass	Riparian	DistWater	RdDens	Developed	RuggedMN	DisDistMN	DstCovMN
Speed	1.000	1.000	0.399	0.311	-0.395	0.736	-0.691	-0.521	0.403	-0.150	-0.055
Nlanes	1.000	1.000	0.399	0.311	-0.395	0.736	-0.691	-0.521	0.403	-0.150	-0.055
Forest	0.399	0.399	1.000	-0.601	-0.458	0.508	-0.268	-0.286	0.306	-0.704	-0.664
ShrubGrass	0.311	0.311	-0.601	1.000	-0.184	0.038	-0.127	-0.170	-0.132	0.521	0.567
Riparian	-0.395	-0.395	-0.458	-0.184	1.000	-0.440	0.236	0.150	-0.113	0.324	0.267
DistWater	0.736	0.736	0.508	0.038	-0.440	1.000	-0.470	-0.225	-0.100	-0.370	-0.316
RdDens	-0.691	-0.691	-0.268	-0.127	0.236	-0.470	1.000	0.313	-0.198	0.138	0.105
Developed	-0.521	-0.521	-0.286	-0.170	0.150	-0.225	0.313	1.000	-0.097	0.096	0.072
RuggedMN	0.403	0.403	0.306	-0.132	-0.113	-0.100	-0.198	-0.097	1.000	-0.185	-0.118
DisDistMN	-0.150	-0.150	-0.704	0.521	0.324	-0.370	0.138	0.096	-0.185	1.000	0.949
DstCovMN	-0.055	-0.055	-0.664	0.567	0.267	-0.316	0.105	0.072	-0.118	0.949	1.000

Table 2.10. Model selection results used to assess variables selected by non-migratory moose at n = 90 crossing locations along US 20 in the eastern Idaho, USA 2011-2013. Variables were grouped into models to evaluate how non-migratory moose select for characteristics associated with natural habitat and highway characteristics.

Model#	Model	K	AICc	Δ AICc	AICc w_i
13	Riparian+DstCovMN+Speed+RuggedMN	5	343.1511	0	0.9995
7	Riparian+DstCovMN+RuggedMN	4	360.2541	17.1030	0.0002
8	Riparian+DstCovMN+Speed	4	360.4789	17.3279	0.0002
12	Speed+RuggedMN	3	362.0509	18.8999	0.0001
11	Riparian+Speed+RuggedMN	4	362.9246	19.7735	0.0001
9	DstCovMN+Speed	3	366.8374	23.6864	0
6	DstCovMN+RuggedMN	3	373.1819	30.0309	0
10	Riparian+Speed	3	376.8583	33.7073	0
4	Speed	2	378.3440	35.1930	0
5	Riparian+DstCovMN	3	378.8388	35.6877	0
14	Riparian+RuggedMN	3	381.4973	38.3462	0
2	RuggedMN	2	386.4160	43.2649	0
1	Riparian	2	396.6723	53.5212	0
3	DstCovMN	2	398.4141	55.2630	0

Table 2.11. Parameter estimates and standard errors of variables from the top model (Δ AIC < 4) and 95% confidence intervals for parameter estimates for habitat selection of crossing locations by non-migratory moose along US 20 in eastern Idaho, USA, 2011-2013.

Model #	AICc w_i	Riparian	DstCovMN	Speed1 (65mph)	RuggedMN
13	1	1.9140 (0.8940)	-0.0115 (0.0028)	-1.4901 (0.3420)	-1815.1220 (734.4106)
95% CI		0.1755 ; 3.6949	-0.0175 ; -0.0063	-2.1718 ; -0.8250	-3488.09 ; -616.4843

(Figures 2.7, 2.8, 2.9); 2) near Sawtelle Peak Road from approximately mile post 392 to just north of 394 (Figures 2.7, 2.8, 2.10A); 3) north of Island Park from mile post 389-390 (Figures 2.7, 2.8, 2.10B); 4) south of Island Park from just south of mile post 386-388 (Figures 2.7, 2.8, 2.10B); 5) where the Henry's Fork River is just west of US 20 near Trout Hunter Lodge from mile post 382-384 and near mile post 381 (Figures 2.7, 2.8, 2.10B); 6) near Swan Lake from mile post 375-378 (Figures 2.7, 2.8, 2.11A); and 7) a couple miles north of Big Bend Ridge from mile post 371-372 (Figures 2.7, 2.8, 2.11B).

Migratory moose selection of crossing locations along US 20

Akaike weights indicated that road density (0.99) was the most important variable associated with highway crossings for migratory moose and this variable did not overlap zero. Road density was in the top 3 models and the main effect model with only road density was the model with the greatest support (Table 2.12). Riparian (0.29), and distance to cover (0.22) followed in ranking by Akaike weights.

There was uncertainty as to the best model describing habitat selection by migratory moose at road crossings with the first, second, and third models having Akaike weights of 0.49, 0.29, and 0.22 respectively (Table 2.12). Parameter estimates from the averaged model suggest migratory moose select for areas on the landscape with relatively lower average road density (95% confidence intervals do not overlap zero for this parameter), riparian areas, and less distance from the road edge to horizontal vegetative cover. However, 95% confidence intervals did overlap zero for distance to cover and percent riparian habitat (Table 2.13). We did not test for differences in selection among year or season for migratory moose due to insufficient sample sizes necessary to include interaction terms and obtain meaningful results.

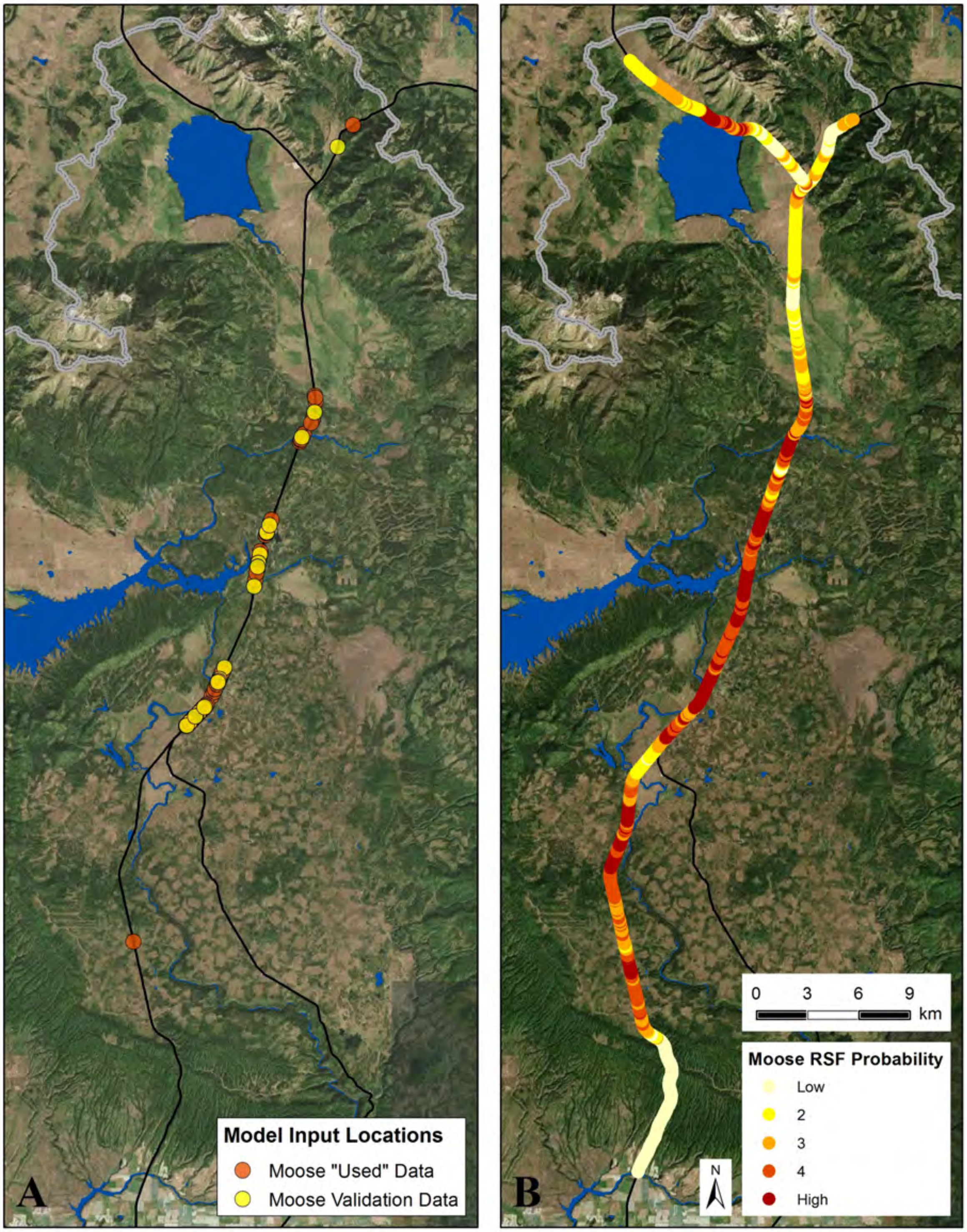

Figure 2.7. A) Crossing locations used in training dataset to model resource selection of non-migratory moose at road crossing locations (n = 90; "used" locations) and validation dataset (n = 30) and B) resource selection function for non-migratory moose showing relative probability of crossing areas along US 20, Idaho, USA 2010-2013.

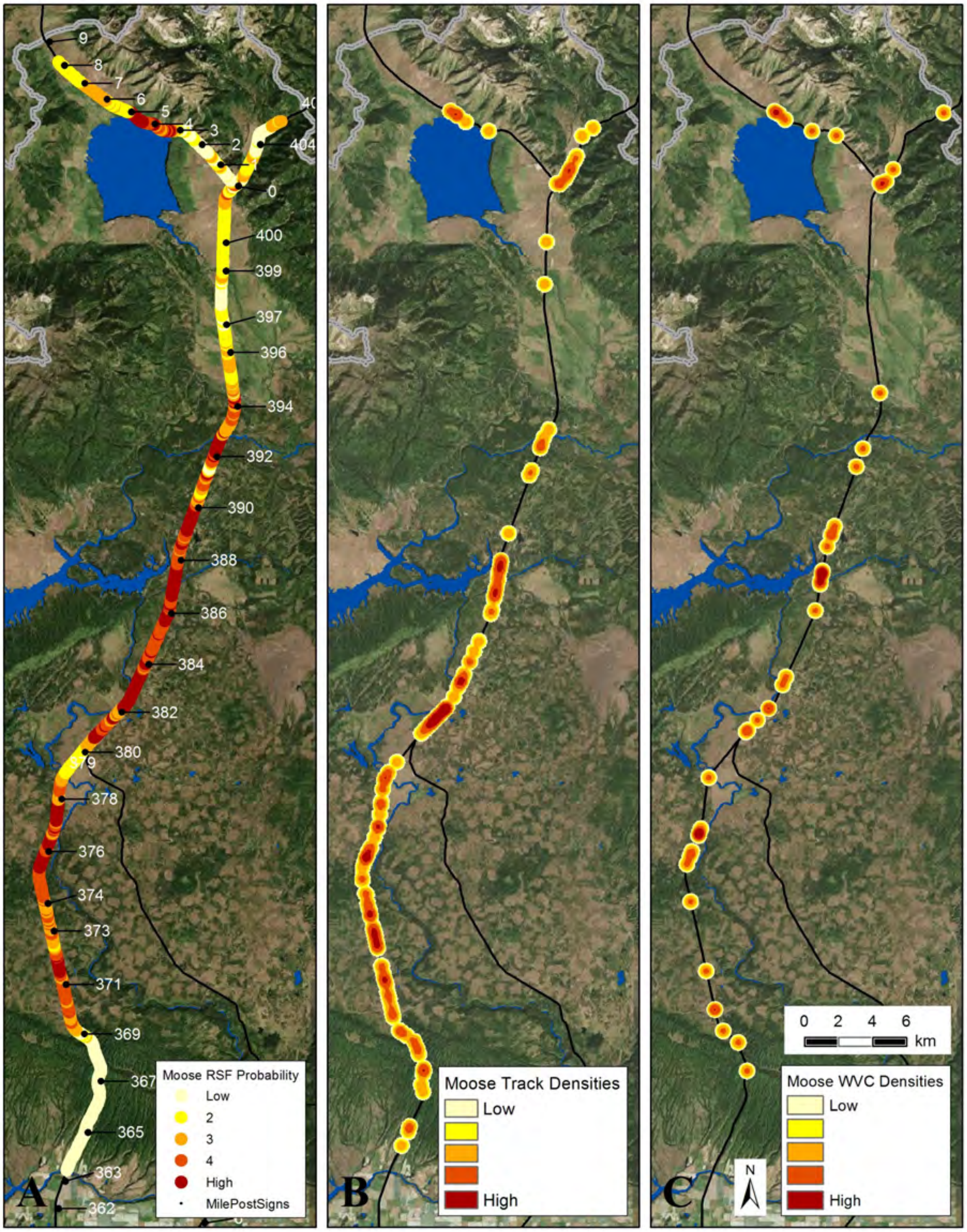

Figure 2.8. A) Resource selection function showing relative probability of crossing areas for non-migratory moose, 2010-2013, B) relative density of road crossing locations of moose recorded during track surveys 2010-2013, and C) moose-vehicle collisions reported along US 20, Idaho, USA from 1982-2012. Note that track survey data were only collected as far south as displayed in the map (i.e., the extent of the track densities represents the extent of the surveys).

Figure 2.9. High probability of road crossing for non-migratory moose near Henry's Lake along Highway 87 from mile post 3-5 in Fremont County, Idaho, USA 2010-2013.

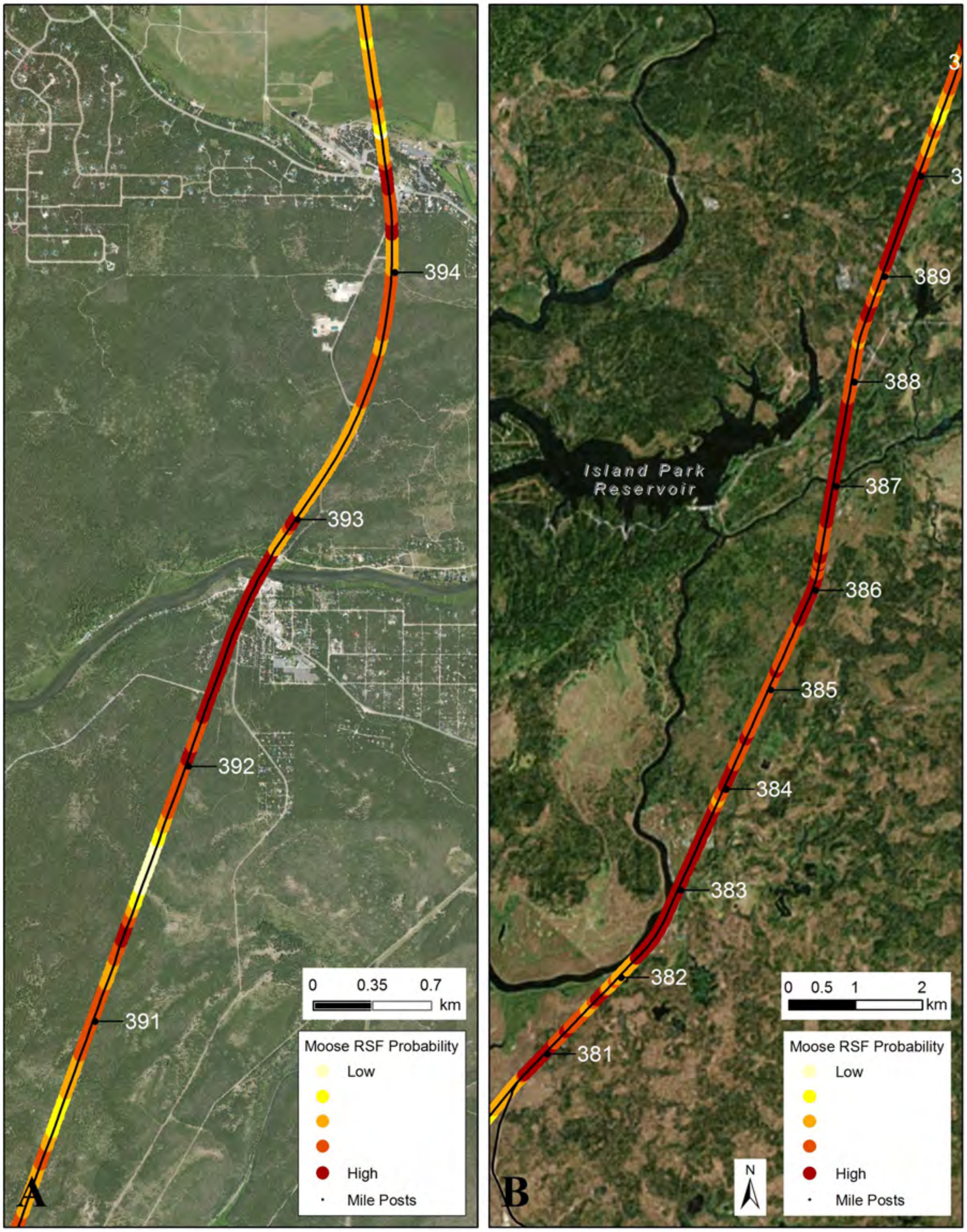

Figure 2.10. High probability of road crossing for non-migratory moose along US 20 A) near Sawtelle Peak Road from approximately mile post 392 to just north of 394 and B) north of Island Park from mile post 389 -390, south of Island Park from just south of mile post 386-388, and where the Henry's Fork River is just west of US 20 near Trout Hunter Lodge from mile post 382-384 and near mile post 381 in Fremont County, Idaho, USA 2010-2013.

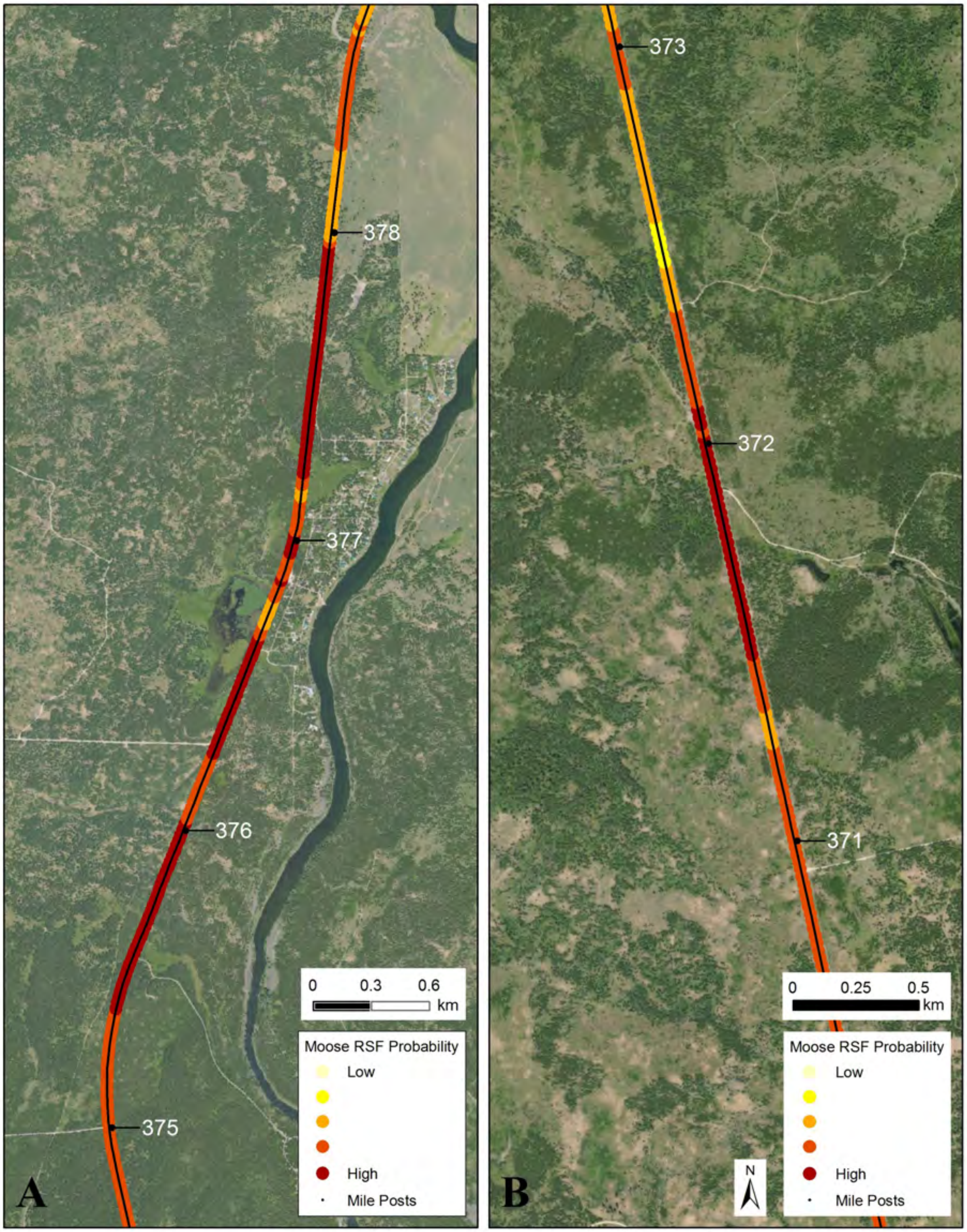

Figure 2.11. High probability of road crossing for non-migratory moose A) near Swan Lake from mile post 375-378 and B) a couple miles north of Big Bend Ridge from mile post 371-372 along US 20 in Fremont County, Idaho, USA 2010-2013.

Table 2.12. Model selection results used to assess variables selected by migratory moose at n = 13 crossing locations along US 20 in the eastern Idaho, USA 2011-2013. Variables were grouped into models to evaluate how migratory moose select for characteristics associated with natural habitat and highway characteristics.

Model#	Model	K	AICc	Δ AICc	AICc w_i
3	RdDens	2	45.6172	0	0.4885
7	Riparian+RdDens	3	46.6591	1.0419	0.2902
6	DstCovMN+RdDens	3	47.2346	1.6174	0.2176
9	DstCovMN+Developed	3	57.7410	12.1238	0.0011
4	Developed	2	58.3487	12.7316	0.0008
2	DstCovMN	2	58.6448	13.0277	0.0007
5	Riparian+DstCovMN	3	59.4754	13.8582	0.0005
8	Riparian+Developed	3	59.6399	14.0227	0.0004
1	Riparian	2	62.5299	16.9127	0.0001

Table 2.13. Parameter estimates and standard errors of variables from the top models (Δ AIC < 4), model averaged parameter estimates (shrinkage estimates) with standard errors, and 95% confidence intervals for parameter estimates for habitat selection of crossing locations by migratory moose along US 20 in eastern Idaho, USA, 2011-2013.

Model #	AICc w_i	Riparian	DstCovMN	RdDens
3	0.49			-2.4763 (0.9972)
7	0.29	3.3320 (3.0621)		-2.5839 (0.9978)
6	0.22		-0.0066 (0.0088)	-2.3975 (1.0260)
Averaged		0.9704 (3.1395)	-0.0014 (0.0091)	-2.4905 (1.0311)
95% CI		-2.8215 ; 9.4855	-0.0244 ; 0.0111	-4.5113 ; -0.4696

In terms of specific locations, the highest probability of migratory moose crossing locations were: 1) on Highway 87 surrounding mile post 2 (Figures 2.12, 2.13, 2.14); 2) at the junction of US 20 and Mesa Falls Road from mile post 379-381 and south of the Osborne Bridge at mile post 378 (Figures 2.12, 2.13, 2.15A); 3) along the flats north of Big Bend Ridge from mile post 368-376, (Figures 2.12, 2.13, 2.15B); and 4) on Ashton Hill below Big Bend Ridge from mile post 365-367 (Figures 2.12, 2.13, 2.15C).

Elk RSF model validation

Fifteen percent of the test locations randomly held out prior to model development fell into probability bins that were ranked low to low-medium (bins 1 – 2) and 75% of the test locations fell into bins that were regarded as medium-high to high (bins 4 – 5: r_s (3) = 0.718, P = 0.086; R^2 = 0.688, P = 0.082). Twenty-three percent of road crossings made by elk recorded by track surveys fell into bins 1 – 4 and 54% fell into bins 7 – 10 (r_s (8) = 0.794, P = 0.005; R^2 = 0.555, P = 0.013). Twenty-five percent of the WVC locations fell into bins 1 – 4 while 55% fell into bins 7 – 10 (r_s (8) = 0.856, P < 0.001; R^2 = 0.609, P = 0.008; Table 2.14).

Non-migratory moose RSF model validation

Ten percent of the test locations randomly held-out from the non-migratory moose data fell into bins that were regarded as low to low-medium (bins 1 – 2) and 67% fell into bins regarded as medium-high to high (bins 4 – 5; r_s (3) = 0.900, P = 0.042; R^2 = 0.822, P = 0.034). Twenty percent of crossings recorded by track surveys occurred in bins 1 – 4 while 56% occurred in medium-high to high bins (7 – 10; r_s (8) = 0.821, P = 0.002; R^2 = 0.667, P = 0.004). Similarly, 18% of road mortality locations for non-migratory moose

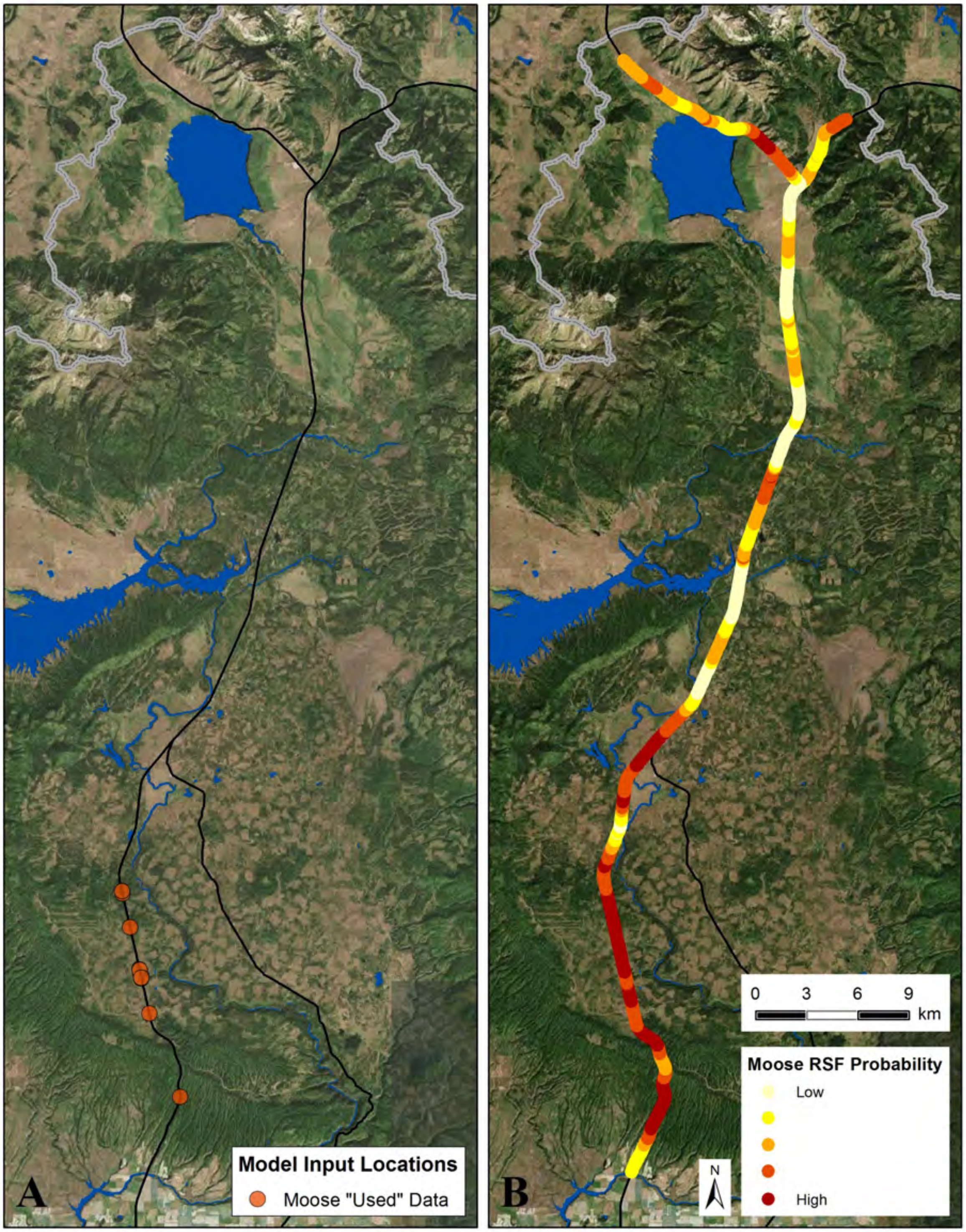

Figure 2.12. A) Crossing locations used in dataset to model resource selection of migratory moose at road crossing locations (n = 13; "used" locations) and B) resource selection function for migratory moose showing relative probability of crossing areas along US 20, Idaho, USA 2010-2013.

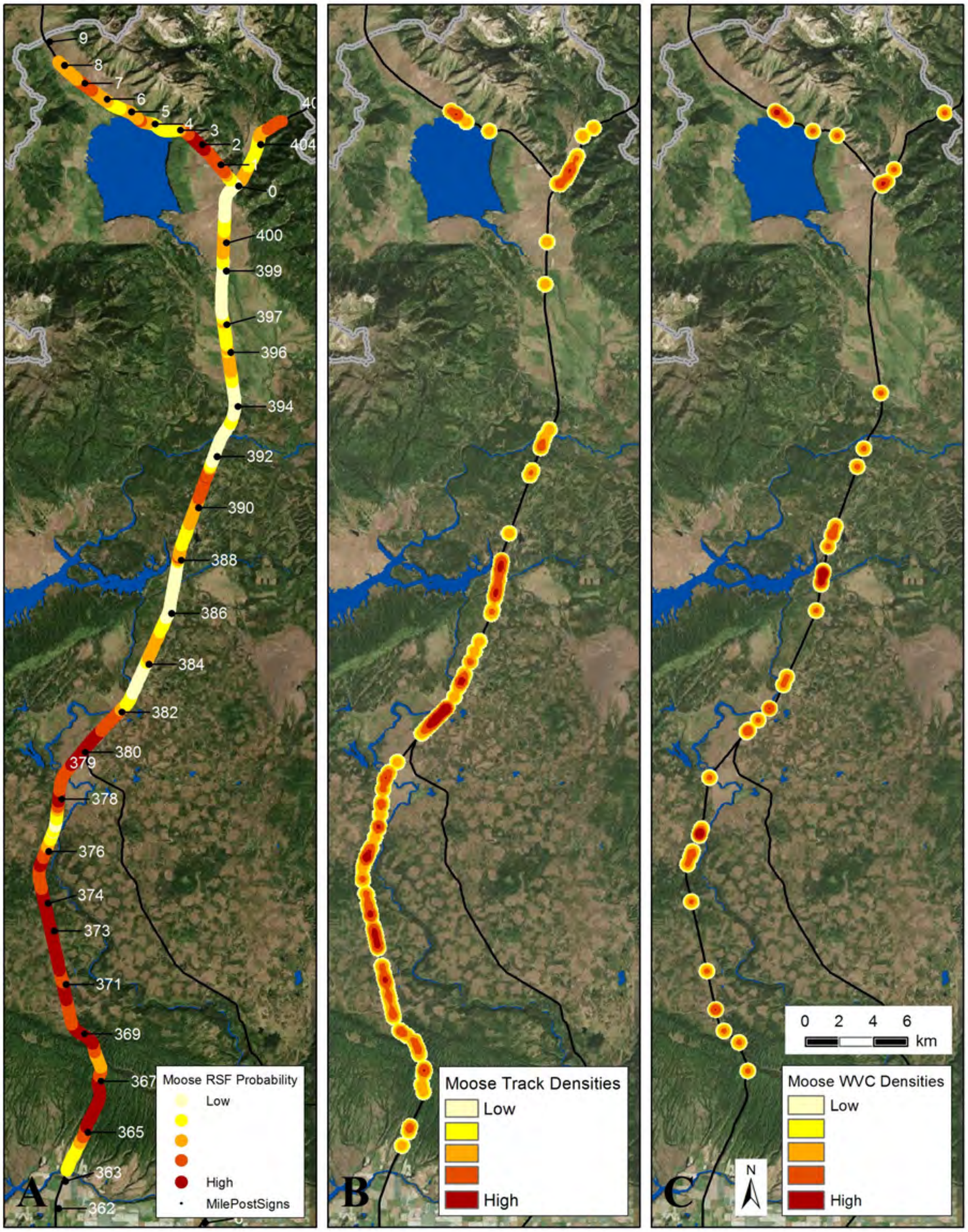

Figure 2.13. A) Resource selection function showing relative probability of crossing areas for migratory moose, 2010-2013, B) relative density of road crossing locations of moose recorded during track surveys 2010-2013, and C) moose-vehicle collisions reported along US 20, Idaho, USA from 1982-2012. Note that track survey data were only collected as far south as displayed in the map (i.e., the extent of the track densities represents the extent of the surveys).

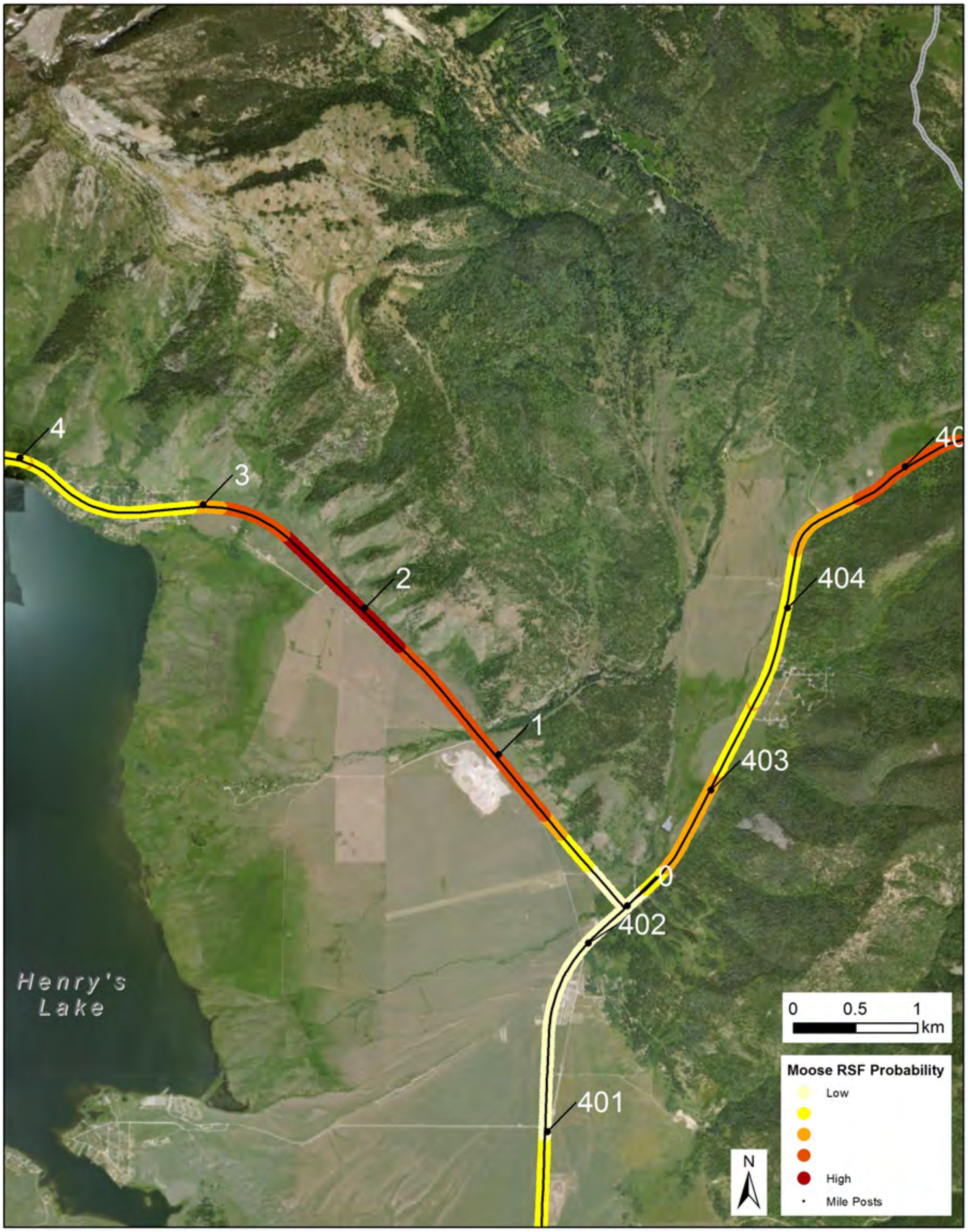

Figure 2.14. High probability of road crossing for migratory moose on Highway 87 surrounding mile post 2 in Fremont County, Idaho, USA 2010-2013.

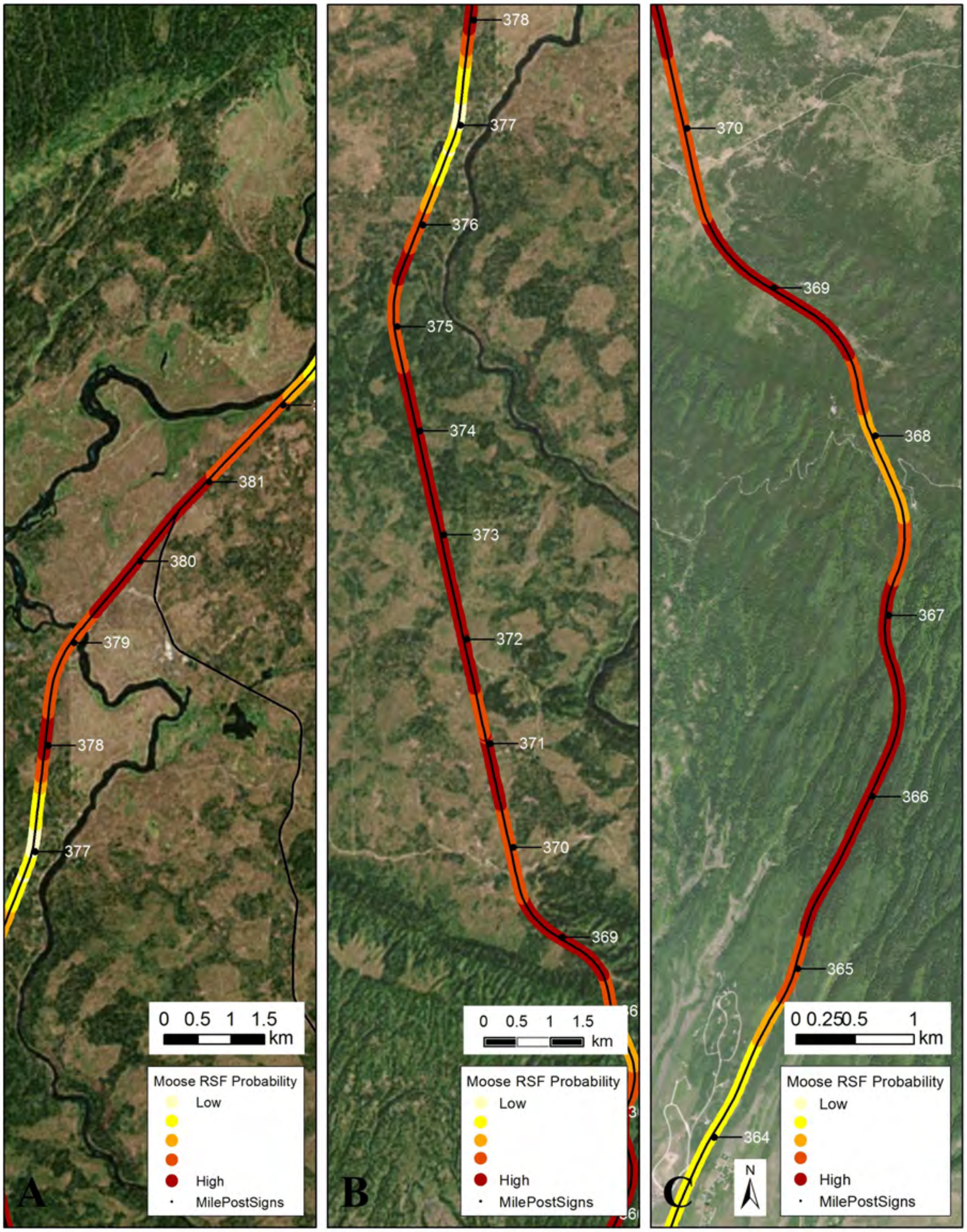

Figure 2.15. High probability of road crossing for migratory moose A) at the junction of US 20 and Mesa Falls Road from mile post 379-381 and south of the Osborne Bridge at mile post 378, B) along the flats north of Big Bend Ridge from mile post 368-376, and C) on Ashton Hill below Big Bend Ridge from mile post 365-367 in Fremont County, Idaho, USA 2010-2013.

Table 2.14. Percentage of locations from each of the 3 test datasets falling into ranked bin categories with corresponding Spearman rank correlation coefficients (r_S) and coefficients of determination (R^2) resulting from linear regression testing predictions of elk resource selection functions of crossing locations by elk along US 20 in eastern Idaho, USA, 2011-2013.

Validation Data Set	n	Number of Bins	r_s	P	R^2	P
1. Subset of Data	20	5	0.718	0.086	0.688	0.082
2. Track Survey Data	432	10	0.794	0.005	0.555	0.013
3. WVC Data	55	10	0.856	<0.001	0.609	0.008

Table 2.15. Percentage of locations from each of the 3 test datasets falling into ranked bin categories with corresponding Spearman rank correlation coefficients (r_S) and coefficients of determination (R^2) resulting from linear regression testing predictions of non-migratory moose resource selection functions of crossing locations by non-migratory moose along US 20 in eastern Idaho, USA, 2011-2013.

Validation Data Set	n	Number of Bins	r_s	P	R^2	P
1. Subset of Data	30	5	0.900	0.042	0.822	0.034
2. Track Survey Data	200	10	0.821	0.002	0.667	0.004
3. WVC Data	49	10	0.794	0.003	0.460	0.031

Table 2.16. Percentage of locations from each of the 3 test datasets falling into ranked bin categories with corresponding Spearman rank correlation coefficients (r_S) and coefficients of determination (R^2) resulting from linear regression testing predictions of migratory moose resource selection functions of crossing locations by migratory moose along US 20 in eastern Idaho, USA, 2011-2013.

Validation Data Set	n	Number of Bins	r_s	P	R^2	P
1. Subset of Data	-	-	-	-	-	-
2. Track Survey Data	200	10	0.632	0.025	0.341	0.077
3. WVC Data	49	10	-0.511	0.934	0.424	0.041

fell into low and low-medium categories (bins 1 – 4) with 67% of the road mortality locations falling into medium-high and high bins (bins 7 – 10; r_s (8) = 0.794, P = 0.003; R^2 = 0.460, P = 0.031; Table 2.15).

Migratory moose RSF model validation

Twenty-eight percent of the crossing locations identified by track surveys fell into the low to low-medium bins (1 – 4) while 58% fell into bins regarded as medium-high (bins 7 – 10; r_s (8) = 0.632, P = 0.025; R^2 = 0.341, P = 0.077). The model for migratory moose however showed no ability to predict road mortality locations for moose with more than 50% of WVCs falling in low and low-medium categories (bins 1 – 4) (r_s (8) = -0.511, P = 0.934; Table 2.16).

DISCUSSION

The ability to model and predict road crossing locations for migrating ungulates in the GYE is an important first step in mitigating the impacts of roads on these species, improving habitat connectivity between seasonal (i.e., summer and winter) ranges, and enhancing the safety of the traveling public. In the case of elk and moose in the western portion of the GYE in the Island Park, Idaho region, significant numbers of WVCs over the past 30 years indicate that US 20 may present an anthropogenic impediment to habitat connectivity. Given that all elk and some moose in the region are migratory as an adaptive response to deep snow and harsh winter conditions on the Henry's Fork Caldera, maintaining habitat connectivity and the ability of individuals to move between summer and winter range is of paramount importance for the long-term persistence of these populations.

We generated RSF models based on GPS locations and resulting 2-point Brownian bridge movement models which identified crossing locations to predict: 1) specific locations along US 20 and Highway 87 where elk and moose have a high probability of crossing roads; and 2) features of both habitat and roads that elk and moose select for when crossing US 20 that can be useful for other regions in the northern US Rockies.

Elk

Our RSF model results demonstrate that elk selected strongly for areas with relatively low average density of roads on the landscape, in riparian habitats, with relatively less distance between horizontal vegetative cover and the highway when crossing US 20 and Highway 87 in this region and that selection for these features while crossing did not vary between seasons or among years. For elk, the highest probability of crossing locations were located in the relatively open flats along US 20 that were associated with riparian areas and relatively few roads on the landscape, and much of Ashton Hill below Big Bend Ridge. Elk appear to be selecting highway crossings at a relatively large spatial scale with the average density of roads within a 1 kilometer neighborhood doing a much better job of explaining road crossing behavior of elk than the amount of development within the 225 m buffer. Elk are crossing US 20 in areas with relatively lower density of roads and avoiding the more intensely developed areas of Island Park, Mack's Inn, Swan Lake, and other places of exurban sprawl along US 20.

Despite small sample sizes, and considerable model uncertainty, the final averaged model had fairly good predictive power for road crossing locations for elk. With nearly half of all elk crossing data collected from track surveys (n = 432 crossings) falling into the areas mapped as relatively high probability of crossing (bins 7 – 10), we have moderate confidence in the model. The model also appeared to accurately predict areas of low probability crossings (e.g., between the Henry's Fork Lake Outlet and Macks Inn) where few tracks were recorded during surveys and WVCs are relatively rare and Spearman rank correlation suggested a moderately strong positive relationship between bin rank and frequency of test data within bin ranks. Intuitively, WVC data would be very useful for determining where road crossings by wildlife species occur. However, various research efforts suggest that the locations where wildlife is struck by vehicles may have little in common with where they safely cross roads (see Clevenger et al. 2002). Many factors associated with roads and adjacent habitats are related to wildlife-vehicle collisions and these factors may be completely different between successful and unsuccessful crossings by various species (see Clevenger and Ford 2010). Use of WVC data alone provides very limited insight into wildlife movement at roadways and should be combined with location data and movement models as we have done here. However, comparing the RSF model of successful road crossings made by collared elk to unsuccessful road crossings documented by WVCs suggest there are similarities in areas where road crossings are successful and where WVCs occur ($r_s = 0.856$; $P < 0.001$).

Moose

Given their large body size, moose are of particular concern when involved in WVCs, as the probability of human fatalities increases when vehicles strike moose (Huijser et al. 2008). From a population perspective, given the smaller size of the moose population in southeast Idaho compared to species such as elk, any loss due to anthropogenic barriers such as roads can be a concern. In addition to population demographic and human safety concerns, there is an economic impact from WVCs with moose. In fact, IDFG estimates that the cost of wildlife-vehicle collisions is $28,600 per moose with estimates accounting for vehicle repair, consumptive and non-consumptive recreational loss of the animal, removal of the carcass, police investigation, and human injury or fatality (IDFG; Gregg Servheen, personal communication). This figure is very similar to national estimates calculated by Huijser et al. (2008).

Similar to elk in the western portion of the GYE in the Island Park, Idaho region, moose have also been involved in significant numbers of WVCs over the past 30 years indicating that US 20 may present an anthropogenic impediment to habitat connectivity. However, unlike elk in the study area, the picture for moose is more complex given the dual strategy of moose in the region. Although all elk in the region are migratory as an adaptive response to deep snow and harsh winter conditions in the Henry's Fork Caldera, the moose population contains a percentage of year-round non-migratory moose in the caldera. From our capture efforts in which we attempted to collar migratory moose, approximately 67% of adult female moose were migratory and 33% were non-migratory moose. Migratory moose in the region indeed migrate a significant distance to winter range in the Snake River Plain. Our results demonstrate that the impacts of US 20 on moose may be a more complicated picture because non-migratory moose and migratory moose cross US 20 in different areas (although there are some similar areas; see discussion below) and select for differing habitat, road and anthropogenic features when crossing the highway. Additionally, there may be a slight impact of season on selection patterns by non-migratory moose that was not apparent for elk along US 20. However, we did not test for differences in selection among year or season for migratory moose due to insufficient sample sizes necessary to include interaction terms and obtain meaningful results. All of these factors create a more complex picture from the stand-point of mitigating the impacts of US 20 on moose in southeast Idaho compared to elk. Further, given the small sample sizes for migratory moose that actually crossed US 20 during this study, migratory moose results should be viewed with caution and an understanding that as more data are collected results could change. Further, we recommend additional study to augment sample sizes to get a better understanding of migratory moose (see discussion below).

Non-migratory moose

The parameter estimates from our top RSF model suggest non-migratory moose select for areas on the landscape that are relatively less rugged with lower highway speeds, less distance between the road edge and horizontal vegetative cover and a greater amount of riparian habitat.

The model for habitat selection by non-migratory moose performed well when tested against road crossing locations randomly withheld from the data obtained from GPS collars with a relatively high correlation between the test data and training data, track data, and WVC data. The fact that the non-migratory moose model appeared to fit the moose road mortality data much better than the migratory moose model (r_s = 0.794 versus r_s = -0.511), suggests that non-migratory moose are more susceptible to WVCs along US 20. The magnitude of road crossings recorded by non-migratory moose versus migratory moose and the greater correspondence of the non-migratory moose model with track data in the study area also suggests that non-migratory moose may be more likely to be struck by vehicles more frequently than migratory moose, an idea that warrants further investigation. When looking at the specific locations that non-migratory moose cross US

20, it is clear that several of the highest probability crossing points are located adjacent to or inside fairly heavily developed regions along US 20 and Highway 87 (e.g., north shore of Henry's Lake, Mack's Inn, along the Buffalo River in Island Park near the city offices, near Elk Creek gas station, near the Trout Hunter), suggesting that non-migratory moose are more habituated to living near and among humans and developed areas. Further evidence of this is the fact that non-migratory moose selected for lower speeds along US 20, suggesting that non-migratory moose in the town of Island Park, where speed limits are slower (45 mph vs 65 mph) along US 20, are habituated to human presence. This is particularly true when compared to migratory moose, where their highest probability road crossing locations are more similar to elk in being further away from areas of high density of roads or development (see below).

Migratory moose

The averaged parameter estimates of our final RSF model suggest migratory moose select for areas on the landscape with relatively lower average road density, with less distance between the road edge and horizontal cover, and with greater riparian habitat. Migratory moose appear more similar to elk in their selection patterns for habitat features than compared to non-migratory moose. This suggests that unlike non-migratory moose, migratory moose are likely not as habituated to humans and developed areas. The end result is that, although there are areas that both non-migratory and migratory moose cross US 20 using similar habitat selection patterns (e.g., south of Trout Hunter Lodge and along the flats above Big Bend Ridge), in other high probability crossing areas used by non-migratory moose (e.g., at Mack's Inn and along the Buffalo River in Island Park near the city offices) migratory moose are more similar to elk because they avoid these otherwise suitable habitats in or adjacent to developed areas along US 20. As stated previously, given our small sample sizes for migratory moose crossings of US 20, further investigation and study is needed to fully understand differences between non-migratory and migratory moose, and seasonal and yearly differences for both groups.

CONCLUSIONS

Migrations could be enhanced or restored by identifying and removing, or rectifying, anthropogenic barriers, such as an impermeable fence, which may restore historic movements. In cases where the barrier itself cannot be changed or removed, such as a highway, construction of wildlife over- and under-passes could be considered similar to efforts in Wyoming (US Highway 191 at Trapper's Point) and in Idaho on State Highway 21 (http://idahowildlifecrossings.com/). Using BBMMs and RSF models, as we did here, provides managers with the tools to target where road mitigation could occur (see chapter 3). Proactive management decisions to protect long-distance migrations are only possible when existing knowledge about migration and threats are included in the decision making process (Seidler et al. 2014). Brownian bridge movement models and analyses of resource use provide a mechanism not only to delineate long-distance migration, but also to identify threats and changes in use over time, offering veritable knowledge for mitigation and protection of this endangered natural heritage.

CHAPTER 3

SUMMARY AND RECOMMENDATIONS FOR MITIGATING IMPACTS OF US HIGHWAY 20 ON ELK AND MOOSE IN THE GREATER YELLOWSTONE ECOSYSTEM

Recently, conservation and management addressing roads and wildlife is being increasingly prioritized by not only NGOs, state and federal agencies, but also communities. At the same time, new technologies (e.g., GPS collars, spatially explicit models) and resulting findings in ecology also have led us to recognize the importance of habitat connectivity and the need to minimize and mitigate barriers to connectivity to insure long-term persistence of populations (see Beckmann et al. 2012, Seidler et al. 2014). This is particularly true for those species and/or populations that undergo the ever-increasingly vulnerable ecological phenomenon of long-distance migration.

Because of the rapid human expansion in the West and globally, the challenge of roads severing connectivity of wildlife populations is likely to increase in the foreseeable future (Beckmann et al. 2010). Similarly, as more people move into the GYE, the iconic system in North America for ecological phenomena such as long-distance migration of large ungulates, there will be an increasing level of WVCs that endanger the lives of people. Additionally, the prospect of climate change elevates the importance of maintaining and restoring connectivity for wildlife. Given these stressors, there is a continuing need to pro-actively incorporate new science from the fields of engineering, ecology and others. This will help to insure that our approaches to mitigate the impacts of WVCs and roads on wildlife, and to enhance the safety of the traveling public, integrate the latest and best knowledge if our work is to be robust in the long-term.

The importance of good, rigorous science and information cannot be overstated. Science is an influential component that should underlay decision-making. Science can also provide the impetus or inspiration for developing road ecology projects and guiding priorities. For example, high profile projects such as the Banff National Park road crossings have informed and inspired new projects around North America and even the globe (Clevenger et al. 2002). Similarly the Path of the Pronghorn project that those of us at WCS have been involved with since 2002 in western Wyoming and resulting overpass and underpass structures on U.S. Highway 191 demonstrate the value of 1) long-term data sets, 2) baseline data on wildlife densities, health, population dynamics, movements, and other behaviors near and across roads either slated for new construction or under consideration for mitigation, 3) the latest structural engineering, technologies, and other highway mitigation approaches, and 4) follow-up monitoring and diagnostic research to examine if the adapted mitigation strategies are functioning as intended, allowing project improvements to be made, as necessary, to ultimately achieve project goals. Road ecology projects in places like Banff, the Upper Green River Basin of Wyoming, and this project demonstrate that mixed partnerships appear to offer many potential benefits. For example, citizens (volunteers helping with track surveys on this project) and non-profits (Wildlife Conservation Society ecologists) can engage with state wildlife (Idaho Department of Fish and Game [IDFG]) and transportation (Idaho Transportation Department [ITD]) agencies to successfully address issues surrounding roads, public safety, and healthy wildlife populations. As awareness about road ecology is growing, the needs to support such projects and programs going forward are large.

Historically, transportation planning did not incorporate wildlife needs or concepts of ecosystem processes. If wildlife needs were considered at all, it was late in the planning stages, which allowed little time for funding the project and gathering necessary data to incorporate the needs of wildlife. In the future, more projects such as this one in which a greater consideration of the ecological and societal effects of roads on wildlife, connectivity, and other ecosystem processes must continue to rise as a priority by federal, state, and local entities involved in transportation planning. Here we make recommendations for mitigating the impacts of US 20 on habitat connectivity for elk, migratory and non-migratory moose and to enhance the safety of the traveling public along this stretch of highway in the western GYE. Our recommendations are based on all data analyzed and presented in this report (GPS locations, mortality data, track survey data, etc. collected for elk and moose from the region during 2010-2013 and WVC data going back as far as 1982) as well as our experience with road ecology issues for these and other species in the GYE and other regions of North America. See Beckmann et al. (2010) for a comprehensive overview of road ecology issues, case studies from North America for successfully mitigating road impacts on wildlife, and in-depth discussion of many points highlighted in this summary.

The recommendations found in this chapter are suggested as potential mitigation measures that could be examined and considered at each of the key crossing locations identified by the data and resulting models. Keep in mind that these are not the ONLY option for mitigating the impact of the road on wildlife at each of these locations and it may be that other options are more suitable for a given location due to a myriad of factors (e.g., logistical constraints, funding, time elapsed since last road rebuild or repair, projected time to future road repair, rebuild, or re-design, engineering logistics, etc.).

Thus any and all potential mitigation options for each of these key areas would necessitate additional discussions about what mitigating option would actually be the most effective (considering all different perspectives such as cost, potential of reduction in WVCs, future maintenance, funding, etc.). These discussions would need to involve these data, logistical and engineering considerations, road and traffic engineers, other ITD personnel, IDFG, WCS, and the community of Island Park and Fremont County among others.

SUMMARY OF RESULTS

For elk, non-migratory and migratory moose our 2-point Brownian bridge movement models and resulting RSF models based on GPS collar locations for each species demonstrate there are several specific locations along US 20 and Highway 87 where the highest probability of road crossings are similar between elk and moose. In addition to the RSF models, we also examined track data and WVC data to highlight specific areas that have a high level of congruency between all types of data. These specific areas are: 1) Highway 87 from the junction with US 20 to the north shore of Henry's Lake between mile post 0-5; 2) US 20 in the vicinity of the Valley View RV Park Campground to north of the junction with Highway 87 from mile post 402-405; 3) US 20 just north of the intersection with Sawtelle Peak Road near mile post 394; 4) the relatively open flats along US 20 south of Island Park Reservoir near the bend in the Henry's Fork of the Snake River when the river is just west of US 20 (i.e., just south of the Buffalo Run RV Park and Cabins continuing to the south of Trout Hunter Lodge) from mile post 382-384; 5) US 20 near Railroad Ranch and again where US 20 crosses the river at Osborne Bridge near mile post 381 and 379; and 6) south of Swan Lake to the bridge north of Ashton between mile posts 365-376. Thus, these 5 areas are the sections of US 20 and Highway 87 that make the most sense to target initially for mitigation to achieve the greatest impacts for both species. However, there are 2 additional locations that also make sense to consider for mitigation given their importance for non-migratory moose (the animals responsible for the largest number of crossings of US 20 in this study and thus the animals potentially most susceptible to WVCs). These regions include: 1) US 20 where it crosses the Henry's Fork of the Snake River at Mack's Inn from mile post 392-393; and 2) US 20 where it crosses the Buffalo River south of the Island Park city offices from mile post 386-388. There is one additional region of high probability road crossing by elk and migratory moose: the flats along US 20 just west and north of Sheep Falls from mile post 370-376.

We do recognize that these areas represent the locations of the highest probability of road crossings by these species and do NOT represent the only locations that elk or moose (non-migratory or migratory) cross US 20. In fact, the entire stretch of US 20 in the study area has some probability of crossing by both species associated with each section and thus eliminating all WVCs would likely require mitigation efforts on the level of Banff National Park along the Trans-Canada Highway (see Ford et al. 2010). Logistical and aesthetic considerations might prohibit the entire stretch of US 20 from being mitigated, at least initially, so we focus our recommendations on the above highlighted key areas where mitigation is likely to have the biggest impact.

RECOMMENDATIONS

Mitigating US 20 for elk and moose will likely be most economical during road expansion or future planned upgrade projects. As Clevenger and Ford (2010) point out, wildlife crossings and road mitigation efforts should not lead to ecological "dead-ends"

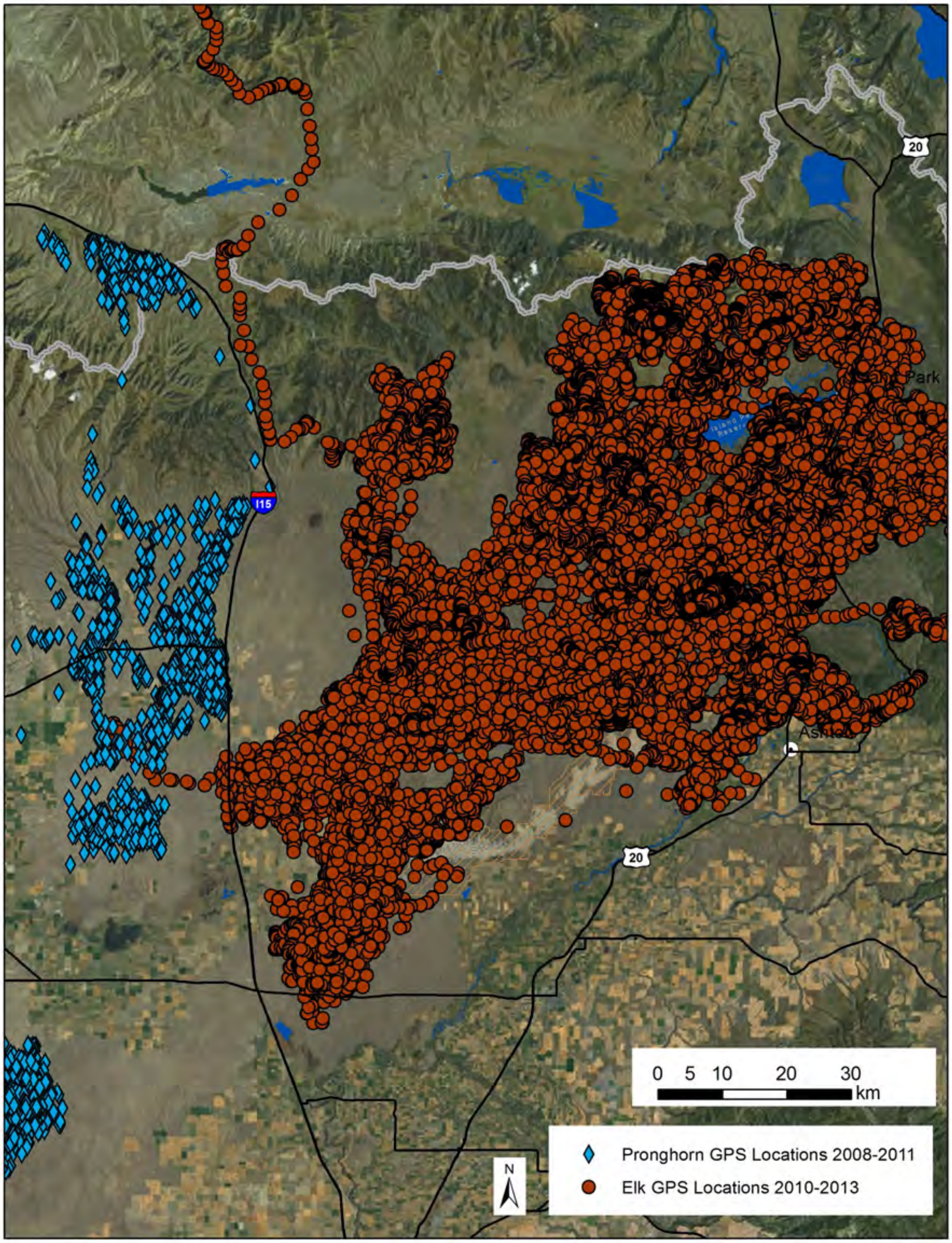

Figure 3.1. Pronghorn (n = 43) GPS locations (blue diamonds) collected from 2008-2011 suggest that I-15 truncated spring animal movements beyond the interstate. Similar patterns arise from elk GPS locations (red circles) collected from 2010-2013 during this study. Only one collared elk moved beyond I-15; at least 20 other collared elk approached the interstate but did not cross. Pronghorn data were obtained from WCS, IDFG, BLM, the National Park Service, and Lava Lake Institute for Science and Conservation.

or “cul-de-sacs”. Road mitigation efforts must occur in regions where there exists a larger functional landscape and all necessary habitats that allow individuals to meet their daily and life requirements. Because movement of elk and moose in this region successfully tie the Greater Yellowstone Ecosystem, one of the most intact temperate ecosystems across the globe, to the Snake River Plain this is not a major concern. Thus we present our mitigation recommendations for increasing conservation and reducing deadly accidents in the western GYE. However, there is some concern that even if US 20 is mitigated for ungulate movements and migration, I-15 may represent an additional barrier to ungulate migrations and movement in the larger landscape (see below discussion on considerations of larger landscape-scale when making mitigation decisions). These concerns are based on movement data for elk from this study and other studies on pronghorn (*Antilocapra americana*) in the Upper Snake River Plain (see Figure 3.1). Wildlife crossings and road mitigation efforts are only as effective as the management strategies developed around them that incorporate all the key landscape elements (development, terrain, natural resources, and transportation). Thus the mitigation strategies we recommend here must be contemplated at the 2 scales suggested by Clevenger and Ford (2010): 1) the site-level or local-scale impacts from current and future development, or human disturbance adjacent to proposed mitigation efforts; and 2) the landscape at a broader regional-scale in order to insure a functional landscape for elk and moose such that mitigation efforts are effective in the long-term. This will require inclusion of IDFG, USFS, BLM, ITD, Island Park municipal planning groups and the public in southeast Idaho in the immediate planning process and over the long-term. This will be a considerable challenge given the current and future rapid expansion of the human population in the GYE and along US 20 in the Island Park region. Comprehending the growing infrastructure and exurban development in Island Park, Idaho in the future, how the physical and biological elements of the natural landscape will be impacted, and planning such that any mitigation efforts that are undertaken remain effective over the long-term will be key.

OPTIONS AND RECOMMENDATIONS TO MITIGATE THE IMPACTS OF US 20

Note: For each of the below recommendations we suggest considerable planning that involves talking to 1) local experts, 2) other states, provinces, and regions that have mitigated the impacts of roads for either elk and/or moose or other similar species, and 3) an exhaustive literature search for design, sighting, and construction parameters for each of these mitigating structures and approaches. We also suggest planning not only for the building or installation of the crossing structures or mitigation features using the best available data and science, but for long-term maintenance plans and funding of maintenance of structures and associated infrastructure (e.g., jump-outs, fencing, etc).

Large mammal underpass

Large mammal underpasses are the largest and most common underpass structures designed specifically for wildlife movement. Although these are primarily designed for large mammals, use will depend mainly on how these are adapted for species-specific crossing requirements. According to Clevenger and Ford (2010), large mammal underpasses are generally at least 10 m (32 feet) wide and 4 m (13 feet) high, while some smaller structures may be 7 m (23 feet) wide and 4 m (13 feet) high. For elk, there is a fair amount of data and information on suitable size, planning, sighting, construction and use of underpasses (e.g., Dodd et al. 2007, Dodd and Gagnon 2010) and any underpass constructed for elk should incorporate this type of prior knowledge. However, data are much more limited for moose and thus using elk and other ungulates as guides could prove useful in planning, designing, sighting, and constructing any underpasses for this species as well. Of the highest probability crossing locations for both elk and moose (migratory and non-migratory) in the study site, 3 of them lend themselves to having underpasses considered for construction for both elk and moose. We recommend underpass structures designed specifically for elk and moose be considered along US 20 at the following locations: 1) where US 20 crosses the river at Osborne Bridge; 2) where US 20 crosses the Henry's Fork of the Snake River at Mack's Inn; and 3) where US 20 crosses the Buffalo River south of the Island Park city offices. Each of these high probability crossing locations are associated with water and therefore already have bridges spanning and near the riparian areas. Additionally, because of the associated water at these high probability crossing locations, any underpass constructed or modified for wildlife would likely also serve the dual-purpose of maintaining water flow.

Dual-purpose underpass with water

These underpass structures are designed to accommodate dual needs of moving water and wildlife. They are generally located in multi-species wildlife movement corridors given their association with riparian habitats. These underpass structures are frequently used by several large mammal species, and use will depend on how the structure may be adapted for each species' specific crossing requirements. According to Clevenger and Ford (2010), for these types of underpass structures, it will be important to include travel paths adjacent to the water that are generally at least 3 m (10 feet) wide and have a vertical clearance of 4 m (13 feet) high. Placement of these travel paths will be important such that they are available even during periods of high-water flows. However, some smaller structures may have travel paths at least 2 m (6.5 feet) wide with 3 m (10 feet) vertical clearance (see Clevenger and Ford 2010). As with any crossing structure, associated fencing will be extremely important to guide animals towards the crossing structure. We recommend typical fencing for large mammals that consists of 2.4 meter high page wire fencing material with wooden or steel posts spaced at 5 meter intervals be associated with each of these underpass structures if considered. Extensive planning with respect to the length of associated fencing on both sides of US 20 would need to be undertaken to insure that most animals in these areas are kept off of US 20 and directed to the crossing structure. If an additional overpass (see discussion below) or underpass for elk and moose were placed on the relatively open flats along US 20 south of Island Park Reservoir near the bend in the Henry's Fork of the Snake River when the river is just west of US 20, then it would make sense to fence both sides of US 20 from a yet-to-be-determined distance south of Osborne bridge to a yet-to-be determined location north of the crossing structure.

Large mammal overpass

Wildlife overpasses are one of the largest crossing structures to span roadways. They are primarily intended to move large mammals, however, small and medium-sized fauna will also use wildlife overpasses if the right habitat elements are provided. Clevenger and Ford (2010) suggest that wildlife overpasses are generally 50-70 m (165-230 feet) wide, while some may be as narrow as 40-50 m (130-165 feet). Wildlife overpasses should be closed to the public and any other human activities and roads should not be on or near wildlife overpasses, as it will hinder wildlife use of the structure (Clevenger and Ford 2010). Overpasses can be highly effective structures at reducing WVCs if designed and placed correctly on the landscape. Overpasses also need associated fencing to guide animals to the overpass and jump-outs if animals do access the road surface (see Clevenger and Ford 2010). As an example, in places such as Banff National Park in Canada, overpass structures and associated fencing have reduced WVCs with all ungulates by > 90% and with all large mammals by 86% (Woods 1990, Clevenger et al. 2002). Mitigation structures such as overpasses are generally very expensive, but the expenses are mostly up-front (although there are continual maintenance expenses), and several studies have demonstrated that the savings in reduced costs from fewer WVCs ends up saving states, agencies, and the public money over time (see Beckmann et al. 2010).

We suggest that 3 locations in the study area are candidates to be mitigated by overpasses and associated fencing given their importance for elk and moose crossings, the topography, and the large geographical size of the high probability crossing location. Overpasses that would work for both elk and moose (and other species) could be considered for: 1) Highway 87 near the north shore of Henry’s Lake; 2) US 20 in the vicinity of the Valley View RV Park Campground to US 20 just north of the junction with Highway 87; and 3) south of Swan Lake to the bridge north of Ashton between mile posts 365-376. Each of these areas represent high probability crossing locations for each of these species, and in the case of Highway 87 north of Henry’s lake, the area of high probability crossing extends from the junction with US 20 to mile post 5. This area has been previously highlighted as an important region for elk (Grigg 2007). Thus a properly sighted, designed and constructed overpass with associated fencing to guide animals to the overpass could be highly successful in reducing WVCs and increasing connectivity over a relatively large distance of this highway (see Clevenger et al. 2002). One other site that may be considered for an overpass to mitigate the impact of US 20 on migrating elk and moose is the flats along US 20 just west and north of Sheep Falls from mile post 370-376.

We concede, it may be that other options besides an overpass or underpass are more suitable for a given location due to a myriad of factors (e.g., logistical constraints, funding, time elapsed since last road rebuild or repair, projected time to future road repair, rebuild, or re-design, engineering logistics, etc.). Thus any and all potential mitigation options for each of these key areas would necessitate additional discussions about what mitigating option would actually be the most effective (considering all different perspectives such as cost, potential of reduction in WVCs, future maintenance, funding, etc.). These discussions would need to involve these data, logistical and engineering considerations, road and traffic engineers, other ITD personnel, IDFG, WCS, and the community of Island Park and Fremont County among others.

As stated previously, comprehending the growing infrastructure and exurban development in Island Park, Idaho in the future and how the physical and biological elements of the natural landscape will be impacted, and planning such that any mitigation efforts that are undertaken remain viable over the long-term will be key. As such, we have avoided recommending the consideration of overpasses in high probability crossing locations that already have a relatively high level of exurban development adjacent to the crossing location (e.g., overpass structures in Island Park near the Trout Hunter likely do not make sense given the higher density of human structures already present in that specific location, and the presence of private lands). However, mitigation tools such as reliable animal detection systems may make sense in these areas and these approaches can have success rates similar to overpasses in certain settings (see discussion below). Our data show that multiple mortalities have occurred for elk and moose in areas such as Mack's Inn and near Last Chance and that these areas represent a fairly high probability of road crossing by non-migratory moose. Even though these areas contain relatively high human and development densities, mitigating the impacts of US 20 in these regions is still important.

Any crossing structure, whether an overpass or an underpass must be associated with proper fencing and the fenced distance between crossing structures must also be considered. Wildlife can become trapped inside the fenced area on the road if a breech in the fence is created, thus measures are needed to allow them to safely exit the highway area. Earthen ramps or jump-outs are some commonly used methods and should be considered if mitigation using crossing structures is to move forward for elk and moose to reduce WVCs along US 20 (see Clevenger and Ford 2010).

The spacing of wildlife crossings on a given section of roadway will depend largely on the terrain and habitats that intersect the roadway. For an excellent review of wildlife crossing structures in general and spacing issues more specifically, see Beckmann et al. (2010). Although there is no simple formula to determine the recommended distance between wildlife crossings, Clevenger and Ford (2010) in a review of 8 projects in the USA and Canada, estimated that the spacing interval for crossing structures for large mammals varied from one wildlife crossing per 1.5 km (0.9 mile) to one crossing per 6.0 km (3.8 miles). Clevenger and Ford's (2010) review demonstrated that wildlife crossings are variably spaced but average about 1.9 km (1.2 miles) apart when multiple crossing structures have been used on various projects for large mammals. Irrespective of crossing structure type, it is important to plan for long-term maintenance and funding for the maintenance of the crossing structure itself and associated infrastructure (e.g., fencing, jump-outs, etc).

Mitigation measures to influence driver behavior: warning signs, wildlife detection systems, vegetation removal

For a full review of mitigation measures aimed at influencing driver behavior see Huijser and McGowen (2010). Mitigation measures aimed at influencing driver behavior range from public information and education, to various types of permanent warning signs, seasonal warning signs, animal detection systems, reduced speed limits, and measures that increase the visibility for drivers. There is a significant amount of information on each of these and our purpose here is not to review each of these except to make key points. First, permanently visible wildlife warning signs do not appear to be effective in reducing wildlife-vehicle collisions (Rogers 2004, Meyer 2006). Second, although enhanced wildlife warning signs (e.g., signs with flashing lights) do lower driver speeds, enhanced warning signs have also not been shown to significantly reduce the number of wildlife-vehicle collisions (Pojar et al. 1975, Stanley et al. 2006). In contrast to wildlife warning signs, road-based animal detection systems use sensors to detect large animals that approach the road. The effectiveness of *reliable* animal detection systems in reducing collisions with large ungulates has been estimated at 82 percent (Mosler-Berger and Romer 2003) and 91 percent (Dodd and Gagnon 2008) in certain conditions and settings. Finally, reduced vehicle speeds, while they may lower WVCs in certain instances, can create the additional hazard of speed dispersion, i.e., some drivers may follow the new posted speed limit, while others drive the speed they perceive is safe given the design of the road (Huijser and McGowen 2010). Speed dispersion can lead to an overall increased number of traffic accidents.

Therefore, if warnings are to be used along stretches of US 20 to alter driver behavior, we recommend that the most reliable animal detection system available be used in places that make sense on a seasonal basis. One area of high probability of crossing that makes sense for a reliable animal detection system in this study area is along US 20 near the intersection with Sawtelle Peak Road. This area has a high probability of crossing for both elk and moose, but due to proximity to high density development and little to no associated water, crossing structures may not be ideal for this locale. Additionally, our data demonstrate that there are several stretches along US 20 where non-migratory moose cross the highway at very high frequencies (see chapter 2) and these locations may represent areas where reliable animal detection systems may make sense. As Huijser and McGowen (2010) point out there are several pros for animal detection systems compared to wildlife crossing structures. These include the fact that animal detection systems have the potential to provide wildlife with safe crossing opportunities anywhere along the roadway; they are less restrictive to wildlife movement than fencing or crossing structures; they can be installed without major road construction or traffic control for long periods; and they are likely to be less expensive than wildlife crossing structures (Huijser and McGowen 2010). The biggest con of animal detection systems is their unreliability and somewhat sporadic behavior at present time (e.g., during snow storms or high wind events that give 'false animal detection'), although these issues are improving as more research and development occurs on these systems.

Finally, in addition to warning signs and animal detection systems, vegetation removal and alteration may be an effective strategy to reduce WVCs, particularly for moose along US 20 in the study area. Our RSF model results demonstrate that horizontal cover/disappearance distance is indeed important in selection of road crossing locations by elk and moose. A study of the effect of vegetation removal on moose-train collisions in Norway found that clearing vegetation across a 20-30 meter (70-100 feet) swath on each side of the railway reduced moose-train collisions by 56 percent (Jaren et al. 1991). Additionally, clearing of vegetation along roadsides in Sweden resulted in a 20 percent reduction in moose-vehicle collisions (Lavsund and Sandegren 1991) as this kept animals further off the roadway. Thus clearing of vegetation in key areas may have value in reducing WVCs involving moose along US 20, although this is an idea that warrants further investigation. One potential consideration is the fact that re-growth of forbs and shrubs may attract moose and other species, perhaps increasing their presence and the probability of collisions over time, an idea that also warrants further investigation if this idea is to be explored more fully along US 20.

SUMMARY

Ultimately, irrespective of the mitigation measure or approach taken, monitoring needs to be an integral part of a highway mitigation project even long after the measures have been in place. Mitigation is costly but post-construction evaluations are a prudent use of public funds and can help agencies save money on future projects. Long-term monitoring is important as lessons learned can be applied to future projects, and if certain design, sighting, or construction parameters are not working as intended changes can be made during mitigation efforts. Long-term monitoring is also important because for some species, use of crossing structures may not be immediate, and may occur gradually over time. This is something that those involved in mitigating impacts of roads on wildlife and habitat connectivity should be aware of up-front. For example, grizzly bears (*Ursus arctos*) in Banff National Park in Canada took a significant amount of time (e.g., in some cases 5 years) before they began using crossing structures, but now demonstrate a high level of use (see Ford et al. 2010). Ultimately, as more and more people move into the northern U.S. Rockies, including the GYE and southeast Idaho, higher traffic volumes and additional necessary transportation infrastructure will continue to increase the impacts of US 20 and other highways on elk, moose and other species. Conservation and mitigation efforts for elk and moose, if done correctly will likely have significant positive impacts on habitat connectivity for other species in the region as well (e.g., mule deer [*Odocoileus hemionus*], pronghorn, grizzly bears, wolverines [*Gulo gulo*], etc). These efforts would also enhance the safety of the traveling public along U.S. 20 and Highway 87. Transportation planning based on the best available science, such as the results demonstrated here, will be critical to include in future planning in order to allow the people of Idaho and the USA to enjoy the open road while at the same time allowing wildlife the freedom to move across the landscape.

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Appendix A. This table includes relevant data for all collared elk and moose referenced within this report.

	Identification Information			Capture Information		Survival Data	
Eartag	*Collar ID*	*Species*	*Seasonal Strategy*	*Capture Date*	*Capture Effort*	*Fate*	*Cause of Death*
5084	30277	elk	migratory	12/4/2010	1	deceased	harvested
8900	30253	elk	migratory	12/4/2010	1	collar recovered	
8901	30254	elk	migratory	12/4/2010	1	collar removed	
8902	30250	elk	migratory	12/4/2010	1	collar recovered	
8903	30251	elk	migratory	12/4/2010	1	collar removed	
8904	30252	elk	migratory	12/5/2010	1	deceased	depredation harvest
8905	30255	elk	migratory	12/5/2010	1	deceased	unknown
8906	30256	elk	migratory	12/5/2010	1	deceased	unknown
8907	30257	elk	migratory	12/5/2010	1	collar removed	
8908	30258	elk	migratory	12/5/2010	1	collar removed	
8909	30259	elk	migratory	12/5/2010	1	collar replaced	
8910	30260	elk	migratory	12/4/2010	1	deceased	unknown
8911	30261	elk	migratory	12/4/2010	1	deceased	unknown
8912	30262	elk	migratory	12/4/2010	1	collar recovered	
8913	30263	elk	migratory	12/5/2010	1	collar recovered	
8914	30264	elk	migratory	12/5/2010	1	deceased	unknown
8915	30265	elk	migratory	12/5/2010	1	collar removed	
8916	30266	elk	migratory	12/4/2010	1	collar removed	
8917	30267	elk	migratory	12/4/2010	1	collar recovered	
8918	30270	elk	migratory	12/4/2010	1	collar didn't drop	
8919	30269	elk	migratory	12/5/2010	1	deceased	unknown
8920	30268	elk	migratory	12/5/2010	1	collar recovered	
8921	30271	elk	migratory	12/5/2010	1	deceased	unknown
8922	30272	elk	migratory	12/4/2010	1	collar recovered	
8923	30273	elk	migratory	12/4/2010	1	collar recovered	
8924	30274	elk	migratory	12/4/2010	1	deceased	unknown
8925	30276	elk	migratory	12/4/2010	1	deceased	unknown
8926	30275	elk	migratory	12/4/2010	1	deceased	unknown
8928	30278	elk	migratory	12/5/2010	1	collar recovered	
8929	30279	elk	migratory	12/5/2010	1	collar recovered	
12947	30252	elk	migratory	12/3/2011	2	deceased	harvested
12989	30276	elk	migratory	2/26/2012	2	collar active	
12990	30274	elk	migratory	2/26/2012	2	collar active	
12991	30264	elk	migratory	2/26/2012	2	collar active	
12992	30269	elk	migratory	2/26/2012	2	collar active	
12993	30275	elk	migratory	2/26/2012	2	collar active	
12997	30259	elk	migratory	2/26/2012	2	collar removed	
8930	30280	moose	migratory	12/5/2010	1	collar recovered	
8931	30283	moose	migratory	12/5/2010	1	animal missing	
8932	30285	moose	non-migratory	1/19/2011	1	deceased	unknown

Appendix A.1

	Identification Information			Capture Information		Survival Data	
Eartag	*Collar ID*	*Species*	*Seasonal Strategy*	*Capture Date*	*Capture Effort*	*Fate*	*Cause of Death*
8933	30287	moose	migratory	12/5/2010	1	deceased	unknown
8934	30289	moose	non-migratory	1/13/2011	1	collar recovered	
8935	30291	moose	migratory	12/2/2011	2	deceased	unknown
8937	30296	moose	non-migratory	2/12/2011	1	collar recovered	
8938	30297	moose	non-migratory	1/20/2011	1	collar recovered	
8939	30298	moose	non-migratory	1/13/2011	1	deceased	hit by vehicle
8940	30281	moose	migratory	12/5/2010	1	collar recovered	
8941	30282	moose	migratory	12/5/2010	1	deceased	unknown
8942	30284	moose	migratory	12/5/2010	1	collar recovered	
8943	30286	moose	non-migratory	2/12/2011	1	collar recovered	
8944	30288	moose	non-migratory	2/13/2011	1	deceased	unknown
8945	30295	moose	non-migratory	1/20/2011	1	collar didn't drop	
8946	30302	moose	migratory	12/16/2010	1	collar recovered	
8947	30303	moose	migratory	12/16/2010	1	collar recovered	
8948	30290	moose	non-migratory	2/15/2011	1	collar recovered	
8949	30292	moose	non-migratory	1/18/2011	1	deceased	hit by vehicle
8950	30294	moose	non-migratory	2/14/2011	1	deceased	unknown
8951	30299	moose	migratory	12/16/2010	1	deceased	unknown
8952	30300	moose	migratory	12/16/2010	1	collar recovered	
8953	30301	moose	migratory	12/16/2010	1	deceased	unknown
8954	30304	moose	non-migratory	1/14/2011	1	collar recovered	
8955	30305	moose	non-migratory	1/18/2011	1	deceased	unknown
8956	30306	moose	migratory	12/16/2010	1	deceased	unknown
8957	30307	moose	migratory	12/2/2011	2	collar removed	
8958	30308	moose	migratory	12/16/2010	1	collar recovered	
8959	30309	moose	migratory	12/16/2010	1	deceased	fell through ice
12935	30285	moose	migratory	12/2/2011	2	collar active	
12937	30299	moose	migratory	12/2/2011	2	collar recovered	
12938	30301	moose	migratory	12/2/2011	2	collar active	
12939	30307	moose	migratory	12/3/2011	2	collar recovered	
12940	30293	moose	migratory	12/2/2011	2	deceased	unknown
12941	30306	moose	migratory	12/3/2011	2	collar recovered	
12942	30288	moose	migratory	12/2/2011	2	collar recovered	
12943	30294	moose	migratory	12/2/2011	2	collar recovered	
12944	30282	moose	migratory	12/2/2011	2	deceased	unknown
12945	30305	moose	migratory	12/2/2011	2	collar recovered	
12946	30298	moose	migratory	12/2/2011	2	collar recovered	
12995	30309	moose	migratory	2/26/2012	2	collar active	
12996	30293	moose	migratory	2/26/2012	2	collar recovered	

Appendix A.2

	US 20 Highway Crossing Data (for RSF Model)				
Eartag	*US20 Crosser*	*Number of US20 Crossings*	*Crossings: 30 min*	*Number of US20 Crossings: 12 hrs*	*Number of 30 min Crossings Used in RSF*
5084	n	0	0	0	0
8900	y	8	2	6	2
8901	n	0	0	0	0
8902	y	4	4	0	4
8903	n	0	0	0	0
8904	[1]unknown	-	-	-	-
8905	n	0	0	0	0
8906	y	0	0	0	0
8907	y	4	2	2	2
8908	y	49	19	30	19
8909	y	1	1	0	1
8910	y	1	1	0	1
8911	n	0	0	0	0
8912	n	0	0	0	0
8913	n	0	0	0	0
8914	n	0	0	0	0
8915	y	17	4	13	4
8916	y	38	4	34	4
8917	y	13	5	8	5
8918	n	0	0	0	0
8919	n	0	0	0	0
8920	y	4	3	1	3
8921	n	0	0	0	0
8922	n	0	0	0	0
8923	n	0	0	0	0
8924	n	0	0	0	0
8925	[1]unknown	-	-	-	-
8926	[1]unknown	-	-	-	-
8928	n	0	0	0	0
8929	y	10	7	3	7
12947	[1]unknown	-	-	-	-
12989	y	2	1	1	1
12990	n	0	0	0	0
12991	y	1	1	0	1
12992	[1]unknown	-	-	-	-
12993	y	2	1	1	1
12997	n	0	0	0	0
8930	n	0	0	0	0
8931	[1]unknown	-	-	-	-
8932	n	0	0	0	0

Appendix A.3

	US 20 Highway Crossing Data (for RSF Model)				
Eartag	*US20 Crosser*	*Number of US20 Crossings*	*Crossings: 30 min*	*Number of US20 Crossings: 12 hrs*	*Number of 30 min Crossings Used in RSF*
8933	n	0	0	0	0
8934	n	0	0	0	0
8935	n	0	0	0	0
8937	y	2	0	2	0
8938	y	9	1	8	1
8939	y	19	17	2	17
8940	y	4	3	1	3
8941	n	0	0	0	0
8942	y	3	1	2	1
8943	y	51	5	46	5
8944	[1]unknown	-	-	-	-
8945	y	198	85	113	85
8946	n	0	0	0	0
8947	n	0	0	0	0
8948	y	16	3	13	2
8949	y	15	10	5	10
8950	[1]unknown	-	-	-	-
8951	n	0	0	0	0
8952	y	2	0	2	0
8953	n	0	0	0	0
8954	n	0	0	0	0
8955	n	0	0	0	0
8956	n	0	0	0	0
8957	n	0	0	0	0
8958	n	0	0	0	0
8959	[1]unknown	-	-	-	-
12935	y	1	0	1	0
12937	n	0	0	0	0
12938	n	0	0	0	0
12939	y	14	6	8	6
12940	[1]unknown	-	-	-	-
12941	y	2	1	1	1
12942	[1]unknown	-	-	-	-
12943	y	2	1	1	1
12944	n	0	0	0	0
12945	n	0	0	0	0
12946	y	16	1	15	1
12995	n	0	0	0	0
12996	n	0	0	0	0

[1]Not sufficient data collected to determine US 20 crossing status

Appendix A.4

	Data Used to Create Migratory Utilization Distribution (Full BBMM)						Seasonal Range KDE *ad hoc* Bandwidth	
Eartag	***BBMM Spg2011***	***BBMM Fall2011***	***BBMM Spg2012***	***BBMM Fall2012***	***BBMM Spg2013***	***BBMM Fall2013***	***Summer***	***Winter***
5084							2909	6469
8900	✓		✓				1007	3580
8901							944	4603
8902	✓	✓	✓	✓			3175	2562
8903							2836	3618
8904								
8905							983	5996
8906							1362	4047
8907			✓				2114	4658
8908	✓	✓	✓	✓			1324	3618
8909	✓						468	2114
8910	✓							1536
8911								1203
8912							3249	4675
8913							641	6927
8914							2683	2965
8915	✓	✓	✓				1404	3104
8916	✓		✓				1405	2814
8917	✓	✓	✓				1457	8199
8918							2214	10148
8919							1173	1785
8920	✓	✓	✓				2625	1587
8921							1570	4714
8922							827	1953
8923							3572	1567
8924							952	1833
8925								
8926								
8928							1463	4591
8929	✓		✓	✓			1434	
12947								
12989			✓		✓	✓	1863	3382
12990							2568	2490
12991			✓				2540	4984
12992								
12993			✓				5092	2518
12997								3192
8930							357	8085
8931								
8932								

Appendix A.5

	Data Used to Create Migratory Utilization Distribution (Full BBMM)						Seasonal Range KDE *ad hoc* Bandwidth	
Eartag	***BBMM Spg2011***	***BBMM Fall2011***	***BBMM Spg2012***	***BBMM Fall2012***	***BBMM Spg2013***	***BBMM Fall2013***	***Summer***	***Winter***
8933							350	1577
8934								
8935								
8937								
8938	✓							
8939								
8940	✓	✓		✓			821	3977
8941								
8942	✓						1578	7167
8943		✓					1559	428
8944								
8945								
8946							1355	5016
8947							480	3344
8948								
8949								
8950								
8951								
8952							639	5591
8953								2626
8954								
8955								
8956							1240	1787
8957							2866	816
8958							637	2851
8959								
12935							1022	4881
12937							605	4646
12938							500	4715
12939			✓				913	1738
12940								
12941			✓				540	1342
12942								
12943				✓			3663	2785
12944								
12945								
12946			✓				747	1446
12995							470	5365
12996							3048	4063

Appendix A.6

Appendix B-1. Elk univariate model selection.

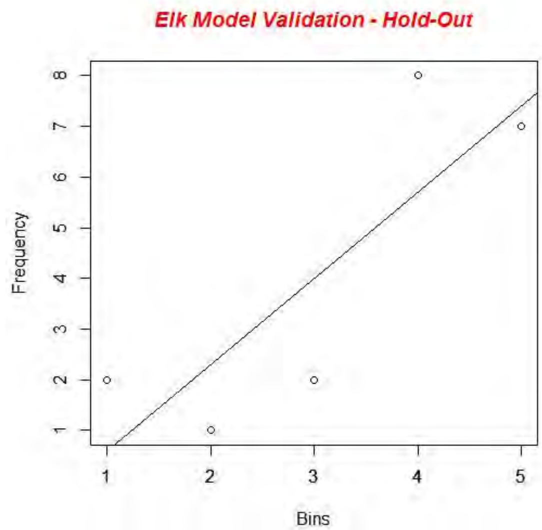
Model#	Model	K	AICc	Delta_AICc	AICcWt
3	RdDens	2	153.76	0	0.99
9	Nlanes	2	166.76	13	0
8	Speed	2	166.76	13	0
10	DisDistMN	2	167.35	13.59	0
11	DstCovMN	2	167.5	13.74	0
7	Developed	2	167.56	13.81	0
4	Riparian	2	169.5	15.75	0
1	DistWater	2	169.99	16.24	0
6	ShrubGrass	2	170.26	16.5	0
2	Forest	2	170.37	16.62	0
5	RuggedMN	2	170.52	16.76	0

Appendix B-2. Non-migratory moose univariate model selection.

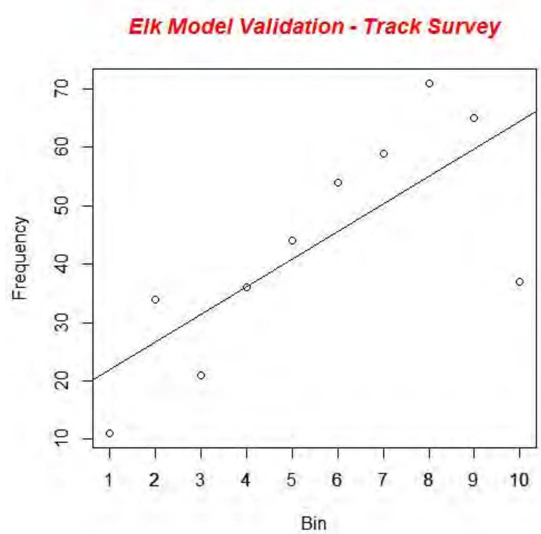
Model#	Model	K	AICc	Delta_AICc	AICcWt
10	Speed	2	378.34	0	0.49
11	Nlanes	2	378.34	0	0.49
1	DistWater	2	386.20	7.86	0.01
5	RuggedMN	2	386.42	8.07	0.01
2	Forest	2	395.59	17.25	0
3	RdDens	2	395.93	17.58	0
4	Riparian	2	396.67	18.33	0
9	DstCovMN	2	398.41	20.07	0
8	DisDistMN	2	400.03	21.68	0
7	Developed	2	403.76	25.42	0
6	ShrubGrass	2	408.70	30.36	0

Appendix B-3. Migratory moose univariate model selection.

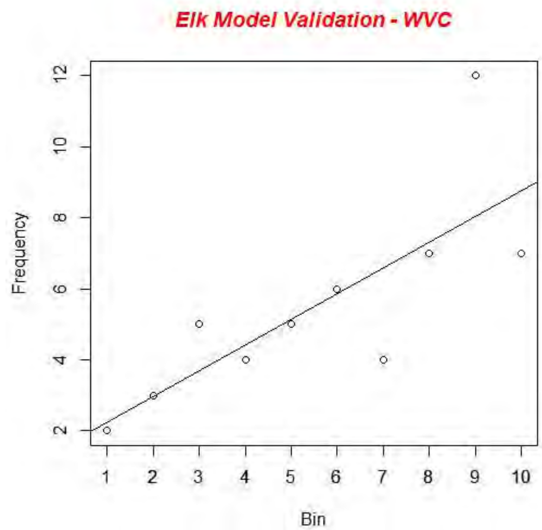
Model#	Model	K	AICc	Delta_AICc	AICcWt
9	RdDens	2	45.62	0	0.99
4	Developed	2	58.35	12.73	0
11	DstCovMN	2	58.64	13.03	0
10	DsDistMN	2	58.98	13.37	0
5	Speed	2	59.02	13.40	0
7	DistWater	2	59.79	14.18	0
6	Nlanes	2	60.00	14.38	0
2	Riparian	2	62.53	16.91	0
8	ShrubGrass	2	62.68	17.06	0
1	Forest	2	62.70	17.09	0
3	RuggedMN	2	62.71	17.09	0



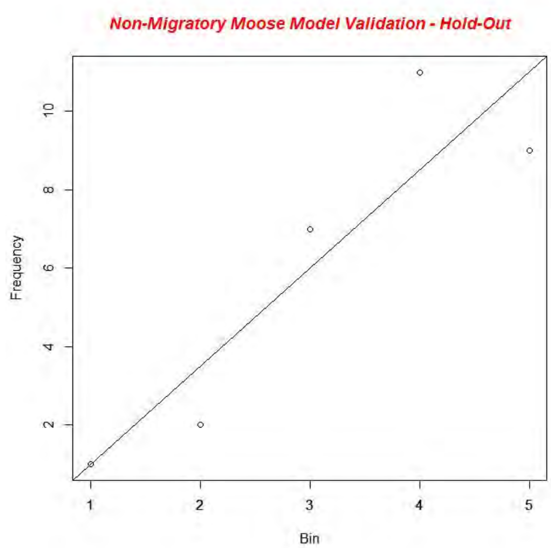
Appendix C-1. Frequency of withheld crossing locations of elk (n = 20) in RSF validation bins. Bins were created from the random locations (n = 111) used for RSF development along US 20, Idaho, USA 2010-2013. An approximately equal number of random locations were in each bin (e.g., 22) and the relative probability minimum cut-offs of random locations to demarcate 5 bins were 0.004, 0.058, 0.102, 0.166, 0.331.



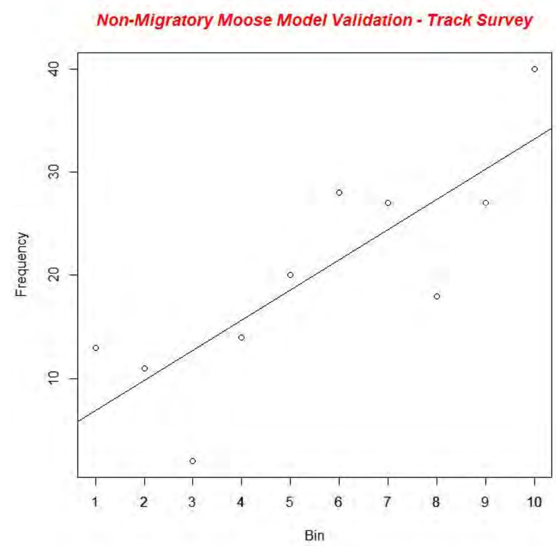
Appendix C-2. Frequency of successful road crossing locations of elk recorded by track surveys (n = 432) in RSF validation bins along US 20, Idaho, USA 2010-2013. The road was split into 10 equal length bins demarcated at relative probabilities of 0.004, 0.034, 0.078, 0.104, 0.131, 0.165, 0.209, 0.296, 0.362, 0.467.



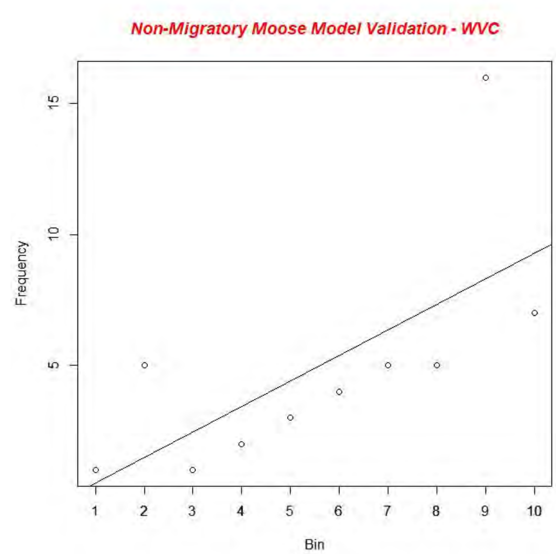
Appendix C-3. Frequency of unsuccessful road crossing locations of elk recorded by WVCs (n = 55) in RSF validation bins along US 20, Idaho, USA 2010-2013. The road was split into 10 equal length bins demarcated at relative probabilities of 0.004, 0.034, 0.078, 0.104, 0.131, 0.165, 0.209, 0.296, 0.362, 0.467.



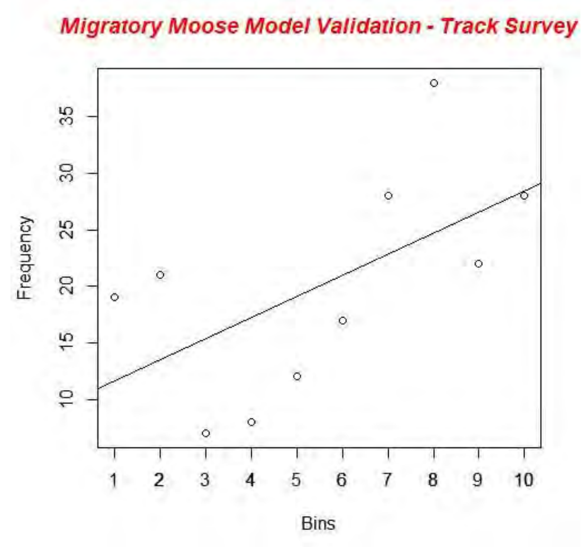
Appendix C-4. Frequency of withheld crossing locations of non-migratory moose (n = 30) in RSF validation bins using data from random locations (n = 270) along US 20, Idaho, USA 2010-2013. An equal number of random locations was in each bin and the relative probability minimum cut-offs of random locations to demarcate 5 bins were 0, 0.029, 0.097, 0.153, 0.185.



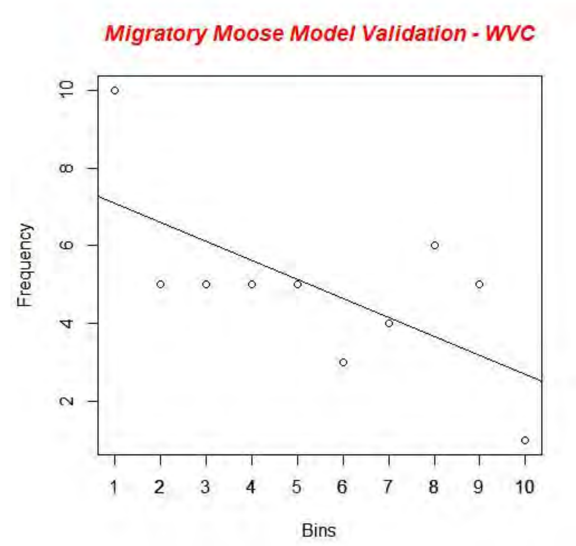
Appendix C-5. Frequency of successful road crossing locations of non-migratory moose recorded by track surveys (n = 200) in RSF validation bins along US 20, Idaho, USA 2010-2013. The road was split into 10 equal length bins demarcated at relative probabilities of 0, 3.2E-05, 0.018, 0.030, 0.051, 0.082, 0.131, 0.162, 0.181, 0.263.



Appendix C-6. Frequency of unsuccessful road crossing locations of non-migratory moose recorded by WVCs (n = 49) in RSF validation bins along US 20, Idaho, USA 2010 -2013. The road was split into 10 equal length bins demarcated at relative probabilities of 0, 3.2E-05, 0.018, 0.030, 0.051, 0.082, 0.131, 0.162, 0.181, 0.263.



Appendix C-7. Frequency of successful road crossing locations of migratory moose recorded by track surveys (n = 200) in RSF validation bins along US 20, Idaho, USA 2010-2013. The road was split into 10 equal length bins demarcated at relative probabilities of 0, 2.50E-05, 4.14E-04, 0.0013, 0.0027, 0.0049, 0.0098, 0.0254, 0.0521, 0.0931.



Appendix C-8. Frequency of unsuccessful road crossing locations of migratory moose recorded by WVCs (n = 49) in RSF validation bins along US 20, Idaho, USA 2010-2013. The road was split into 10 equal length bins demarcated at relative probabilities of 0, 2.50E-05, 4.14E-04, 0.0013, 0.0027, 0.0049, 0.0098, 0.0254, 0.0521, 0.0931.