Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

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Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Executive Summary

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The Alaska Department of Transportation and Public Facilities (ADOT&PF) in cooperation with the Federal Highway Administration (FHWA), is seeking to improve the Sterling Highway in the Cooper Landing and Kenai River area between Milepost (MP) 45 and MP 60 (project area) to rural principal arterial standards. As part of their responsibilities under the National Environmental Policy Act, ADOT&PF and FHWA sponsored this wildlife mitigation study in collaboration with wildlife management agencies to identify the best locations for mitigation measures that would help to retain wildlife movement patterns. The scope of the study was developed in consultation with an interagency wildlife team (USDI Fish and Wildlife Service, USDA Forest Service, and Alaska Department of Fish and Game) (Suring 2013). The results of the study are expected to aid DOT&PF and FHWA in refining the locations of wildlife crossings and making commitments to other measures to accommodate wildlife movement based on examination of the focal species evaluated in this report.

This study was designed to identify wildlife habitat associations and movement patterns in the project area with a goal of providing information for identifying locations for potential wildlife crossings and related actions that could be incorporated into the highway design. We conducted an evaluation of the movement patterns of 6 focal species (brown bear [*Ursus arctos*], black bear [*Ursus americanus perniger*], wolverine [*Gulo gulo katschemakensis*], Canada lynx [*Lynx canadensis*], moose (*Alces americanus*), Dall sheep [*Ovis dalli kenaiensis*]) on the Kenai Peninsula, Alaska. This work focused on the potential influence of the existing alignment of the Sterling Highway on the movement patterns of these focal species to form a basis for mitigation during reconstruction of the Highway.

The objectives of this study were to:

- Describe the use of landscapes by the focal species on the Kenai Peninsula through the use of published research findings, through original analysis of existing data, or through the development of original models.

- Use those landscape use patterns to model and describe potential movements of focal species throughout the Kenai Peninsula with an emphasis on the area between MP 45–60 on the Sterling Highway.

- Use those patterns of movement by the focal species to describe movement corridors for these species throughout the Kenai Peninsula with an emphasis on the area between MP 45–60 on the Sterling Highway.

- Describe management actions suitable to mitigate the potential effects of the Sterling Highway MP 45–60 Project on movement corridors used by the focal species.

The resulting information will be useful in planning and implementing management practices and other measures that may mitigate the effects of the highway project alternatives on wildlife movement patterns (Suring 2013: vii).

Study Overview

This study consisted of analysis of existing data, model development and application, and a year-long field verification phase. We used resource selection functions (RSFs) and Bayesian networks (BNs) to describe habitat quality for the focal species and least-cost corridor (LCC) and circuit theory analyses to describe potential movement paths. The field verification effort used camera-capture technology to indicate frequency of presence and location of the focal species throughout the year in the project area to evaluate models used to predict movement corridors. The analysis of the 6 focal species (Chapters 3 through 12), were combined to identify corridor hot spots (Chapter 13), (i.e., areas anticipated to have the greatest benefit for potential mitigation to maintaining wildlife movements).

We identified the most likely locations for wildlife crossings for the 6 focal species along the Sterling Highway MP 45–60 to provide information for the mitigation of impacts to populations of species susceptible to wildlife-vehicle collisions (WVCs) and disruption of movement patterns. Wildlife crossings and associated structures (e.g., fencing) are often built to mitigate the barrier effect of roads. There is compelling evidence that many wildlife species regularly and frequently use crossing structures (reviewed in van der Ree et al. 2007), and that well-designed and maintained fencing greatly reduce rates of wildlife mortality and funnels animals towards the crossing structures (reviewed in Glista et al. 2009 and Rytwinski et al. 2016). Consequently, application of these practices have greatly expanded in the last 30 years (van der Ree et al. 2015). To be effective, crossings should be built as close as possible to natural corridors (i.e., integrated into the connectivity network of species of interest). They need to have favorable landscape configuration and composition, and they must be short (i.e., <70 m [230 ft]) but with low gradients that provide good connections to the natural habitat (Clevenger and Huijser 2011, van der Ree et al. 2015). However, designing corridors and crossing structures for single species based on ecological criteria can lead to extremely expensive costs for mitigation and is not recommended, except in special circumstances (Dilkina et al. 2017; T. Clevenger, personal communication).

Summary of Results by Focal Species

Brown Bear

Suring et al. (Chapter 3; 2017a) used RSFs previously developed for brown bears on the Kenai Peninsula (Suring et al. 2006) in combination with LCC and circuit theory analyses to estimate movement paths for brown bears. Potential primary crossing points for female brown bears in the spring with cubs and without cubs and in the summer with cubs and without cubs were located at MP 44 near Quartz Creek and between MPs 49 and 51 near Cooper Creek on the south and Juneau Creek on the north sides of the Sterling Highway (Chapter 3; Suring et al. 2017a) (Figure ES-1).

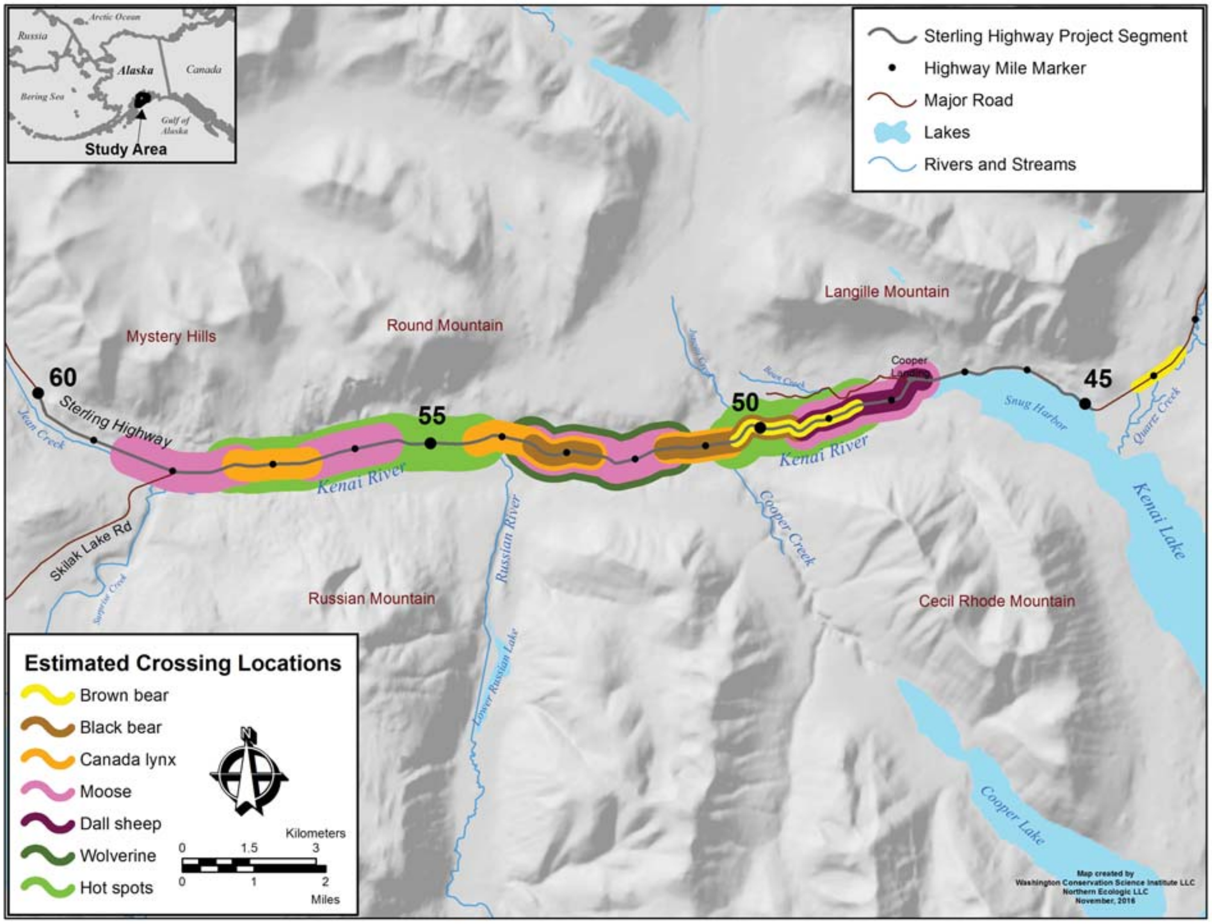

Figure ES-1. Primary estimated crossing locations of the Sterling Highway within the project area for individual focal species and for multispecies hot spots by milepost on the Kenai Peninsula, Alaska, USA.

Black Bear

Suring et al. (Chapter 6; 2017b) developed RSFs for black bears on the Kenai Peninsula and then used those RSFs in combination with LCC and circuit theory analyses to estimate movement paths for black bears (Chapter 7; Suring et al. 2017c). Based on those analyses, potential north-south movements of black bears across the Sterling Highway in the vicinity of Cooper Landing revealed 2 primary pinch points where animals were most likely to concentrate their crossings (MP 50–51 in the vicinity of Juneau and Cooper creeks and MP 53 where the Sterling Highway currently crosses the Kenai River) (Figure ES-1).

Wolverine

Suring et al. (Chapter 10; 2017d) developed a BN for wolverines on the Kenai Peninsula and then used that BN in combination with LCC and circuit theory analyses to estimate movement paths for wolverines. Based on that analysis, potential north-south movements of wolverines across the Sterling Highway in the vicinity of Cooper Landing revealed 1 primary pinch point where animals were most likely to concentrate their crossings (MP 52–53) (Figure ES-1).

Canada Lynx

Gaines et al. (Chapter 8; 2017a) developed RSFs for Canada lynx on the Kenai Peninsula and then used those RSFs in combination with LCC and circuit theory analyses to estimate movement paths for Canada lynx (Chapter 9; Gaines et al. 2017b). Based on those analyses, they identified 3 primary north-south habitat linkages across the Sterling highway between MP 45–60. The first linkage was near MP 51, west of where Cooper Creek and Juneau Creek join the Kenai River. The second linkage occurred near the confluence of the Russian and Kenai rivers near MP 53–54. The third linkage extended east-west across the Sterling highway near MP 57 (Figure ES-1).

Moose

Gaines et al. (Chapter 4; 2017c) developed RSFs for moose on the Kenai Peninsula and then used those RSFs in combination with LCC and circuit theory analyses to estimate movement paths for moose (Chapter 5; Gaines et al. 2017d). Based on those analyses, they identified 4 primary north-south habitat linkages within the project area for female moose. There was a linkage near MP 48–49 west of Kenai Lake near Cooper Landing and another near MP 52–53. West of the confluence with the Russian River and east of the intersection with the Skilak Lake Road there was a third (MP 56) and a fourth linkage (MP 58) (Figure ES-1).

Dall Sheep

Suring et al. (Chapter 11; 2017e) developed a BN for Dall sheep on the Kenai Peninsula and then used that BN in combination with LCC and circuit theory analyses to estimate movement paths for Dall sheep. Based on that analysis, potential north-south movements of Dall sheep across the Sterling Highway in the vicinity of Cooper Landing revealed 1 primary pinch point where animals were most likely to concentrate their crossings (MP 48–49 near the outlet of Kenai Lake) (Figure ES-1).

Conclusions

Specific patterns of habitat use and avoidance were identified for all 6 focal species. Those patterns were used to identify potential movement paths for each species through application of LCC and circuit theory analyses. Movement paths estimated for individual focal species and a hot spot analysis indicated that the section of the existing Sterling Highway between MP 48–54 contained crossing sites for all focal species (Figure ES-1). Other crossing sites for brown bear, moose, and Canada lynx occurred outside of this section (i.e., MP 44 for brown bear, MP 56 and 58 for moose, MP 57 for Canada lynx).

Previous analyses of movement patterns of brown bears (Graves et al. 2006, 2007) and moose (Ernst et al. 2009) verified our estimates of movement patterns for these species. Our efforts at evaluating the modeled movement corridors with camera trapping showed support for the corridors identified for brown bear, black bear, and Canada lynx. Results for moose were mixed. We did not capture images of wolverines or Dall sheep and were unable to evaluate movement corridors modeled for them.

Concentrating mitigation measures within the MP 48–54 area provides an opportunity to optimize mitigation practices associated with the existing highway for all focal species while containing the potential costs of crossing structures. This section of highway coincided with, or was in proximity to, the confluences of Bean Creek, Juneau Creek, Cooper Creek, and Russian River with the Kenai River.

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Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 1 – Introduction

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The Alaska Department of Transportation and Public Facilities (ADOT&PF) in cooperation with the Federal Highway Administration (FHWA), is seeking to improve the Sterling Highway in the Cooper Landing and Kenai River area between milepost (MP) 45 and MP 60 to rural principal arterial standards. The purpose of the project is to bring the highway up to current standards for a designated rural principal arterial to efficiently and safely serve through-traffic, local community traffic, and traffic bound for recreation destinations in the area, both now and in the future. In achieving this transportation purpose, ADOT&PF and FHWA recognize the importance of protecting the Kenai River corridor (HDR, Inc. 2015: Chapter 1). Specifically, the proposed project alternatives address, in varying degrees, the following 3 interrelated needs: reducing highway congestion, upgrading the highway to meet current highway design standards, and improving highway safety.

Effects of Highways on Wildlife

Wildlife-vehicle collisions (WVCs) affect the safety of drivers. Recent data reported by insurance companies indicated that annually there are approximately 1,000,000 WVCs within the United States based on the number of claims processed for collisions with deer (*Odocoileus* spp.), elk (*Cervus elaphus*), and moose (*Alces americanus*) (Conover et al. 1995, Ament et al. 2007). Further, roads have been shown to have significant impacts on wildlife populations (Forman and Alexander 1998, Trombulak and Frissell 2000). Effects on wildlife include impediments to movements and road avoidance behaviors; direct wildlife mortality; and habitat loss, degradation, and fragmentation (Andrews 1990, Bennett 1991, Forman and Alexander 1998). Further, animals may respond negatively to human activity along roads and other developed areas by reducing their use of certain areas or habitats (Suring et al. 2006, Shanley and Pyare 2011), by altering their movement patterns within an area, or by leaving the area (Shepard et al. 2008). Roads may also present barriers to movement for many species of wildlife or may act as partial barriers, blocking some but not all movements across them (Forman and Alexander 1998).

Wildlife Movements

Landscape permeability describes the extent to which wildlife are able to move across a landscape (Frair et al. 2008). A landscape has high permeability when wildlife are able to move to access habitat, important resources, find mates, or to disperse (Kramer-Schadt et al. 2004). A landscape has low permeability when barriers impede movements, potentially limiting wildlife from accessing needed resources (Singleton et al. 2002). Transportation corridors often represent such barriers to movement (e.g., Dyer et al. 2002).

Three main road characteristics affect behavioral responses of wildlife to crossing roads: (1) traffic volume, (2) road width, and (3) road surface (Forman and Alexander 1998, Yale Conrey and Mills 2001, Fahrig and Rytwinski 2009). Traffic volume has been identified as a significant deterrent to wildlife movement (Chruszcz et al. 2003, Eigenbrod et al. 2009). Additional features of roads, such as gap width (number of lanes), median, hard versus soft shoulder, ditches, and fencing all constitute potential obstacles to movement (Swihart and Slade 1984, Yale Conrey and Mills 2001, Rico et al. 2007). Roads are often located in combination with natural barriers (e.g., rivers). These parallel barriers likely contribute to cumulative effects on the movement abilities of certain wildlife. Such barriers can subdivide populations (e.g., Mader 1984, Clarke et al. 1998), creating genetically distinct subpopulations (e.g., Reh and Seitz 1990, Gerlach and Musolf 2000) that may ultimately affect population viability and persistence for some species (e.g., Lode 2000, Borda-de-Água et al. 2011).

Impediments to movements are amplified with increasing overall width of the roadway (Lovallo and Anderson 1996), increasing vehicle speeds (Gunther et al. 2000), and traffic volume (Seiler 2003, Waller and Servheen 2005). The number and timing of road crossings by wildlife may be related to traffic volumes which may be sufficient to impede normal movement across road corridors. Wildlife can usually cross a road corridor with minimal probability of getting hit by a vehicle at low traffic volumes. As traffic volumes increase, wildlife shift their movement patterns to favor periods of the day when traffic volume is low. Eventually though, there is a threshold in traffic volume and road corridor configuration beyond which wildlife crossings are not possible. At extremely high traffic volumes, and in areas where multiple traffic lanes exist, wildlife may find it nearly impossible to cross. Gibeau (2000) reported that along the Trans-Canada Highway brown bears did not cross when traffic volumes exceeded >20,000/day. Kaczensky et al. (2003) reported a similar situation along a 4-lane highway in Slovenia when traffic volume was >7,500/day.

Other effects include disruptions of daily and seasonal movements that have consequences associated with the species population growth. Limiting population growth may affect the species contribution to ecological services and to social and economic interests (e.g., hunting opportunity and associated revenue) (Muradian 2001). Understanding the degree to which roads create barriers to movements is a critical first step in preventing and mitigating this effect (St. Clair 2003). One contributing cause may be that gaps in habitat have been found to be less permeable to wildlife as noise associated with the gap increases (St. Clair 2003). As a result, as traffic volume increases on roads, their permeability to wildlife is likely to decrease.

Direct Mortality

Road-related mortality is the most visible and direct effect of roads on wildlife (Glista and DeVault 2008). It has the potential to significantly affect the dispersal or immigration and emigration rates of wildlife populations as individuals attempt to move across the landscape. There is also evidence that direct mortality of wildlife on roads can have consequences for local population dynamics (Ramp and Ben-Ami 2006). Recent studies have demonstrated population-level depletions of common species as a result of road impacts at local scales (Fahrig and Rytwinski 2009, Roger et al. 2011). Road fatalities are of concern for a wide range of species (Roger et al. 2012). The frequency of WVCs has been recognized as a public safety issue with economic consequences, for example, in Michigan (Allen and McCullough 1976), Newfoundland (Joyce and Mahoney 2001), and Québec (Dussault et al. 2006). As a result, many associated studies have focused on species that pose a public safety risk (Bennett et al. 2011).

Many factors influence the likelihood of a WVC, including season, life history stage, time of day, diet, habitat variables, and road features (Bennett et al. 2011). These factors may differ considerably between species and sites (Kerth and Melber 2009). While it may be possible to detect and predict mortality hot spots for some species, for others, it may be difficult or impossible to accomplish (Gunson et al. 2009, Litvaitis and Tash 2008).

The relationship between type of road and number of wildlife fatalities is not linear, with various hypotheses presented to predict the effects of traffic on road-kill probability (e.g., Seiler 2004, Jaeger et al. 2005). The effects of the type of road relative to the frequency of road fatality seems highly dependent on wildlife species, with road avoidance behavior likely playing a large role in determining vulnerability (Jaeger et al. 2005).

Mortality associated with WVCs is likely additive to the population, especially if the species has a protracted juvenile stage, small clutch or litter sizes, or few nonhuman sources of adult mortality (Livaitis and Tash 2008). This means that any individual that dies from the 'additive' cause would have survived if this cause was removed (Péron 2013). Long-lived species have naturally low population growth rates and have evolved strategies aimed at minimizing adult natural mortality. They are thus less able to sustain exploitation and are also less able to compensate for increases in anthropogenic mortality, such as WVCs, by decreases in natural mortality or increased productivity (Péron 2013).

Modification and Loss of Habitat

Habitat effects of roads include direct loss of habitat, fragmentation of habitat, and modifications of habitat characteristics. Generally, for every km of new highway construction, an estimated 644 ha of land is converted from its original vegetation cover or made available for further development, resulting in a significant loss of habitat to wildlife (Wolf 1981). However, it should be noted that ADOT&PF committed to "controlled access" along new portions of highway that may be constructed as part of the Sterling Highway MP 45–60 Project. This limited or eliminated opportunities for additional development adjacent to the highway, thus decreasing potential additional habitat loss.

The habitat fragmentation effect of roads can isolate certain wildlife populations that are hesitant, unwilling, or unable to cross roads (Jantz and Goetz 2008, Shepard et al. 2008). Habitat fragmentation is a landscape-level process in which habitat is subdivided into smaller and more isolated fragments (McGarigal and Cushman 2002). It involves changes in composition, structure, and function in habitat patches and the permeability of landscapes (McGarigal and McComb 1999). The process of habitat fragmentation is distinguished from habitat loss, even though these processes are almost always confounded (Fahrig 1997). Although habitat loss always accompanies fragmentation, they are different phenomena and should be distinguished. The direct effects of habitat fragmentation are an increase in habitat edge (and therefore edge effects), potential isolation of a habitat fragment from other similar habitat patches, and a decrease in average patch size across the landscape.

Modification of habitat as a result of roads also includes increased noise (Tremblay and St. Clair 2009) and pollution (e.g., salt, sediment, and chemical runoff) (Oberts 1986). These factors have additional effects that make habitat less favorable for many species.

Cumulative Effects

Cumulative effects occur when sequential and interactive activities occur over time within the same space in an environmental system (MacDonald 2000). Cumulative effects can be additive, synergistic, or antagonistic (Gergel 2002). Synergistic effects occur when the combined effects are greater than the sum of individual effects (i.e. additive effects) while antagonistic effects occur when the combined effects are less than the sum of individual effects (Gergel 2002). MacDonald (2000) stated that additive effects are the most common but that the complexity added by secondary and/or indirect effects can create synergism or antagonism.

Research and management programs addressing the effects of roads and transportation corridors on wildlife have primarily focused their efforts on specific issues associated with transportation corridors (e.g., WVC, avoidance behavior, habitat fragmentation, habitat degradation). Few studies have considered the combined and potentially synergistic outcome of multiple impacts. However, by not considering cumulative effects, we could potentially misunderstand the population-level impact of transportation corridors.

Roger et al. (2011) found that the effects of roads, in addition to the effects of other population pressures, were often the tipping point for threatening viability of wildlife populations. The most obvious cumulative effect of roads is the fragmentation of landscapes as they bisect large patches of a contiguous land cover. In addition to the fragmentation of the landscape caused by roads, however, are the cumulative ecological effects of roads when considered as networked systems. Ecological road network theory suggests that these cumulative effects may be influenced by the design and function of the network structure (Coffin 2007). Jaeger et al. (2005, 2006) used simulation modeling to predict the effects of road configuration networks on animal population persistence. They concluded that the effect of a gridded vs. parallel road network configuration depends on the target species' behavior (i.e., to what degree that species avoids crossing roads and the probability of it being killed if it does). Locating roads in proximity to each other may be beneficial by maintaining core habitat areas and contributing to population persistence. The cumulative effects of roads on landscape structure are relatively easy to detect and measure. However, the effects on wildlife species are much more difficult to detect.

For some species, the cumulative effect of crossing many parallel barriers may exceed the summed effect of isolated impediments. Functional connectivity will be additionally compromised in landscapes where large or multiple linear barriers run closely parallel to one another (Bélisle and St. Clair 2001). Combinations of natural and artificial barriers (e.g., roads, rivers) generally occur in or parallel to valley bottoms. These parallel barriers likely create a synergistic cumulative effect to the movement of certain wildlife disproportionate to the area that they occupy and that exceeds the sum of their individual effects. Among artificial barriers, roads are known to profoundly impede the movement of many wildlife species, particularly those lacking the ability to fly (Forman and Alexander 1998, Trombulak and Frissell 2000). Together with other linear features like pipe, utility, and railway lines, as well as natural barriers like rivers, these valley-bottom barriers are likely to make cross-valley travel considerably more difficult than travel parallel to the valley bottom for wildlife. These cumulative effects would presumably make the barriers created by roads considerably more severe in areas of greater road density (e.g., Reijnen et al. 1995, Forman 2000).

Evaluation and Selection of Focal Species

Although managing the potential effects of the Sterling Highway MP 45–60 Project on wildlife using a species-by-species approach has intuitive ecological merit, the sheer number of species that would need to be considered makes such an approach untenable. Also, in many cases, the ecological understanding and resources needed to manage for all species on an individual basis are not available. A focal species approach streamlines the assessment and mitigation process and can be seen as a pragmatic response to dealing with ecosystem complexity (Noon 2003, Roberge and Angelstam 2004, Suring et al. 2011). The key characteristic of a focal species is that its status and trend provide insights to the integrity of the larger ecological system to which it belongs and to the effects upon that system that are being evaluated (Lambeck 1997, Noss et al. 1996, Noon 2003). Generally, focal species are selected based on knowledge that factors limiting their populations are sensitive to the management actions that are being evaluated (Wiens et al. 2008). In this study, the focus is on landscape-scale characteristics, such as land cover composition and connectivity (Mikusiński et al. 2007). By addressing the needs of focal species, populations of other species, with which they are associated, are expected to experience conservation benefits (e.g., populations will be maintained).

By categorizing species according to their needs for management of threatening processes (e.g., connectivity) they can be ranked in terms of their vulnerability to those threats (Lambeck 1997). Those species most vulnerable to or most dependent upon a given process may become a focal species for defining the intensity, rate, or frequency at which that process should be managed.

Generally, highly mobile species that move on the ground may be negatively affected by the potential effects of the Sterling Highway MP 45–60 Project because they interact with roads more often than do less-vagile species (Carr and Fahrig 2001, Gibbs and Shriver 2002, Forman et al. 2003, Rytwinski and Fahrig 2011). Likewise, species with large home ranges will be more susceptible to road effects based on the presumption that these species cross the transportation system with greater frequency. Species with lower reproductive rates, later sexual maturity, and longer generation times will also be more susceptible to road effects because they will be less able to recover from population declines associated with WVCs (Gibbs and Shriver 2002, Rytwinski and Fahrig 2011). Since species with large home ranges and low reproductive rates usually naturally occur at low densities, it is likely that these species will be more susceptible to road effects than those that occur at high densities (Rytwinski and Fahrig 2012). Therefore, in general, larger species should be more negatively affected at the population level by roads than smaller species because larger species generally occur naturally at lower densities, have lower reproductive rates, longer generation times, and are more mobile than smaller species (Gibbs and Shriver 2002, Forman et al. 2003).

Species at the other end of the spectrum (e.g., relatively low mobility, small size, high fecundity) may also be strongly influenced by the Sterling Highway realignment. For example, if a species of flight-less insect is unable to cross the road corridor, there may be population-level consequences (e.g., genetic discontinuity), even if the species has high rates of reproduction. However, if the species is not biologically endangered, the relative consequences are likely to be localized. It is anticipated that ecological functions associated with the species will be unaltered on both sides of the road corridor (Hunter and Hunter 2008).

Many mammalian carnivores are sensitive to landscape change similar to the potential effects of the Sterling Highway MP 45–60 Project because of their low population density, low fecundity, limited dispersal ability across developed landscapes, and other traits that lower ecological resilience (Weaver et al. 1996, Carroll et al. 2001). As discussed above, this makes them potential focal species for use in this project. Relative to mammals in general, the meta-analysis performed by Rytwinski and Fahrig (2012) provided further support that mammals with lower reproductive rates, greater mobility, and larger body sizes are most vulnerable to the negative effects of roads and/or traffic. WVCs involving large terrestrial mammals tend to result in greater vehicle damage and greater potential for human injury and death than smaller animals, and are a greater safety risk on the road (Forman et al. 2003). As a result, Bissonette and Adair (2008) based their analysis of placement of road crossings for wildlife on carnivores with large ranges and on ungulates.

Using these factors as a basis for assessment we evaluated terrestrial mammals occurring on the Kenai Peninsula for their suitability as focal species for which management approaches will be developed to mitigate the potential effects of the Sterling Highway MP 45–60 Project on wildlife movement patterns (Table 1-1). Ranges of terrestrial mammals in Alaska from the Alaska Natural Heritage Program (2011) and MacDonald and Cook (2009) were examined to create a list of all terrestrial mammals that occurred on the Kenai Peninsula. This resulted in a list of 33 species.

Characteristics related to reproductive rates, age at sexual maturity, and generation time (i.e., litter size, age at first breeding, litters per year) were determined for each species from data provided by Jones et al. (2009). Home range sizes were also recorded for each species from data provided by Jones et al. (2009). We also considered the conservation status for each species as developed by Master et al. (2009) and implemented by the Alaska Natural Heritage Program (2011). Status categories were recorded for each species indicating if they were common, widespread, and abundant (S5); uncommon but not rare with some cause for long-term concern due to declines or other factors (S4); or vulnerable due to restricted range, recent and widespread declines, or other factors making it susceptible to extirpation (S3). All elements were ranked and totaled to provide an index to selection of focal species (Table 1-1).

One challenge in using a focal species approach is the difficulty of identifying the most sensitive species (Roberge and Angelstam 2004). One approach to dealing with this challenge is to use expert judgment in establishing thresholds for species selection (Hess and King 2002). Rank totals in our evaluation ranged from 0–10 with higher scores indicating increasing sensitivity to impaired movement patterns and disruption of population growth. Species with an index value of ≥8 were considered to be good candidates for focal species for this analysis based on their high level of sensitivity to the potential effects of the Sterling Highway MP 45–60 Project. This included black bear, brown bear, wolverine, Canada lynx, and Dall sheep. Black bear, brown bear, wolverine, and Dall sheep were also identified by Suring and Murphy (2006) as species in south-central Alaska with a risk to persistence. Black bear, brown bear, wolverine, Canada lynx, and Dall sheep were also identified as species of highest concern in relation to the Sterling Highway MP 45–60 Project during a wildlife issues workshop (Ruediger 2004).

Moose were subsequently added for consideration as a focal species because of the large population of this species on the Kenai Peninsula; the significance of moose as subsistence, game, and viewing resource; and the incidence of WVCs involving moose. Moose had an index value of 7 in our ranking system. ADOT&PF (2012) included an emphasis on the large number of collisions with moose in their strategic traffic safety plan. Because of the size of a moose, a collision with one often results in major damage to vehicles and sometimes human and moose fatalities (Huijser et al. 2009). The Kenai Peninsula Borough had the highest number and percentage of WVCs involving moose and the highest number of human fatalities resulting from WVCs involving moose among all boroughs in Alaska from 2001–2005 (ADOT&PF 2007).

Table 1-1. Sensitivity to movement being impaired by roads of mammals occurring on the Kenai Peninsula, Alaska, USA.[1]

Order Family Species	Reproductive characteristics			Home range (ha)[2]/rank	Status[2]/ rank	Rank total and index
	Age at first breeding[2]/rank	Litters per year[2]/rank	Litter size[2]/rank			
Insectivora						
Soricidae						
Cinereus shrew (*Sorex cinereus*)	1 year/0	2.0/0	6.49/0	0.50/0	S5/0	0
Dusky shrew (*S. monticolus*)	--	3.0/0	5.74/0	0.16/0	S5/0	0
Pygmy shrew (*S. hoyi*)	--	1.0/1	5.84/0	--	S5/0	1
Chiroptera						
Vespertilionidae						
Little brown myotis (*Myotis lucifugus*)	--	1.0/1	1.00/2	--	S4/1	4
Carnivora						
Canidae						
Coyote (*Canis latrans*)	1-2 years/0	1.0/1	5.72/0	2,000/2	S5/0	3
Wolf [3] (*C. lupus pambasileus*)[4]	1.8 years/0	1.0/1	4.98/0	16,000/4	S4/1	6
Wolf [5] (extinct) (*C. l. alces*)	--	--	--	--		
Red fox [6] (*Vulpes vulpes kenaiensis*)	<12 months/0	1.0/1	4.59/0	350/0	S5/0	1
Ursidae						
American black bear [7] (*Ursus americanus perniger*) [4]	5 years/2	<0.5/2	2.39/1	3,400/4	S5/0	9

Table 1-1. Sensitivity to movement being impaired by roads of mammals occurring on the Kenai Peninsula, Alaska, USA.[1]

Order Family Species	Reproductive characteristics Age at first breeding[2]/rank	 Litters per year[2]/rank	 Litter size[2]/rank	Home range (ha)[2]/rank	Status[2]/ rank	Rank total and index
Brown bear (*U. arctos*)[4]	6-9 years/2	0.4/2	2.24/1	33,000/4	S4/1	10
Mustelidae						
Wolverine[8] (*Gulo gulo katschemakensis*)	>2 years/2	<0.5/2	2.84/1	36,000/4	S4/1	10
American marten[9] (*Martes americana kenaiensis*)	>1 years/0	1.0/1	2.60/1	390/0	S5/0	2
Ermine (*Mustela erminea*)[4]	<12 months/0	1.0/1	6.74/0	11/0	S5/0	1
Least weasel (*Mustela nivalis*)	3-4 months/0	2.0/0	5.07/0	8/0	S4S5/1	1
American mink[10] (*Neovison vison melampeplus*)[4]	<12 months/0	1.0/1	3.50/0	8-20/0	S5/0	1
North American river otter (*Lontra canadensis*)	2 years/1	1.0/1	2.67/1	1,700/2	S5/0	5
Felidae						
Canada lynx (*Lynx canadensis*)[4]	2 years/1	1.0/1	2.73/1	3,300/4	S4/1	8
Artiodactyla						
Cervidae						
Moose (*Alces americanus*)[4]	1.5 years/0	1.0/1	1.25/2	7,300/4	S5/0	7
Caribou (*Rangifer tarandus*)	2 years/1	1.0/1	2.00/1	8,000/4	S5/0	7
Bovidae						

Table 1-1. Sensitivity to movement being impaired by roads of mammals occurring on the Kenai Peninsula, Alaska, USA.[1]

Order Family Species	Reproductive characteristics			Home range (ha)[2]/rank	Status[2]/rank	Rank total and index
	Age at first breeding[2]/rank	Litters per year[2]/rank	Litter size[2]/rank			
Mountain goat[11] (*Oreamnos americanus kennedyi*)	3 years/2	1.0/1	1.40/2	1,700/2	S5/0	7
Dall sheep[12] (*Ovis dalli kenaiensis*)[4]	2 years/1	1.0/1	1.22/2	1,400/2	S3S4/2	8
Rodentia						
Sciurdae						
Northern flying squirrel (*Glaucomys sabrinus*)	6-12 months/0	1.0/1	3.00/1	4/0	S4/1	3
Hoary marmot (*Marmota caligata*)[4]	--	0.5/2	4.67/0	14/0	S5/0	2
Red squirrel[13] (*Tamiasciurus hudsonicus kenaiensis*)	<12 months/0	1.8/0	3.93/0	0.8/0	S5/0	0
Beaver (*Castor canadensis*)[4]	<2 years/0	1.0/1	3.60/0	5/0	S5/0	1
Northern red-backed vole[14] (*Myodes rutilus dawsoni*)[4]	<12 months/0	4.0/0	5.60/0	<1/0	S5/0	0
Singing vole[15] (*Microtus miurus miurus*)[4]	<2 months/0	2.0/0	3.89/0	0.08/0	S4S5/1	1
Root vole (*M. oeconomus*)[4]	<2 months/0	3.5/0	5.62/0	0.15/0	S5/0	0
Meadow vole (*M. pennsylvanicus*)[4]	1 month/0	2.7/0	5.16/0	0.03/0	S5/0	0
Common muskrat (*Ondatra*	6 months/0	2.4/0	6.55/0	0.34/0	S5/0	0

Table 1-1. Sensitivity to movement being impaired by roads of mammals occurring on the Kenai Peninsula, Alaska, USA. [1]

Order Family Species	Reproductive characteristics Age at first breeding[2]/rank	 Litters per year[2]/rank	 Litter size[2]/rank	Home range (ha) [2]/rank	Status[2]/ rank	Rank total and index
zibethicus)						
Northern bog lemming (*Synaptomys borealis*) [4]	4-6 months/0	3.0/0	4.72/0	<0.4/0	S4/1	1
Meadow jumping mouse (*Zapus hudsonius*) [4]	2 months/0	2.0/0	5.36/0	0.23/0	S5/0	0
Porcupine (*Erethizon dorsatum*)	2 years/1	1.0/1	1.00/2	11/0	S5/0	3
Lagomorpha						
Leporidae						
Snowshoe hare (*Lepus americanus*) [4]	7 months/0	2.5/0	3.54/0	5/0	S5/0	0

[1] Occurrence on the Kenai Peninsula taken from Alaska Natural Heritage Program (2011) and MacDonald and Cook (2009). Nomenclature was taken from MacDonald and Cook (2009).

[2] Life history characteristics were taken from Jones et al. (2009); status was taken from Alaska Natural Heritage Program (2011); rank categories were as follows: age at first breeding-<2=0, 2=1, >2=2; litters per year <1=2, 1=1, >1=0; litter size <2=2, 2-3=1, >3=0; home range <1,000=0, 1,000-2,000=2, >2,000=4; status S3=2, S4=1, S5=0.

[3] Type locality was the Susitna River south of Denali.

[4] Occurrence on the Kenai Peninsula was verified with museum specimens.

[5] Type locality was Kachemak Bay, Alaska.

[6] Known only from the Kenai Peninsula.

[7] Known only from the Kenai Peninsula. Type locality was Homer.

[8] Known only from the Kenai Peninsula. Type locality was Kachemak Bay, Alaska.

[9] Extent of range was unknown. Type locality was the Kenai Peninsula.

[10] Range extended from the Alaska Peninsula through the Kenai Peninsula to Prince William Sound. Type locality was the Kenai Peninsula.
[11] Range included Cook Inlet to Thompson Pass. Type locality was the mouth of the Copper River opposite Kayak Island.
[12] Known only from the Kenai Peninsula. Type locality was Skilak Lake.
[13] Known only from the Kenai Peninsula. Type locality was Hope.
[14] Range included Alaska other than Prince William Sound and most of Canada.
[15] Range included the Kenai Peninsula to Palmer. Type locality was Hope.

Consequently, the Sterling Highway was identified as 1 of the priority areas in the State for the implementation of mitigation measures to address WVCs involving moose (ADOT&PF 2007).

Objectives of This Study

The objectives of this study were to:

- Describe use of landscapes by the focal species on the Kenai Peninsula through the use of published research findings, through original analysis of existing data, or through the development of original models.
- Use those landscape use patterns to model and describe potential movements of focal species throughout the Kenai Peninsula with an emphasis on the area between MP 45–60 along the Sterling Highway.
- Use that analysis of movement on the landscape by the focal species to describe movement corridors for these species throughout the Kenai Peninsula with an emphasis on the area between MP 45–60 on the Sterling Highway.
- Describe management actions suitable to mitigate the potential effects of the Sterling Highway MP 45–60 Project on movement corridors used by the focal species.

The Basis and Content of This Report

Several methods have been used to estimate where the locations of wildlife crossing zones along highways are in an effort to implement effective management and mitigation practices designed to make roads more permeable and to reduce WVCs. These approaches have used information from expert knowledge, track surveys, remote cameras, radio-telemetry locations, genetic information, and landscape modeling. We used a combination of 3 types of analysis for this report.

Type 1 analysis for focal species with existing habitat models developed for the Kenai Peninsula used those models to generate resistance values for movement, and incorporate them into analyses of movement corridors (i.e., Chapter 3 – brown bear, published resource selection functions (RSFs)). In Type 2 analysis, models of habitat selection were developed for focal species that did not have existing local models but did have adequate data on landscape use patterns collected on the Kenai Peninsula (i.e., Chapter 4 – moose (RSF developed), Chapter 6 – black bear (RSF developed), Chapter 8 – Canada lynx (RSF developed)). Those models were incorporated into analyses of movement corridors (i.e., Chapter 5 – moose habitat linkages, Chapter 7 – black bear habitat linkages, Chapter 9 – Canada lynx habitat linkages). Type 3 analysis was used for focal species without existing habitat models and without adequate data on landscape use patterns from the Kenai Peninsula. These species had habitat quality models developed for them using information available in the literature and expert knowledge (i.e., Chapter 10 – wolverine habitat quality using a Bayesian Network and habitat linkages, Chapter 11 – Dall sheep habitat quality using a Bayesian Network and habitat linkages). Those models were incorporated into analyses of movement corridors.

The final step in our analysis was implementation of a year-long field-based monitoring program to evaluate the identified movement corridors prior to using them to locate and plan construction of wildlife crossing structures or other mitigation efforts (Chapter 12). This analysis allowed us to determine if the modeled corridors were selected by focal species as movement/use areas more often than the landscape matrix and if associated locations of potential mitigation measures were appropriate. The resulting information will be useful in planning and implementing management practices and other measures that may mitigate the effects of the highway project alternatives on wildlife movement patterns (Chapter 13).

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Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 2 – Study Area and Data Used to Describe Features of the Landscape

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Introduction

We used a geographic information system (GIS; ArcGIS 10.3) (ESRI 2014) to organize, process, visualize, and analyze data associated with the 6 focal species (i.e., black bear [*Ursus americanus perniger*], brown bear [*U. arctos*], wolverine [*Gulo gulo katschemakensis*], Canada lynx [*Lynx canadensis*], Dall sheep [*Ovis dalli kenaiensis*], and moose [*Alces americanus*]) to describe their habitat use and movement patterns on the Kenai Peninsula (Figure 2-1). This allowed us to describe the potential effects that the current alignment of the Sterling Highway between MPs 45–60, in the vicinity of Cooper Landing, had on movement corridors for those species. This Chapter describes our study area and the sources of the GIS data we used for the analyses.

Study Area

This study was conducted on the 23,310-km^2 Kenai Peninsula which is located in south-central Alaska between 59°–61° N and 148°–152° W. It lies between Prince William Sound to the east, Cook Inlet to the west, and the Gulf of Alaska to the south (Figure 2-1). The Peninsula is connected to the Alaska mainland by a narrow isthmus approximately 18 km wide (Spencer and Hakala 1964, Peterson et al. 1984, Schwartz and Franzmann 1991), which may effectively isolate focal species on the Kenai Peninsula from other populations. The major physiographic landform on the eastern two-thirds of the Peninsula is the rugged, heavily glaciated Kenai Mountain Range, which rises to 2,000 m. The Kenai Lowlands landform, a glaciated plain with limited relief interspersed with numerous lakes, dominates the western third (Spencer and Hakala 1964). Most stream systems on the Kenai Peninsula support wild runs of Pacific salmon (e.g., Chinook [*Oncorhynchus tshawytscha*], sockeye [*O. nerka*], coho [*O. kisutch*], pink [*O. gorbuscha*], chum [*O. keta*]; Johnson and Klein 2009).

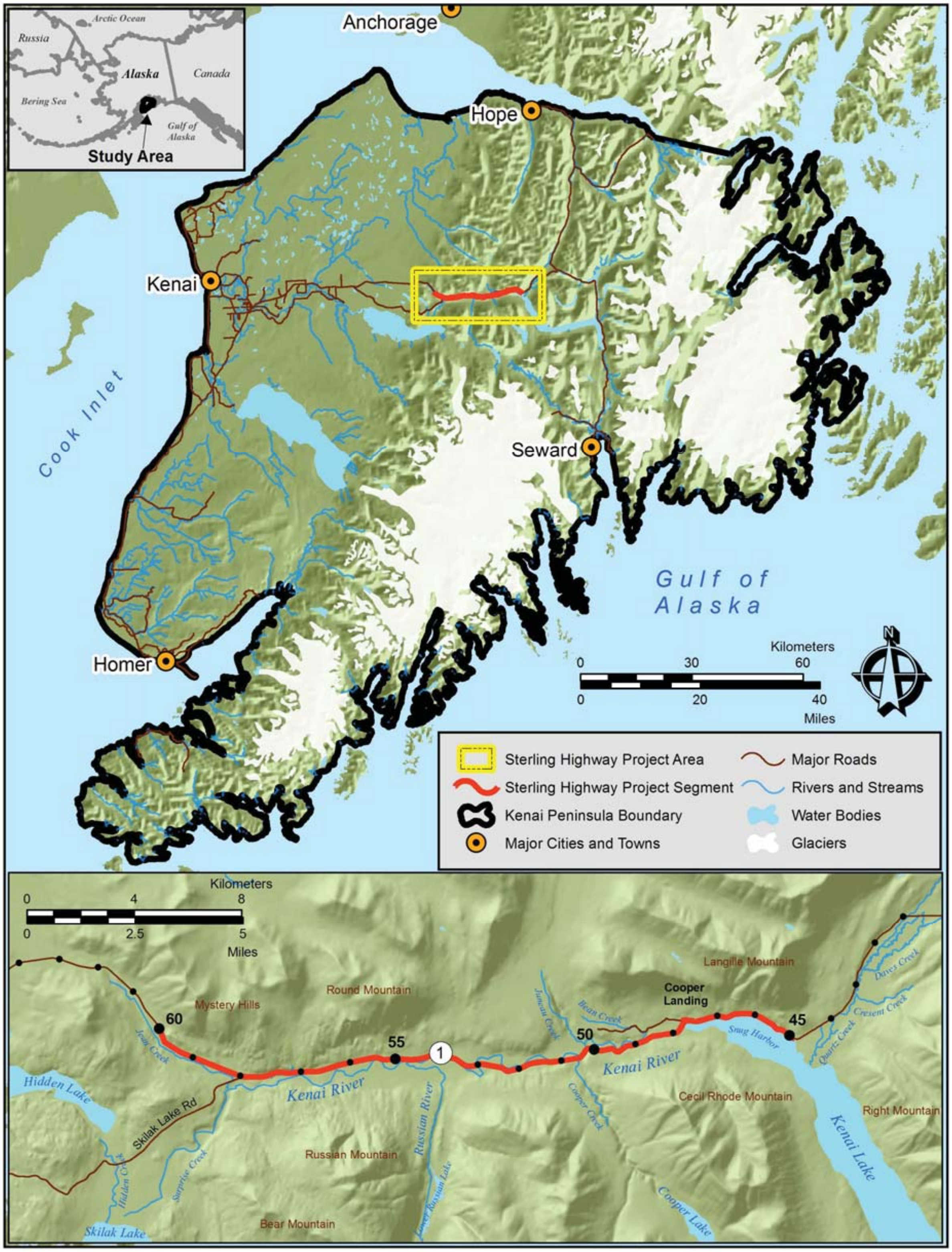

Figure 2-1. Location of the Kenai Peninsula in south-central Alaska, USA.

Forests on the Kenai Peninsula lowlands support typical northern boreal forest species, including white spruce (*Picea glauca*), black spruce (*Picea mariana*), black cottonwood (*Populus trichocarpa*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). Mature forest vegetation on dry upland sites includes white spruce, paper birch, quaking aspen, or some combination of these species. Black spruce dominates poorly drained sites (Lutz 1956, Spencer and Hakala 1964) while Sitka spruce (*Picea sitchensis*) occurs in wetter, coastal areas. Lutz spruce (*Picea lutzii*), a hybrid of Sitka and white spruce, occurs in forested areas throughout the Kenai Peninsula. Deciduous tree species typically occur in early to mid-successional stages following fire. The Kenai Mountains also support coniferous and mixed hardwood forest up to approximately 500 m elevation (Peterson et al. 1984). Mountain hemlock (*Tsuga mertensiana*), mountain alder (*Alnus crispa*), willow (*Salix* spp.), and bluejoint reedgrass (*Calamagrostis canadensis*) occur in the transition zone between forest and alpine tundra.

Alpine communities tend to be lichen tundra, dwarf shrub tundra, or a combination of both. Lichen tundra occurs on ridges and mountain tops while dwarf shrub tundra occurs below the lichen zone. Ice fields, glaciers, and snowfields with associated bare rock and scree slopes occur throughout the Kenai Mountains.

GIS Databases

Vegetation/Land Cover Classes

Vegetation and land cover data for the Kenai Peninsula were acquired from the Multi-Resolution Land Characteristics Consortium (www.mrlc.gov). We used the National Land Cover Database 2001 (NLCD 2001; Selkowitz and Stehman 2011) to represent vegetation and other land cover components for our modeling process (Homer et al. 2007). The NLCD 2001 was the most recent land cover product available for our study area when we initiated this project. The NLCD 2001 was a raster dataset with a spatial resolution of 30-m. The classification system used for NLCD 2001 was a modified version of the Anderson Land Cover Classification System (Anderson et al. 1976). It used a 20-class scheme based on a decision-tree classification of 2001 Landsat satellite imagery (Table 2-1).

We used the NLCD 2001 for modelling habitat and connectivity/corridors for each of the 6 focal species. NLCD 2001 cover classes were reclassified for each analysis based on what land cover classes were preferred or required for each species. The reclassifications are described in the associated chapters for each focal species.

We also acquired NLCD 2001 Percent Tree Canopy (Huang et al. 2001) for habitat and connectivity/corridor modeling for Canada lynx. Again, this is a raster dataset with a spatial resolution of 30-m. Each 30-m pixel was an estimate of the percentage of tree canopy closure that was determined using 2001 Landsat satellite imagery.

Table 2-1. Land cover classes from the NLCD 2001 dataset used on the Kenai Peninsula, Alaska, USA.

Land cover class	Classification description
Water	
Open Water	Areas of open water, generally with < 25% cover of vegetation or soil.
Perennial Ice/Snow	Areas characterized by a perennial cover of ice and/or snow, generally >25% of total cover.
Developed	
Developed, Open Space	Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for <20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
Developed, Low Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
Developed, Medium Intensity	Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
Developed High Intensity	Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
Barren Land (Rock/Sand/Clay)	Areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for <15% of total cover.
Forest	
Deciduous Forest	Areas dominated by trees generally >5 m tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest	Areas dominated by trees generally >5 m tall, and >20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.

Table 2-1. Land cover classes from the NLCD 2001 dataset used on the Kenai Peninsula, Alaska, USA.

Land cover class	Classification description
Mixed Forest	Areas dominated by trees generally >5 m tall, and >20% of total vegetation cover. Neither deciduous nor evergreen species are >75% of total tree cover.
Shrubland	
Dwarf Scrub	Areas dominated by shrubs <20 cm tall with shrub canopy typically >20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
Shrub/Scrub	Areas dominated by shrubs; <5 m tall with shrub canopy typically >20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	
Grassland/Herbaceous	Areas dominated by graminoid or herbaceous vegetation, generally >80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Sedge/Herbaceous	Areas dominated by sedges and forbs, generally >80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
Lichens	Areas dominated by fruticose or foliose lichens generally >80% of total vegetation.
Moss	Areas dominated by mosses, generally >80% of total vegetation.
Planted/cultivated	
Pasture/Hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for >20% of total vegetation.
Cultivated Crops	Areas used for the production of annual crops, such as corn, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for >20% of total vegetation. This class also includes all land being actively tilled.

Table 2-1. Land cover classes from the NLCD 2001 dataset used on the Kenai Peninsula, Alaska, USA.

Land cover class	Classification description
Wetlands	
Woody Wetlands	Areas where forest or shrubland vegetation accounts for >20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
Emergent Herbaceous Wetlands	Areas where perennial herbaceous vegetation accounts for >80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Salmon Spawning Streams and Lakes

We used GIS data acquired from the Alaska Department of Fish and Game's (ADF&G) anadromous waters catalog (AWC) to identify streams/rivers, and lakes important to salmon spawning on the Kenai Peninsula (Johnson and Klein 2009). We also used existing data from Suring et al. (2004) that represented salmon spawning streams and lakes. Suring et al. (2004) further defined salmon spawning rivers and streams into 2 separate datasets of high and low spawning potential. We used end points of known spawning locations of salmon in rivers and streams from the AWC to refine the existing salmon spawning streams and lakes. Distances in km to the nearest salmon stream (high and low) and lake were calculated using the Euclidean Distance tool in Spatial Analyst extension of ArcGIS 10.3 (ESRI 2014). Several layers representing distance to salmon spawning streams and lakes were created and used with analyses for brown bear and black bear.

Roads and Trails

We used GIS data acquired from the Kenai Peninsula Borough (KPB), the Chugach National Forest (CNF), and the Kenai National Wildlife Refuge (KNWR) to represent existing roads and trails within the project area. We created 4 individual road layers: all roads, high-use roads, low-use roads, and forest roads (Table 2-2). We combined roads with street classes from the KPB road layer of "state highway" and "town major" and considered these as high-use roads. We combined street classes from the KPB road data of "town medium volume," "town arterial," "town low/seasonal," "private road," and "driveway" and considered these as low-use roads.

A road feature class provided by the KPB of limited access was used to represent forest roads, which we verified with aerial photography. Within the limited access feature class, an attribute of "Trail Name" existed. Several line features were unlabeled and located in a large area of commercial forest in the southwest portion of the Peninsula. These unlabeled line features were also considered as forest roads for this project. We merged features that had labeled trail names within the limited access layer and any additional trails represented in the CNF and KNWR trail layers to create the trails layer.

Table 2-2. Road classes used on the Kenai Peninsula, Alaska, USA.

Road layer	Combined road classes
High-use roads	State highway, town major collector
Low-use roads	Town medium volume, town arterial, town low/seasonal, private road, driveway
Forest roads	Limited access – unlabeled features
All roads	All road classes combined

Densities of 1 km/1 km^2 and 0.5 km/0.5 km^2 for roads and trials were generated using the Line Density tool in the Spatial Analyst extension in ArcGIS 10.3 (ESRI 2014) (corridors for power lines were not evaluated). Also, distance in km to the nearest road or trail was calculated using the Euclidean Distance tool in Spatial Analyst extension of ArcGIS 10.3 (ESRI 2014) (again, corridors for power lines were not evaluated). The subsequent 30-m resolution raster datasets were used for focal species habitat quality modeling.

Recreation Sites

We acquired and merged GIS point data describing recreation sites (duplicates removed) from the CNF, KNWR, and KPB to represent existing recreation sites within the project area (Table 2-3). The CNF data consisted of individual layers for recreation sites and campgrounds.

Densities of 1 km/1 km2 and 0.5 km/0.5 km2 for recreation sites were generated using the Point Density tool in the Spatial Analyst extension in ArcGIS 10.3 (ESRI 2014). Also, distance in km to the nearest recreation site was calculated using the Euclidean Distance tool in Spatial Analyst extension of ArcGIS 10.3 (ESRI 2014). The subsequent 30-m resolution raster datasets were used for focal species habitat quality modeling.

Table 2-3. Sources for recreation data and attributes incorporated into the final recreation site layer on the Kenai Peninsula, Alaska, USA.

Data source	Feature class name	Site attributes included
Chugach National Forest	Recreation sites	Camp site, trailhead, cabin, fishing dock, interpretative site, overlook, fishing access, boat launch, viewing area,
Chugach National Forest	Camp sites	Camp site
Kenai Peninsula Borough	Facilities	Boat dock, boat launch, camp ground, park, recreation
Kenai National Wildlife Refuge	Facilities	Amphitheatre, boat launch, camp ground, camp ground host, day-use area, education center, fee station kiosk, ferry, fish cleaning station, fishing platform, headquarters, oil/gas buildings, parking lot, pavilion, public use cabin, research center, river access, RV dump station, tent camping area, toilet, viewing platform, visitor contact station, water source, wayside pullout

Human Developments

We acquired land parcel data from the KPB for the year 2012 to represent density of human developments (i.e., building and structures). The land parcel data were polygons that delineated property boundaries within the Kenai Peninsula. To determine the density of human developments we converted the polygons to points using ArcGIS 10.3 (ESRI 2014). In doing so, points were automatically generated as the centroid of the polygon. These placements mainly consisted of small polygons within urban areas and were an acceptable representation of the building or structure. Centroid points in larger polygons in remote areas were manually adjusted using aerial photography and placed over the locations where buildings or structures were actually located.

Using the Point Density tool in the Spatial Analyst extension in ArcGIS 10.3 (ESRI 2014), densities of 1 km/1 km^2 and 0.5 km/0.5 km^2 for buildings or structures were generated. Also, distance in km to the nearest building or structure was calculated using the Euclidean Distance tool in Spatial Analyst extension of ArcGIS 10.3 (ESRI 2014). The subsequent 30-m resolution raster datasets were used for focal species habitat quality modeling.

Elevation, Topography, and Landform Classification

A 30-m resolution digital elevation model (DEM) was acquired from the United States Geological Service (USGS) Alaska Geospatial Data Committee. This dataset was previously used for the Ninilchik River Basin Cook Inlet Alaska National Water-Quality Assessment (Creely and Brabets 1999). We determined that this DEM had the most complete coverage of the Kenai Peninsula of the coverages available to us. An area along the eastern coastline of the Kenai Peninsula was outside the extent of this DEM; however, this was outside of the area of primary interest to us for this analysis. Consequently, any analyses requiring use of the DEM did not have data available for the eastern coastline of the Kenai Peninsula.

Aspect and slope were generated from the DEM using the Spatial Analyst extension in ArcGIS 10.3 (ESRI 2014). Landform classifications were developed using a tool in the Topography Toolbox (Dilt 2015) that was based on Jenness (2006). Using the 30-m DEM as the input, we calculated a topographic position index to derive a landform classification system that represented slope position and landform category (Table 2-4). Also, a GIS process described by Sappington et al. (2007) was used to characterize terrain ruggedness on the Kenai Peninsula.

Table 2-4. Landform classifications on the Kenai Peninsula.

Raster value	Landform classification
1	Canyons, deeply incised streams
2	Midslope drainages, shallow valleys
3	Upland drainages, headwaters
4	U-shaped valleys
5	Plains
6	Open slopes
7	Upper slopes, mesas
8	Local ridges, hills in valleys
9	Midslope ridges, small hills in plains
10	Mountain tops, high ridges

Snow Depth

Snow depth and duration are important attributes in describing habitat quality for Canada lynx, Dall sheep, and wolverine. To represent snow depth, we used “historically observed data” from the Scenarios Network for Alaska and Arctic Planning (SNAP 2012). These historically observed data were represented as an average annual number of observed days with snow (snow days) (McAfee et al. 2013). Within the Kenai Peninsula study area, the minimum recorded number of snow days was 20, while the maximum recorded number of snow days was 85. This was a raster dataset with a spatial resolution of 771-m which we resampled to 30-m for use in our analyses.

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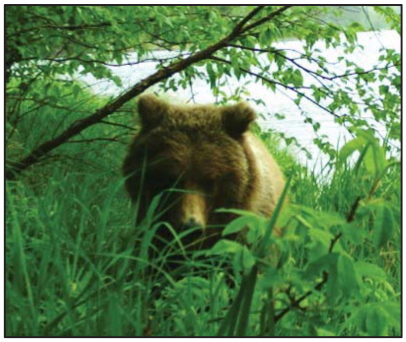

Chapter 3 – Movement Patterns and Potential Corridors for Brown Bears on the Kenai Peninsula, Alaska, USA

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Introduction

Brown bears (*Ursus arctos*) on the Kenai Peninsula have been the subject of study by the Interagency Brown Bear Study Team (IBBST) which included the Alaska Department of Fish and Game, Chugach National Forest, Kenai National Wildlife Refuge, and Kenai Fiords National Park, for approximately 30 years. Their work resulted in publication of A Conservation Assessment of the Kenai Peninsula Brown Bear (IBBST 2001) and numerous other works (e.g., Jacobs and Schloeder 1992, Suring et al. 1998, Hilderbrand et al.1999a,b,c, Suring and Del Frate 2002, Suring et al. 2004, Graves et al. 2006, Suring et al. 2006, Graves et al. 2007, Goldstein et al. 2010).

Brown bears occurred across most of the Kenai Peninsula with the exception of glaciated areas and they moved extensively throughout the Peninsula to access a range of resources during different seasons (e.g., mountainside den sites, alpine foraging areas in the spring, riparian areas and fish streams in the summer, and upland berry patches in the fall) (Suring et al. 2006, Jackson et al. 2008). These brown bears were shown to be associated with areas with low densities of human developments and roads, as well as riparian areas that were close to cover. Presence of streams and lakes that supported spawning salmon (*Oncorhynchus* spp.) positively influenced summertime distribution of brown bears. Movement of brown bears between the Kenai Peninsula and the Alaska mainland was restricted by an isthmus approximately 18 km-wide. However, genetic characterization of brown bears on the Kenai Peninsula did not find evidence of any difference in DNA with that of brown bears on the mainland (Jackson et al. 2008). Jackson et al. (2008) did observe an indication of a genetic bottleneck and that brown bears on the Kenai Peninsula have lower genetic diversity relative to most other brown bear populations in Alaska.

The brown bear population on the Kenai Peninsula was estimated at 582 in 2010 (Morton et al. 2016) with harvests of 5-6 individuals per year from 2008–2011 (Selinger 2011, 2013). However, non-hunting mortalities totaled 34 in 2008–2009, 25 in 2009–2010, 22 in 2011, and 11 in 2012 including ≥5 resulting from wildlife-vehicle collisions (WVCs) (Selinger 2011, 2013). Closely managing the mortality of brown bears, especially females, in small populations is a primary factor in ensuring their conservation (Mattson et al. 1996). Brown bears exhibit very low reproductive potential, with females producing their first litters at ≥6 years of age and then producing <0.5 cubs per year after that. Consequently, populations cannot withstand high mortality, and low total mortality of adult females (<8%) is critical for the continued persistence of brown bears. Avoidance of high-quality habitats in proximity to roads and human developments by female brown bears could result in adult females in poor condition and, consequently, with increased mortality and lower fecundity (Mattson et al. 1987, Gibeau et al. 2002).

The Kenai brown bear population was designated a population of special concern in 1998 by the State of Alaska because it was considered vulnerable to a significant decline (Del Frate 1999). Application of a cumulative effects model on a portion of the Kenai Peninsula including the Sterling Highway Milepost (MP) 45–60 Project area indicated that past management activities appeared to have significantly reduced effective habitat for brown bears (Suring et al. 1998). Model results indicated that habitat effectiveness for brown bears on a large portion of the Kenai Peninsula has been reduced by >70% as a result of disturbance and mortality associated with human facilities and activities. Developments often were concentrated in high-quality brown bear habitats. Increasing the spatial extent and intensity of development generally leads to reductions in habitat effectiveness and increases in mortality for brown bears (Suring and Del Frate 2002, Suring et al. 2006).

Our specific objective in this work was to identify potential movement corridors for brown bear on the Kenai Peninsula so that resource managers could include that information in planning for habitat management, resource development, and infrastructure development (including transportation). Specifically, we wanted to identify potential movement patterns within MP 45–60 on the Sterling Highway that may be suitable areas for practices to mitigate the effects of highway development on brown bears. We focused on this objective by incorporating resource selection functions (RSFs; Manly et al. 2002) developed using telemetry data (Suring et al. 2006) to predict areas of high quality habitat across the Kenai Peninsula and probable movement corridors throughout the Peninsula. We combined RSF modeling with least-cost modeling (e.g., Chetkiewicz and Boyce 2009), and circuit theory (McRae et al. 2008), to identify and map linkage areas within our study area.

Methods

Resource Selection Functions

Development of RSFs describing landscape use by female brown bears on the Kenai Peninsula was reported on by Suring et al. (2006). These analyses were based on locations of 43 adult female radio-collared brown bears from 1995-1998, from which 6,361 telemetry point locations were obtained (Suring et al. 2006). The RSF analyses on the Kenai Peninsula considered 4 strata (i.e., female brown bears with and without cubs, during spring and summer) based on distinct movement and landscape use patterns exhibited by female brown bears (Suring et al. 2006). In brief, landscape use by female brown bears was modeled by logistic regression with multiple explanatory variables. Final models were determined through backwards model selection with a significance level of 0.05. Variable selection was conducted for each analysis stratum separately. Variables were included in the RSF models when significant differences occurred between used and available locations. Through this process, variables were eliminated so the models included those most specifically affecting habitat selection by brown bears. From 3 to 5 variables were selected for each model (i.e., for each analysis stratum).

Landscape characteristics associated with telemetry locations from female brown bears during 1999 and 2000 (n = 495–14,402 depending on model) were used to evaluate the resulting models by strata (following the process described by Howlin et al. 2004) (Suring et al. 2006).

Effect of Variables

The range of the effect each variable had in each model on the relative probability of use of brown bears was determined by holding all other variables at a constant value while running each model repeatedly with increasing values of the variable of interest. Initial values of the variables of interest were set at either 0 or the values that resulted in a relative probability of use of 100. Final values were either those that resulted in a relative probability of use of 100 or those associated with an asymptote-like line near a relative probability of use of 0.

Resistance Surfaces

We generally followed the process outlined by Beier et al. (2007) to move from the range of estimated relative probability of use for each variable used in the RSF calculations for brown bear to the development of resistance surfaces.

We used the inverse of the relative probability of use to generate resistance values for each analysis strata. An exception to this was that we assigned a resistance value of 200 to lakes, snow fields, and glaciers. Through this subjective translation (Beier et al. 2007), we assumed that pixels with higher probability of use (and higher habitat values) afforded lower costs to movement than those with low habitat values. Resistance reflects the ecological cost of brown bears traveling through a pixel. In general, resistance increases with the energetic cost of travel through the pixel. Resistance decreased as the quality of habitat increased in a pixel; this is not necessarily related to the speed of travel through the pixel.

Core Areas

We followed a convention similar to that established by WHCWG (2010) and used the term core area to describe high-quality habitats between which we evaluated movement patterns for focal species. Core areas were generated using the Core Mapper tool from the Gnarly Landscape Utilities ArcGIS toolbox applied to the results of RSF models with probability of use scaled from 0-100 (Shirk and McRae 2013). We calculated the proportion of habitat within a circular moving window with a radius of 2,500 m (i.e., the probable distance from sources of anadromous salmon brown bears on the Kenai Peninsula will move during fish runs [Farley et al. 2001]). Core areas for brown bears were defined as significant habitat areas that were expected or known to be important based on habitat association modeling (WHCWG 2010).

To meet that criterion we used a minimum average probability of use of 25–95 (depending on analysis strata) to describe potential core habitat and a minimum average value of 98.5 per pixel within areas actually mapped as core habitat. A minimum patch size of 2.5 km^2 was used to prevent core areas from forming in areas where high-quality habitat was not sufficiently concentrated. These analysis steps generated spatial data layers representing concentrations of high quality habitat. For the final core habitat layer we combined and dissolved core mapper outputs for all analysis strata and removed areas that were generated outside of the known range of brown bears on the Kenai Peninsula.

Potential Movement Corridors

Connectivity among habitat patches for animals within a landscape depends on characteristics of the landscape (structural connectivity) and on aspects of the mobility of the animal (functional connectivity) (Adriaensen et al. 2003). Least-cost modeling has been used to incorporate detailed information about the landscape as well as behavioral aspects of the animal to describe connectivity. Cost-weighted distance approaches to estimate movement corridors of animals represent the least accumulative cost required to move between a specified source and a specified destination (Beier et al. 2007). This method provides a flexible tool that provides insights into the relationship between animal movement and landscape characteristics. This method identifies a set of near-optimal corridors for the landscape linkage network, with emphasis on corridors with the least cumulative cost-weighted distances (Chetkiewicz et al. 2006, Beier et al. 2008).

While these least-cost models implicitly assume animals have perfect knowledge of the landscape, current flow models assume they do not have knowledge of potential movements more than 1 step ahead (Newman 2005). Real-world movement behavior of animals like brown bears may fall somewhere between these extremes (McRae et al. 2008, Richard and Armstrong 2010). While shortest-path methods have been used to develop empirical multivariate models of habitat connectivity (Schwartz et al. 2009, Richard and Armstrong 2010), predictions from current flow-based models are highly correlated with observed genetic distance in several plant and animal populations and may better reflect actual movement corridors (McRae et al. 2008, Lee-Yaw et al. 2009, Shirk et al. 2010).

Circuit theory has been applied to connectivity analyses in other fields (McRae et al. 2008), and has been used to model gene flow in heterogeneous landscapes (McRae 2006, McRae and Beier 2007). Because connectivity increases with multiple pathways in circuit networks, distance metrics based on electrical connectivity are applicable to processes that respond positively to increasing connections and redundancy (McRae et al. 2008). Circuit theory is based in Markovian random walk theory and describes every movement as a random choice with movement in every direction equally probable. The landscape then acts as an electrical-resistance surface or, inversely, as a conductance surface, as the current travels outward to surrounding cells from the source patch of core habitat. The areas of least resistance or greatest conductance across the landscape are the most probable areas for movement. This theory can be applied to predict movement patterns of random walkers moving across complex landscapes, to generate measures of connectivity or isolation of habitat patches, and to identify important connective elements (e.g., corridors) for conservation planning.

The resistance distance concept of circuit theory incorporates multiple pathways connecting nodes, with resistance distances measured between core area pairs decreasing as more connections are added (McRae et al. 2008). Therefore, the resistance distance does not reflect the distance traveled or movement cost accrued by an individual animal. Rather, it incorporates both the minimum movement distance or cost and the availability of alternative pathways. As additional linkages are added, individuals do not necessarily travel shorter distances, but have more pathways available to them. Current density can be used to identify landscape corridors or ‘‘pinch points,’’ (i.e., features through which moving animals have a high likelihood – or necessity – of passing). High current through these pinch points indicates that stopping the flow through these points, or maintaining it, will have a high impact on connectivity.

To identify potential movement corridors, we used a combination of least-cost modeling and circuit theory (McRae et al. 2008) using the Linkage Mapper Toolkit (McRae and Kavanagh 2011) in ArcGIS 10.3. These analyses were performed by applying the final map of core habitat to identify start and end locations for building the corridor network from the resistance layers associated for each bear analysis strata (e.g., spring with cubs). We used the one-to-many criterion, whereby 1 source was connected to all end nodes in an iterative fashion. Circuit theory supplemented least-cost analyses to identify important areas for prioritization of conservation connectivity associated with the Sterling Highway (McRae et al. 2008).

The Pinchpoint Mapper module (McRae 2012) of Linkage Mapper was used to apply circuit theory through the program Circuitscape (McRae and Shah 2009) to identify and map “pinch points” (i.e., constrictions) within the resulting corridors. Circuitscape calculates the resistance of the landscape to movement between each pair of core areas (analogous to electrical resistance in a circuit diagram), allowing for multiple pathways between core areas. The pinch points we identified represented where loss of a small area could disproportionately compromise connectivity of the broader landscape. Using this hybrid approach, we merged least-cost corridors with pinch points to identify and display the most efficient movement corridors and the critical areas within them that contributed the most to habitat connectivity (McRae and Kavanagh 2011).

Results

Resource Selection Functions

The RSFs indicated that in the spring, female brown bears without cubs were associated with areas with low densities of human developments and roads, as well as with riparian areas that would receive summer salmon (*Oncorhynchus* spp.) runs (Table 3-1). In contrast, during the spring, female brown bears with cubs associated with upland habitats, which could indicate an avoidance of other brown bears and people. Streams with a high potential for containing spawning salmon positively influenced summertime distribution of female bears without cubs. Female brown bears with cubs used similar streams; however these female brown bears also frequented streams with lower potential for containing spawning salmon, apparently in an effort to avoid concentrations of adult brown bears. Female brown bears with cubs also selected habitats that were close to cover and avoided areas that were accessible to humans via roads.

Table 3-1. Models of relative probability of use (RSFs) for female brown bears on the Kenai Peninsula, Alaska, USA, 1995 – 1998 (from Suring et al. [2006]).

	Variable				
Season (cub status)	N	Coefficient	SE	T-statistic	P-value
Spring (with cubs)					
Distance to cover	21	-0.4638	0.1650	-2.8113	0.0108
Density of all salmon streams	21	0.0019	0.0005	3.9036	0.0009
Density of all roads	21	-0.0017	0.0008	-2.0551	0.0532
Intercept	21	-0.9820	0.2036	-4.8238	0.0001
Spring (without cubs)					
Distance to cover	10	-0.6234	0.2422	-2.5740	0.0300
Density of human development	10	-19.5641	0.1573	-124.4010	0.0000
Density of all salmon streams	10	0.0034	0.0008	4.5280	0.0014
Intercept	10	-2.1477	0.2412	-8.9040	0.0000
Summer (with cubs)					
Distance to cover	24	-0.2823	0.1565	-1.8031	0.0845
Density of all salmon streams	24	0.0034	0.0003	10.0884	0.0000
Distance to salmon lakes	24	-0.0023	0.0013	-1.7542	0.0927
Intercept	24	0.0005	0.4550	0.0012	0.9991

Table 3-1. Models of relative probability of use (RSFs) for female brown bears on the Kenai Peninsula, Alaska, USA, 1995 – 1998 (from Suring et al. [2006]).

	Variable				
Season (cub status)	N	Coefficient	SE	T-statistic	P-value
Summer (without cubs)					
Distance to cover	26	-0.4836	0.1945	-2.4859	0.0200
Density of human development	26	-0.4310	0.1774	-2.4288	0.0227
Distance to all salmon streams	26	-0.0142	0.0058	-2.4594	0.0212
Density of all salmon streams	26	0.0034	0.0004	8.8106	0.0000
Density of high potential salmon streams	26	0.0013	0.0003	5.2212	0.0000
Intercept	26	-0.3584	0.2585	-1.3868	0.1778

Effect of Variables

When a variable was included in >1 RSF, the pattern of the effect was similar across all RSFs (Figure 3-1). As distance to cover, distance to all salmon streams, distance to salmon lakes, density of roads, and density of human developments increased, the probability of use of brown bears decreased and the resistance value increased (Figures 3-1 – 3-7). Conversely, as density of salmon streams increased, the probability of use of brown bears also increased and the resistance value decreased (Figures 3-1 – 3-7).

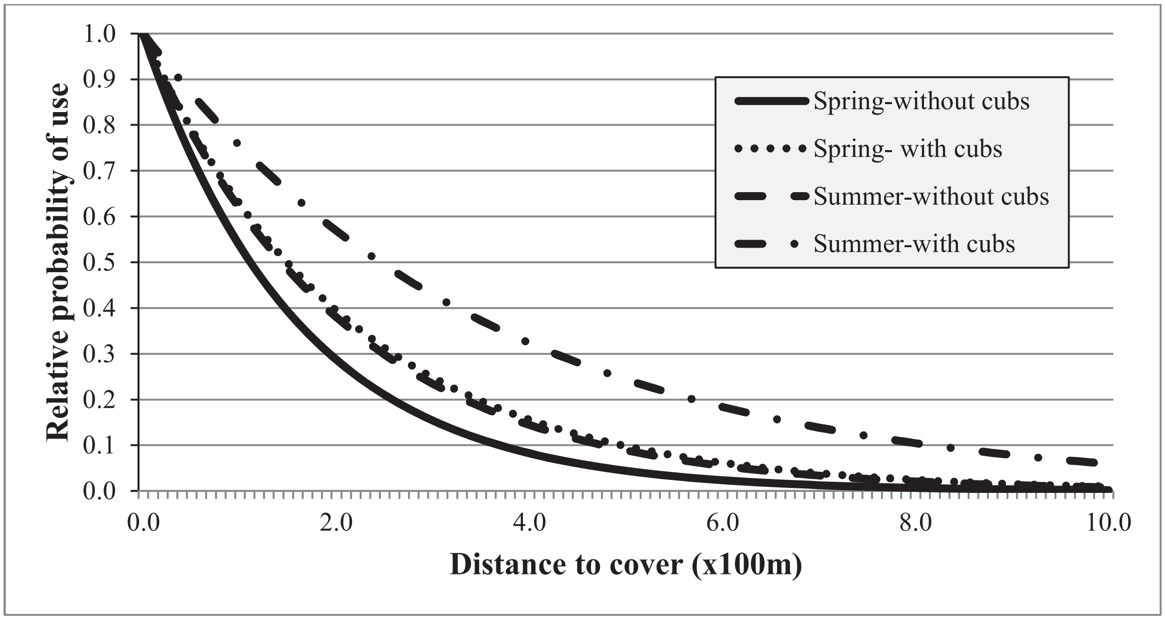


Figure 3-1. Effect of the variable ‘distance to cover’ by Resource Selection Function on relative probability of use of brown bears on the Kenai Peninsula, Alaska, USA.

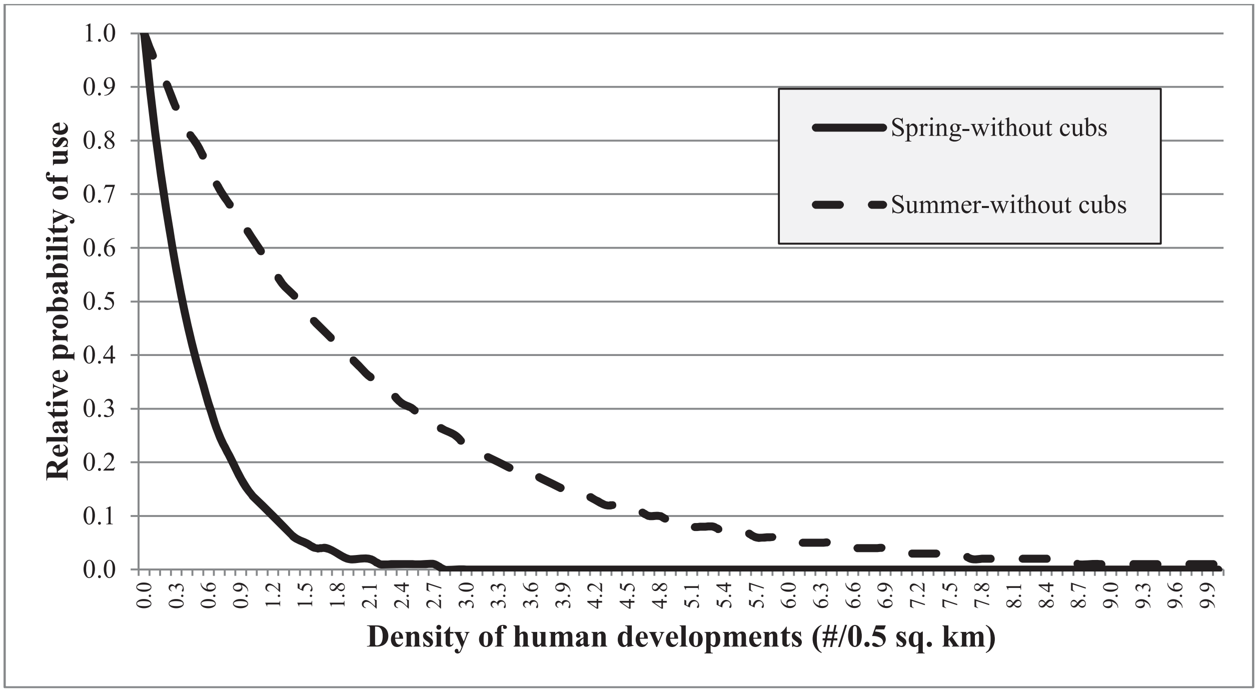


Figure 3-2. Effect of the variable 'density of human developments' by Resource Selection Function on relative probability of use of brown bears on the Kenai Peninsula, Alaska, USA.

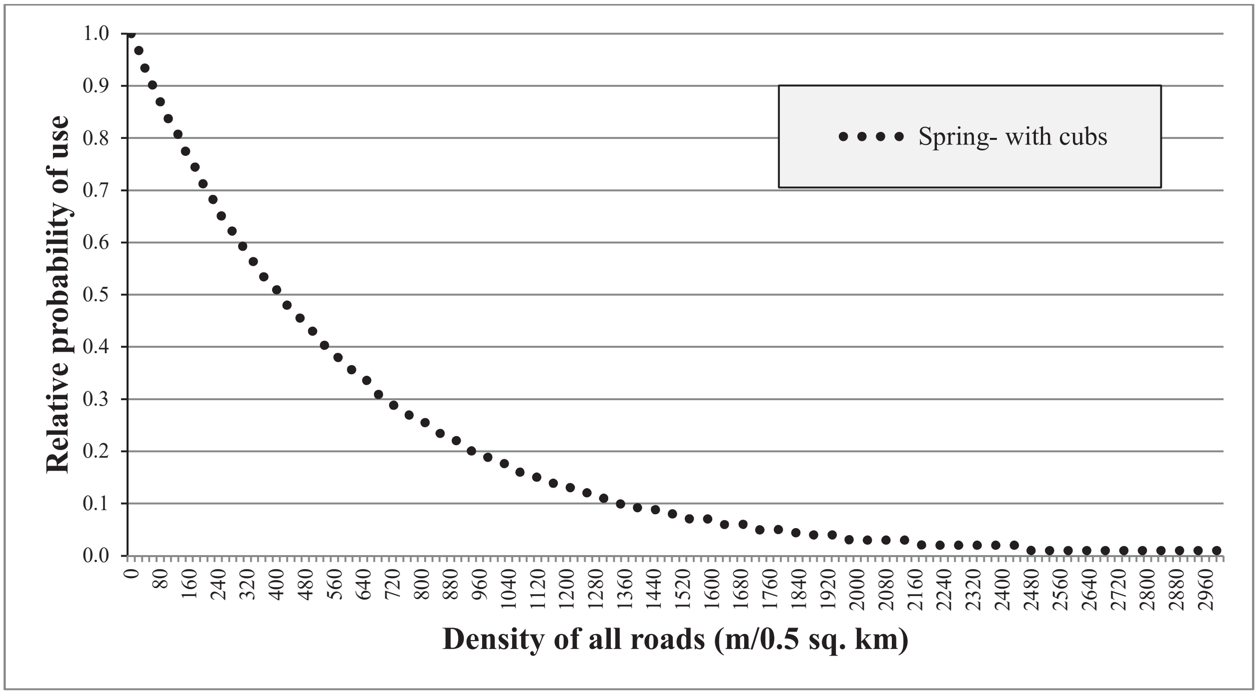


Figure 3-3. Effect of the variable 'density of all roads' by Resource Selection Function on relative probability of use of brown bears on the Kenai Peninsula, Alaska, USA.

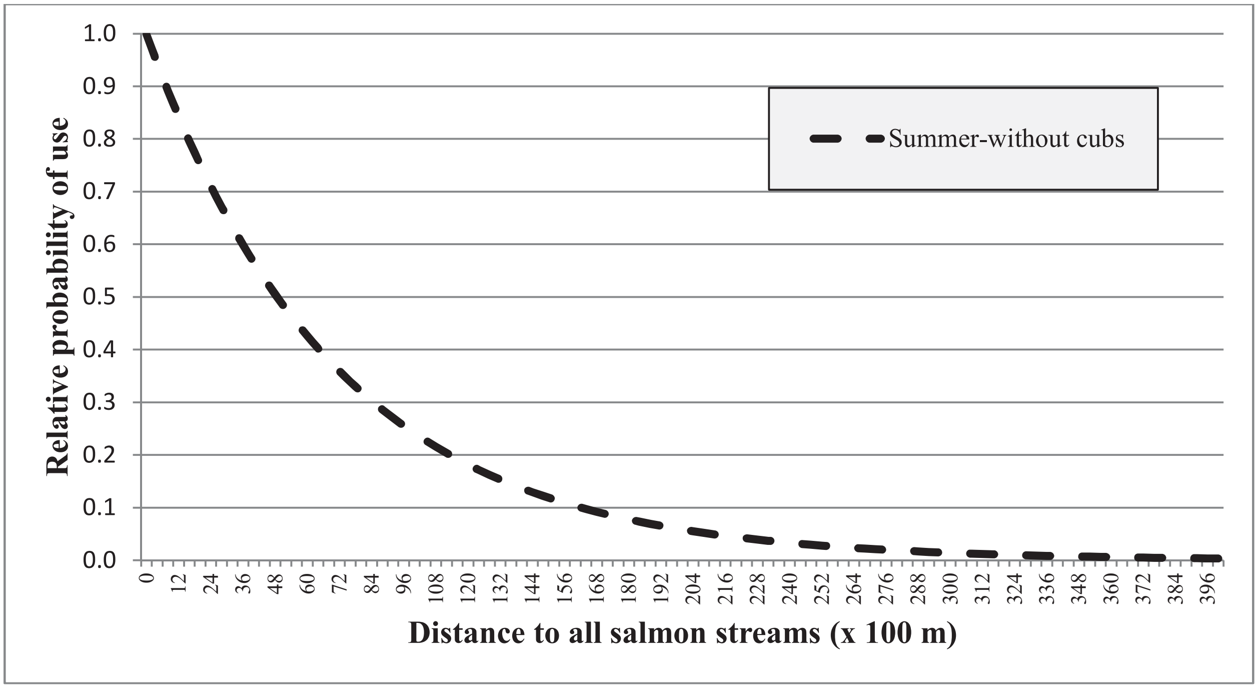


Figure 3-4. Effect of the variable 'distance to all salmon streams' by Resource Selection Function on relative probability of use of brown bears on the Kenai Peninsula, Alaska, USA.

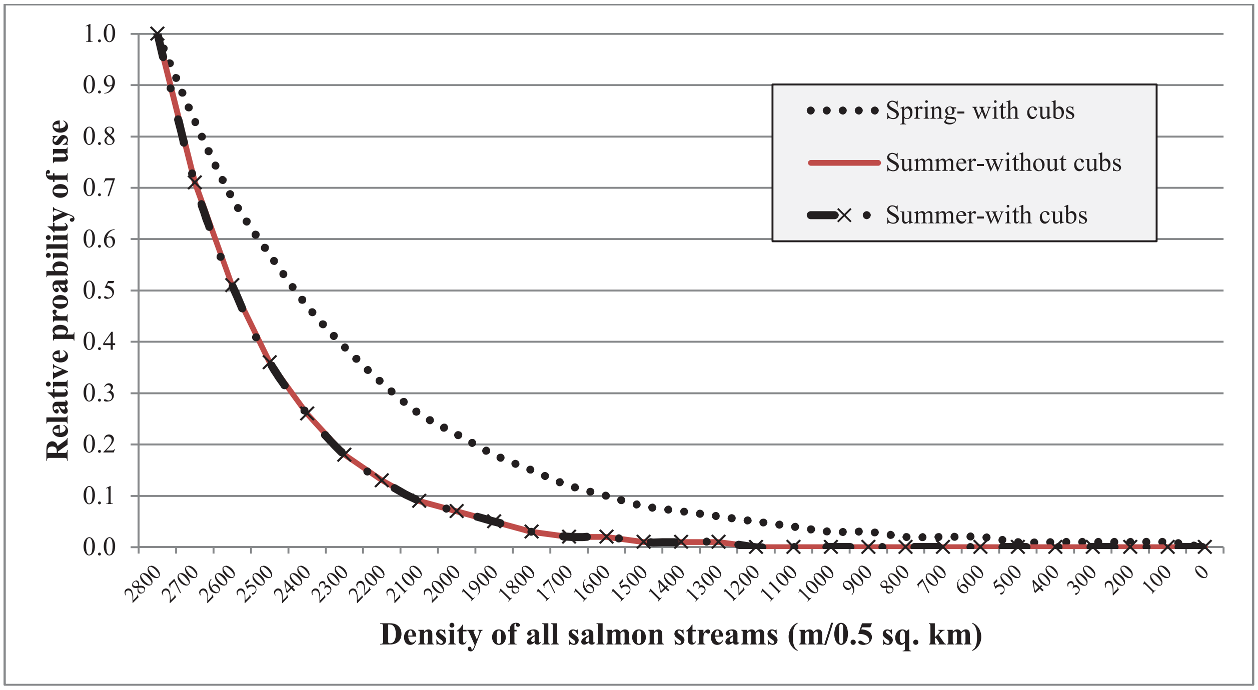


Figure 3-5. Effect of the variable 'density of all salmon streams' by Resource Selection Function on relative probability of use of brown bears on the Kenai Peninsula, Alaska, USA.

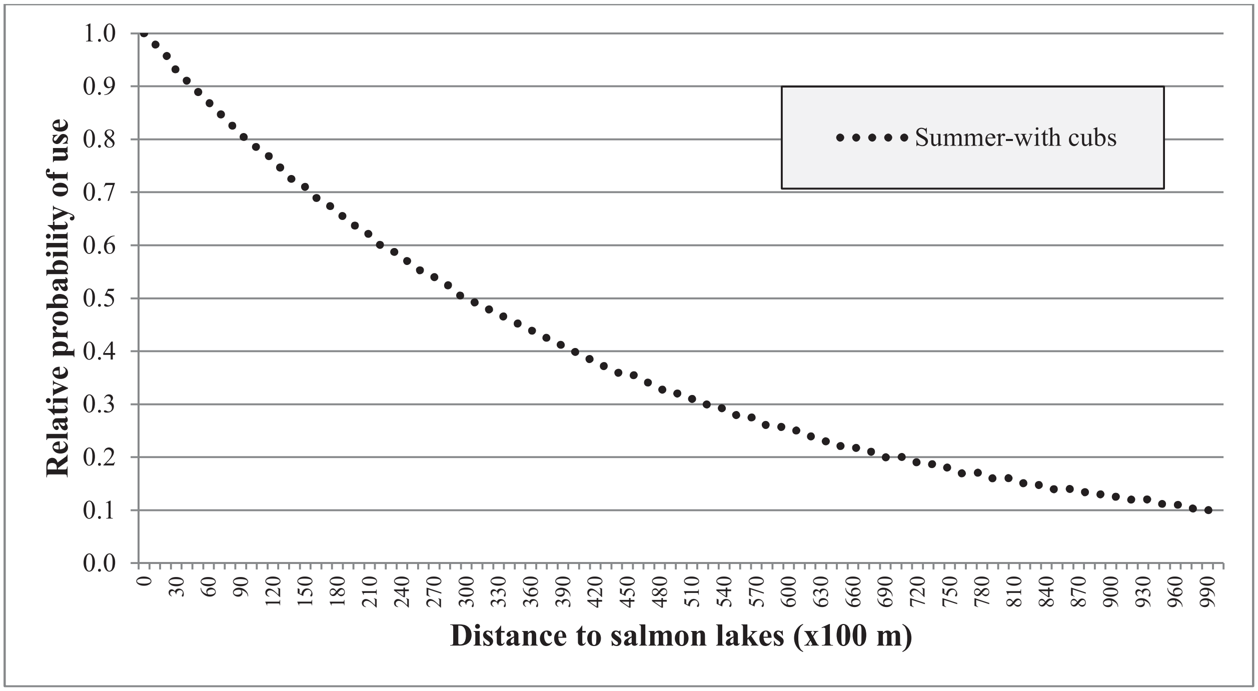


Figure 3-6. Effect of the variable 'distance to salmon lakes' by Resource Selection Function on relative probability of use of brown bears on the Kenai Peninsula, Alaska, USA.

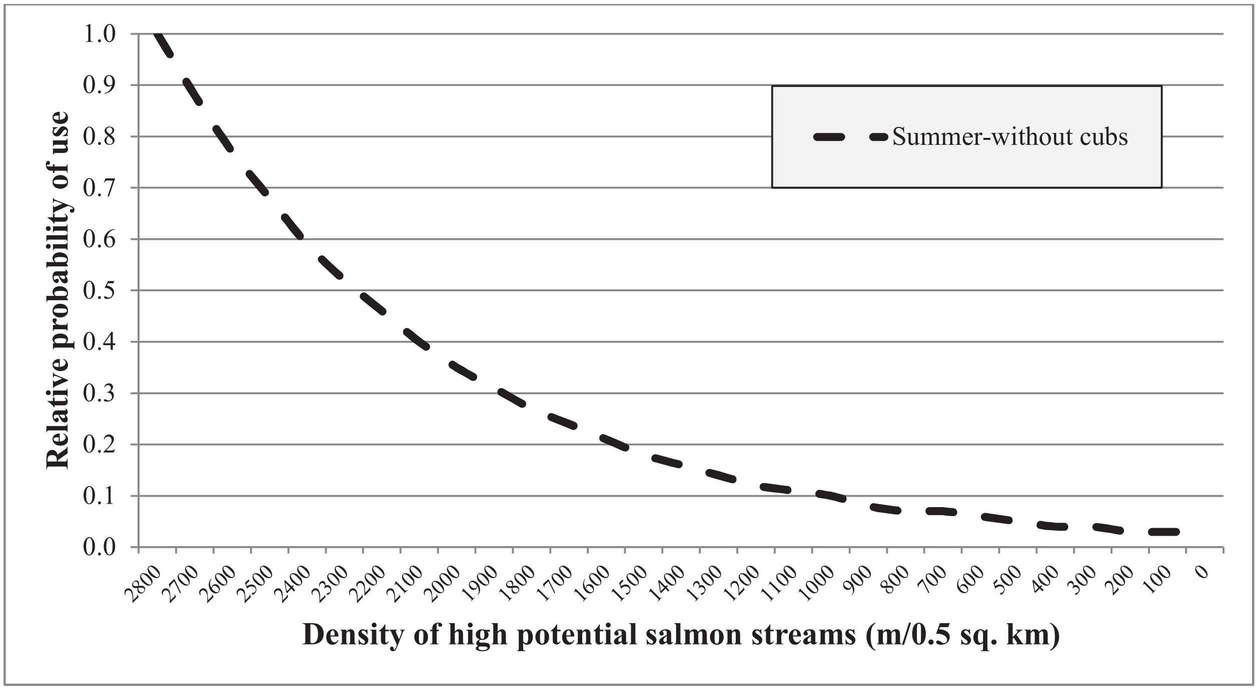


Figure 3-7. Effect of the variable 'density of high potential salmon streams' by Resource Selection Function on relative probability of use of brown bears on the Kenai Peninsula, Alaska, USA.

Probability of Use and Resistance to Movement

Probability of use (and the inverse, resistance to movement) varied across the Kenai Peninsula landscape within all 4 analysis strata and ranged from none (0%; water, ice fields) to very high (>75–100%) (Figure 3-8). After emerging from dens in the spring, brown bears typically selected fresh, young herbaceous material such as horsetail (*Equisetum* spp.), western skunk cabbage (*Lysichiton americanum*), and graminoid vegetation (grasses, sedges and rushes) (McCarthy 1989, Munro et al. 2006). During spring, female brown bears without cubs concentrated in riparian areas where these plants were located (Figure 3-9). As a result, the area of high to very high probability of use for these brown bears was very limited (Figure 3-8). Although female brown bears with cubs followed a similar pattern of use (i.e., concentrated in riparian areas) (Figure 3-10), they also had a higher probability to use adjacent upland areas where they likely retreated with their cubs to avoid dominate female brown bears without cubs and male brown bears (Figure 3-8). Brown bears with cubs have been reported to modify their movements and become subdominant to males and females without young to avoid confrontations with other brown bears (Wielgus and Bunnell 1995, Dahle and Swenson 2003).

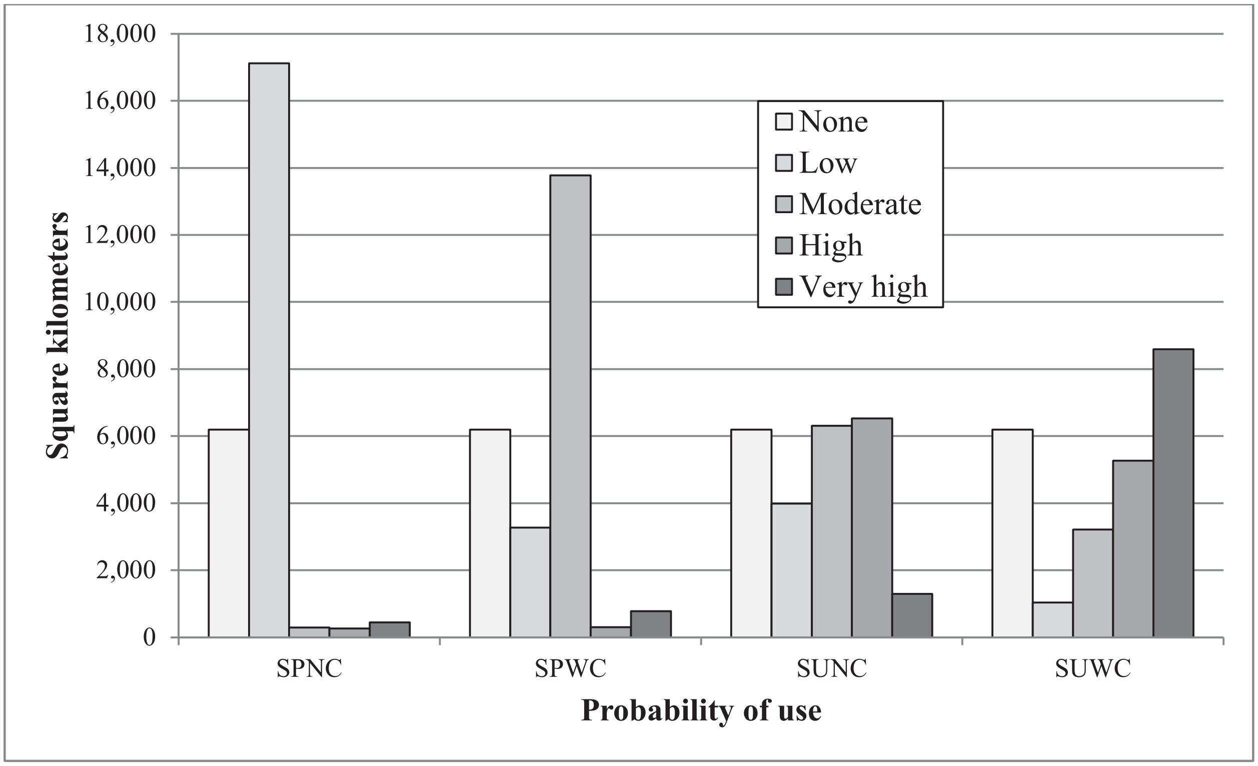


Figure 3-8. Area of probability of use of female brown bears on the Kenai Peninsula, Alaska, USA by analysis strata (SPNC – spring, no cubs; SPWC – spring, with cubs; SUNC – summer, no cubs; SUWC – summer, with cubs).

Female brown bears without cubs continued to associate with riparian areas in the summer when spawning salmon (*Oncorhynchus* spp.) became available in rivers and streams

(Figure 3-11). However, the area of moderate and high probability of use increased from the spring because they likely spent greater time away from, but near, salmon streams (Figure 3-8). Female brown bears, subdominant to males, have been observed to immediately move away from more productive sites following capture of fish (Quinn and Buck 2000, Gende and Quinn 2004).

Female brown bears with cubs likely did not concentrate their movements near rivers and streams with high densities of spawning salmon in order to avoid dominate female brown bears without cubs and male brown bears (Figure 3-12). They apparently moved more than other brown bears and associated with less productive salmon spawning areas (i.e., salmon lakes and streams with low potential for spawning salmon) (Suring et al. 2006) resulting in a relatively large area of high to very high probability of use across the Kenai Peninsula (Figure 3-8).

Core Areas

Patterns of probability of use for female brown bears in spring with and without cubs and female brown bears in summer without cubs were similar in that use was concentrated in riparian areas (Figure 3-9, 3-10, and 3-11). Consequently, core areas for these 3 analysis strata were similar and were combined for subsequent analyses (Figure 3-13). Twenty-eight core habitat areas for brown bears were modeled and mapped across the Kenai Peninsula for these 3 analysis strata. Core areas varied in size from 1.5–98.2 km^2 ($\overline{x}$ = 22.6 km^2) and were distributed across the Kenai Peninsula.

Patterns of probability of use for female brown bears in summer with cubs varied considerably from the other analysis strata (Figure 3-12). Therefore, a larger number of core habitats were identified for female brown bears in summer with cubs that were more dispersed across the Kenai Peninsula than were core areas for other analysis strata (Figure 3-14). Eighty-four core habitat areas for brown bears with cubs in summer were modeled and mapped across the Kenai Peninsula. Core areas varied in size from 1.1–371.9 km^2 ($\overline{x}$ = 20.0 km^2) and were distributed across the Kenai Peninsula.

Potential Movement Corridors

For each of the 4 analysis strata, we used circuit theory to estimate the effective resistance of the landscape between all pairs of core areas (all-to-one mode in the Circuitscape software; McRae and Shah 2009). Based on this analysis, likely north-south movements of brown bears across the Sterling Highway revealed several pinch points where animals were predicted to concentrate their crossings. Potential crossing points were similar for all 4 strata even though each used different resistance layers.

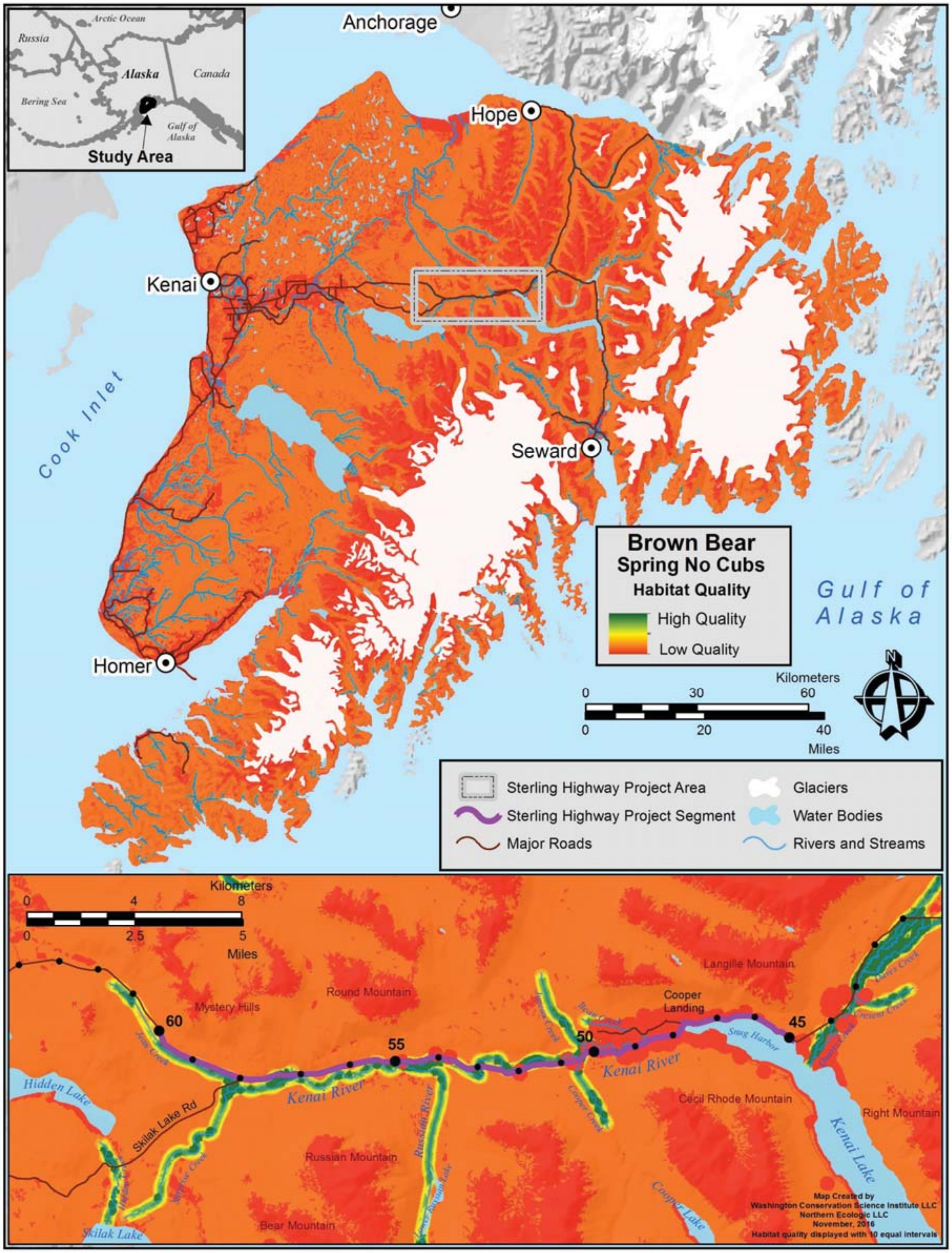


Figure 3-9. Probability of use of female brown bears without cubs in the spring on the Kenai Peninsula, Alaska, USA (as calculated by a Resource Selection Function [Suring et al. 2006]).

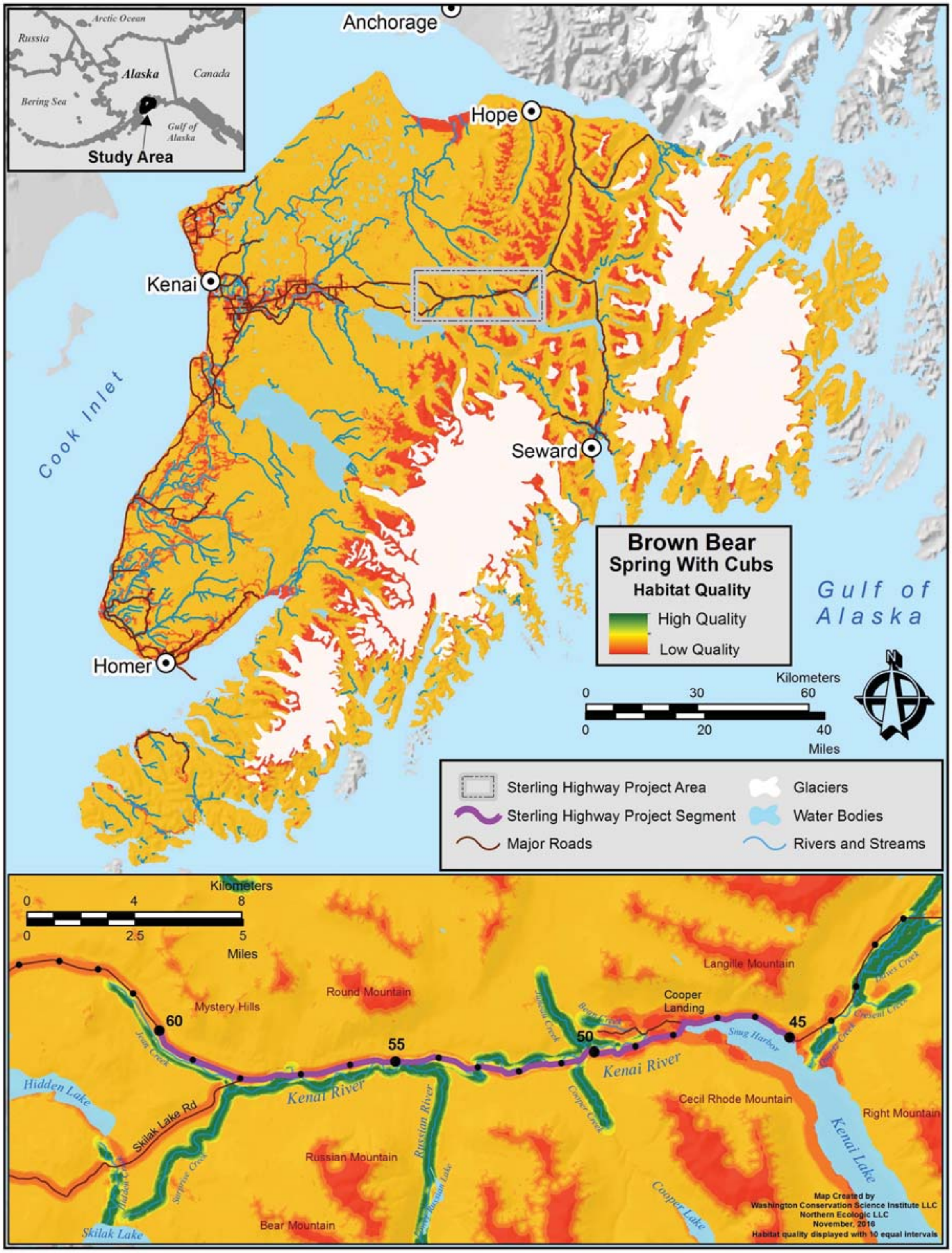


Figure 3-10. Probability of use of female brown bears with cubs in the spring on the Kenai Peninsula, Alaska, USA (as calculated by a Resource Selection Function [Suring et al. 2006]).

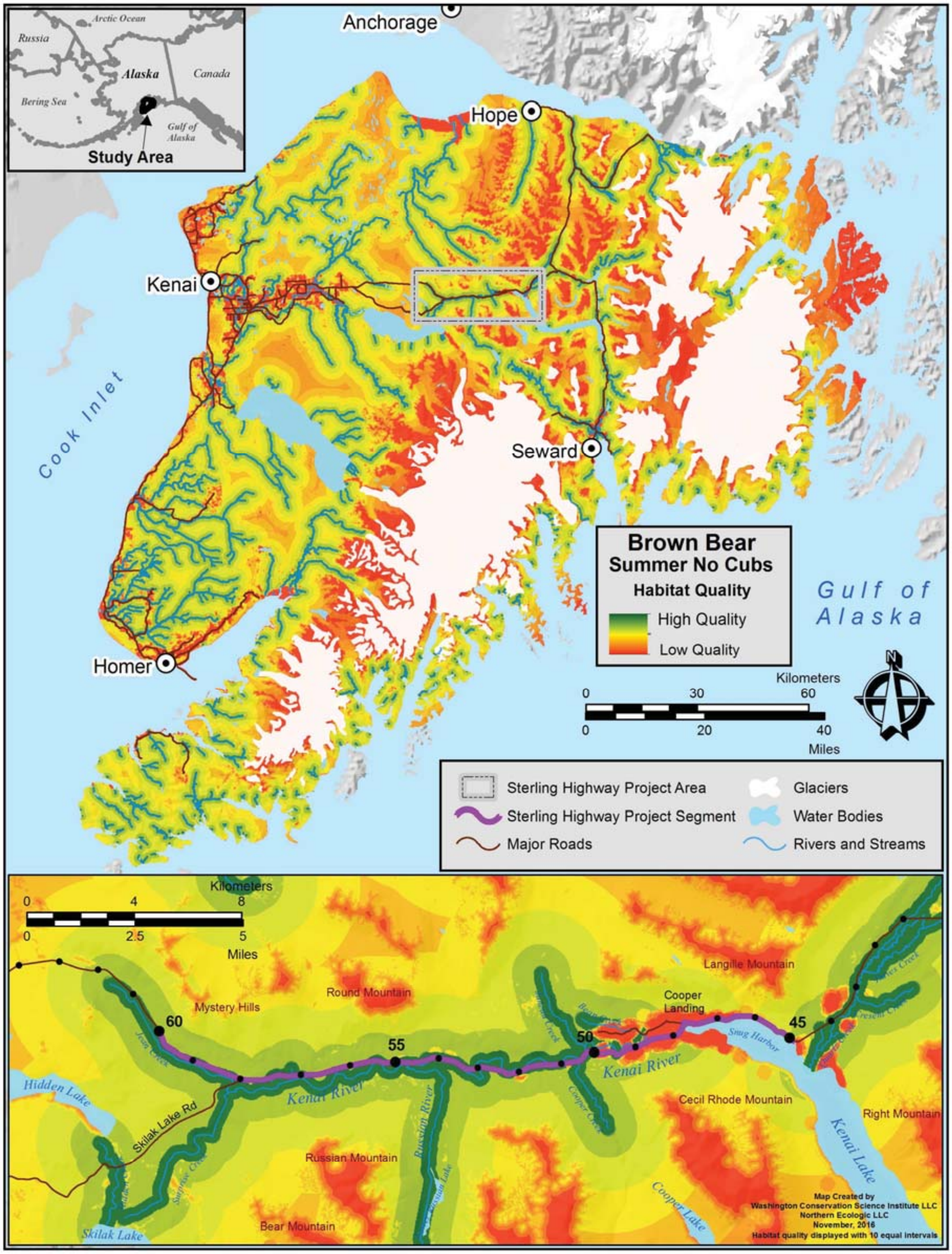


Figure 3-11. Probability of use of female brown bears without cubs in the summer on the Kenai Peninsula, Alaska, USA (as calculated by a Resource Selection Function [Suring et al. 2006]).

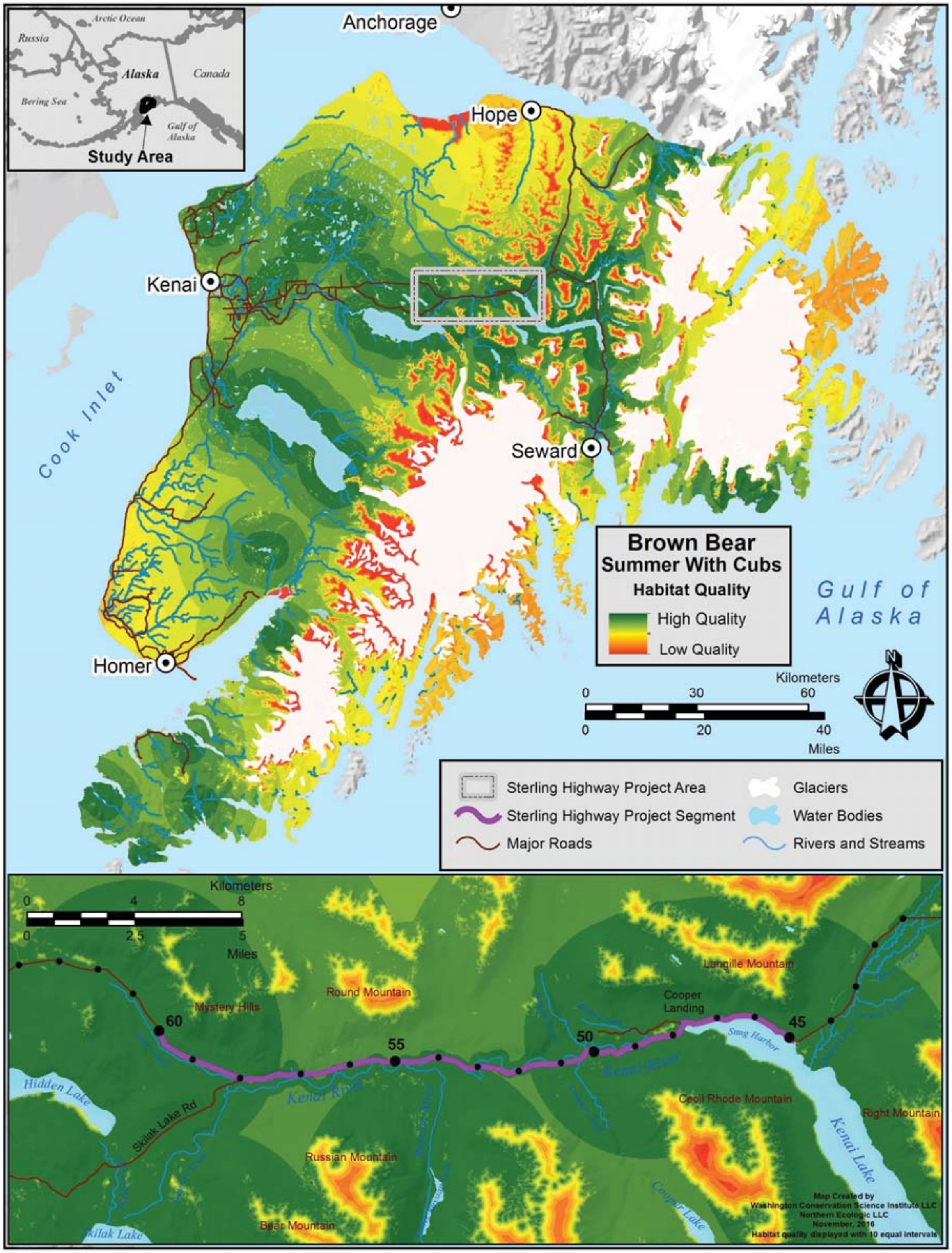


Figure 3-12. Probability of use of female brown bears with cubs in the summer on the Kenai Peninsula, Alaska, USA (as calculated by a Resource Selection Function [Suring et al. 2006]).

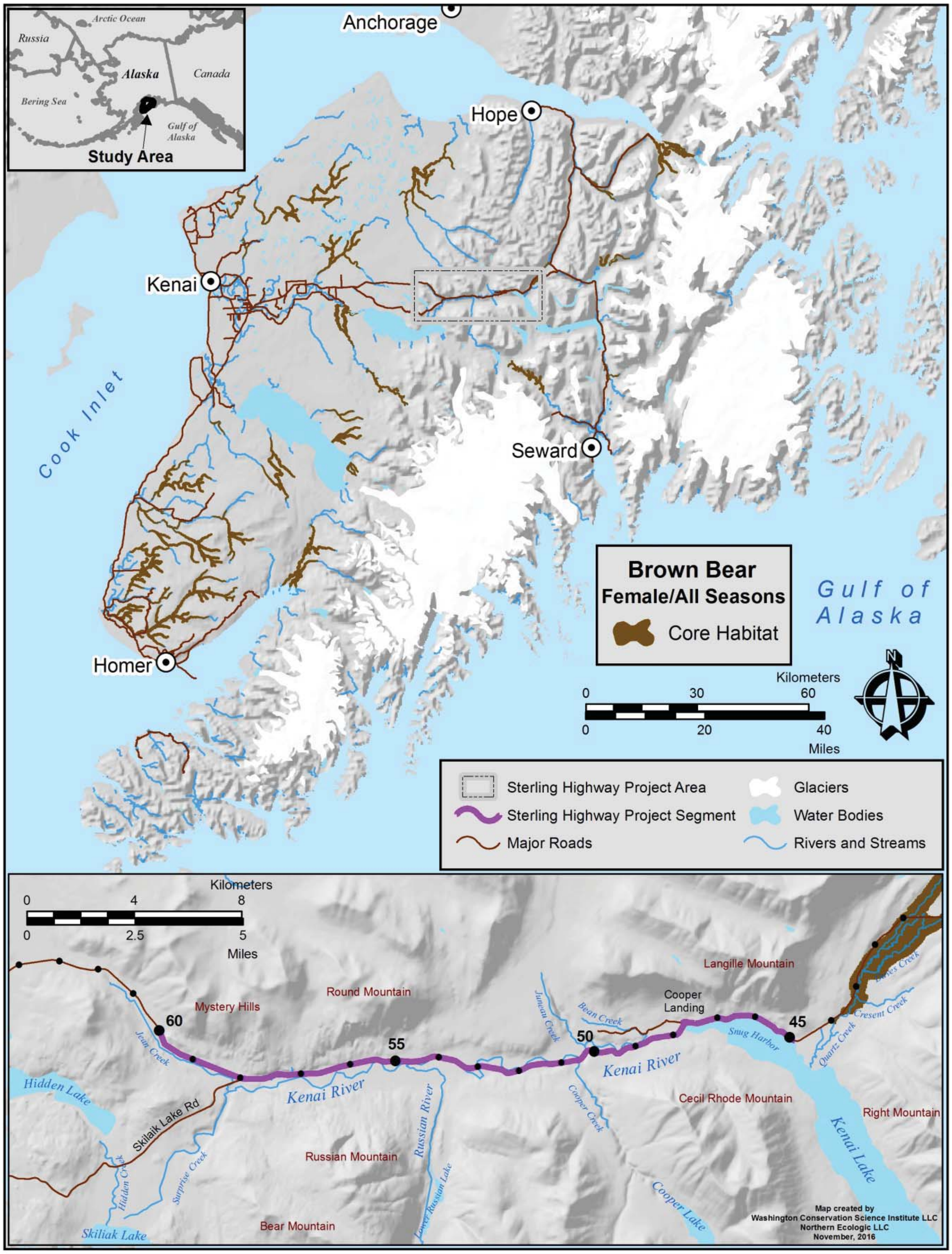


Figure 3-13. Areas of core habitat for female brown bears with and without cubs in the spring and without cubs in the summer on the Kenai Peninsula, Alaska, USA.

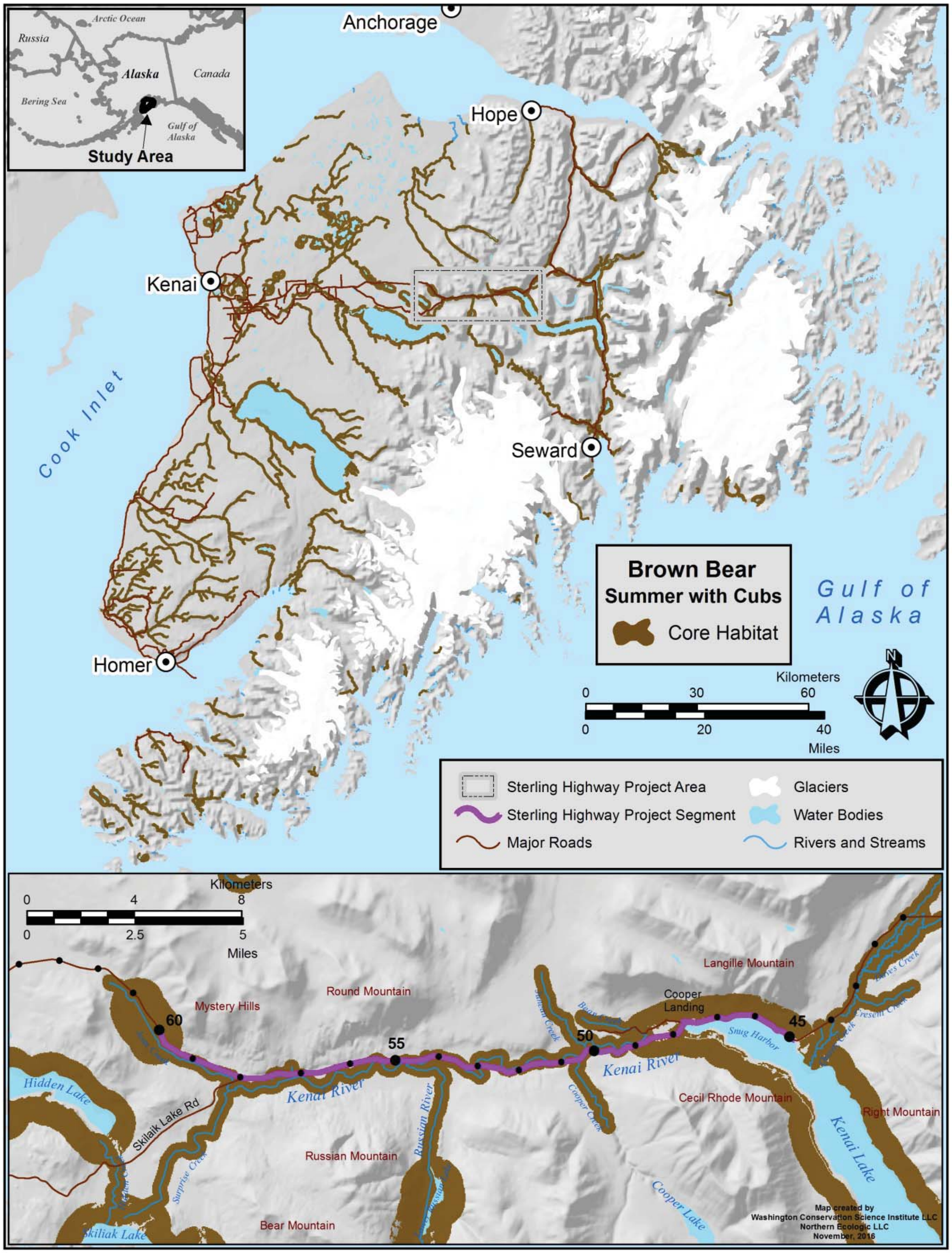


Figure 3-14. Areas of core habitat for female brown bears with cubs in the summer on the Kenai Peninsula, Alaska, USA.

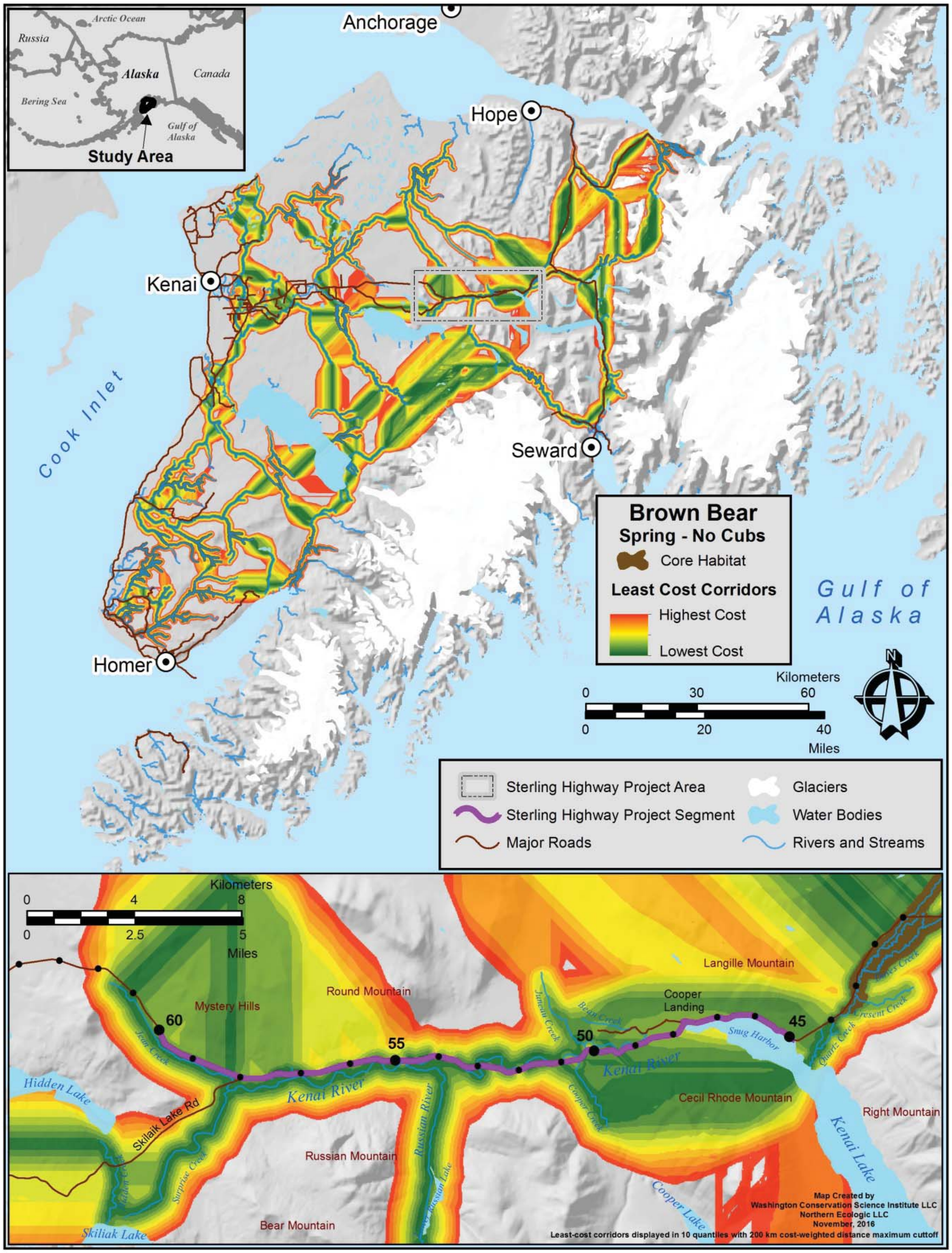
Analysis of least-cost corridors for all strata showed multiple potential corridors for brown bears from MP 45–60 of the Sterling Highway in the vicinity of Cooper Landing (Figures 3-15, 3-16, 3-17, 3-18). This analysis revealed potential crossing points in the vicinity of MP 44 near Quartz Creek, between MPs 48–51 near Cooper Creek on the south and Juneau Creek on the north sides of the highway, at MP 54 near the confluence of the Russian and Kenai rivers, and between MPs 58–59 near the junction of the Sterling Highway and Skilak Loop Road, at MP 61.

We used circuit theory to estimate the effective resistance of the landscape within these corridors between all pairs of core areas throughout the Kenai Peninsula (all-to-one mode in the Circuitscape software; McRae and Shah 2011). This analysis identified potential primary crossing points for female brown bears in the spring with cubs and without cubs and in the summer with cubs and without cubs were located at MP 44 near Quartz Creek, between MPs 49 and 51 near Cooper Creek on the south and Juneau Creek on the north sides of the highway, and near MP 71 near the East Fork of Moose River (Figures 3-19, 3-20, 3-21, 3-22). However, it should be noted that Cooper Creek may not currently serve as a movement corridor because salmon are not present in that creek even through our databases indicated they were present (personal communication, Nathan Jones).

A potential secondary crossing point for female brown bears in the spring with cubs and without cubs and in the summer with cubs and without cubs was located at MP 54 near the confluence of the Russian River with the Kenai River. A potential secondary crossing point for female brown bears in the spring with cubs and without cubs and in the summer with cubs were located at MP 58 near the junction of the Sterling Highway and Skilak Lake Road.

Discussion

Brown bears are particularly vulnerable to the potential effect of roads because of their need to travel widely to meet life requisites combined with their sensitivity to human disturbance (Weaver et al. 1996, Servheen et al. 1998). Brown bear responses to traffic often cause a departure from typical behavior (Northrup et al. 2012). In Banff National Park, Alberta, Canada brown bears crossed roads in areas where habitat quality was high (Chruszcz et al. 2003). When brown bears crossed high-volume roads, they did so to move into areas of higher quality habitat suggesting that there is a trade-off between the risks of crossing roads and benefits in terms of access to higher quality habitat. Avoidance of human developments, such as roads, may be a lower priority for brown bears than exploiting high quality food sources (Gibeau et al. 2002) or taking advantage of dispersal networks (Clevenger and Wierzchowski 2006). Percy (2003) reported that although road-crossing frequency for brown bears was negatively correlated with hourly traffic volume on a low-volume road, they were reported to continue to cross roads.



Map Created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016

Least-cost corridors displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 3-15. Least-cost corridors for movement of female brown bears in the spring without cubs within the Sterling Highway project area on the Kenai Peninsula, Alaska, USA.

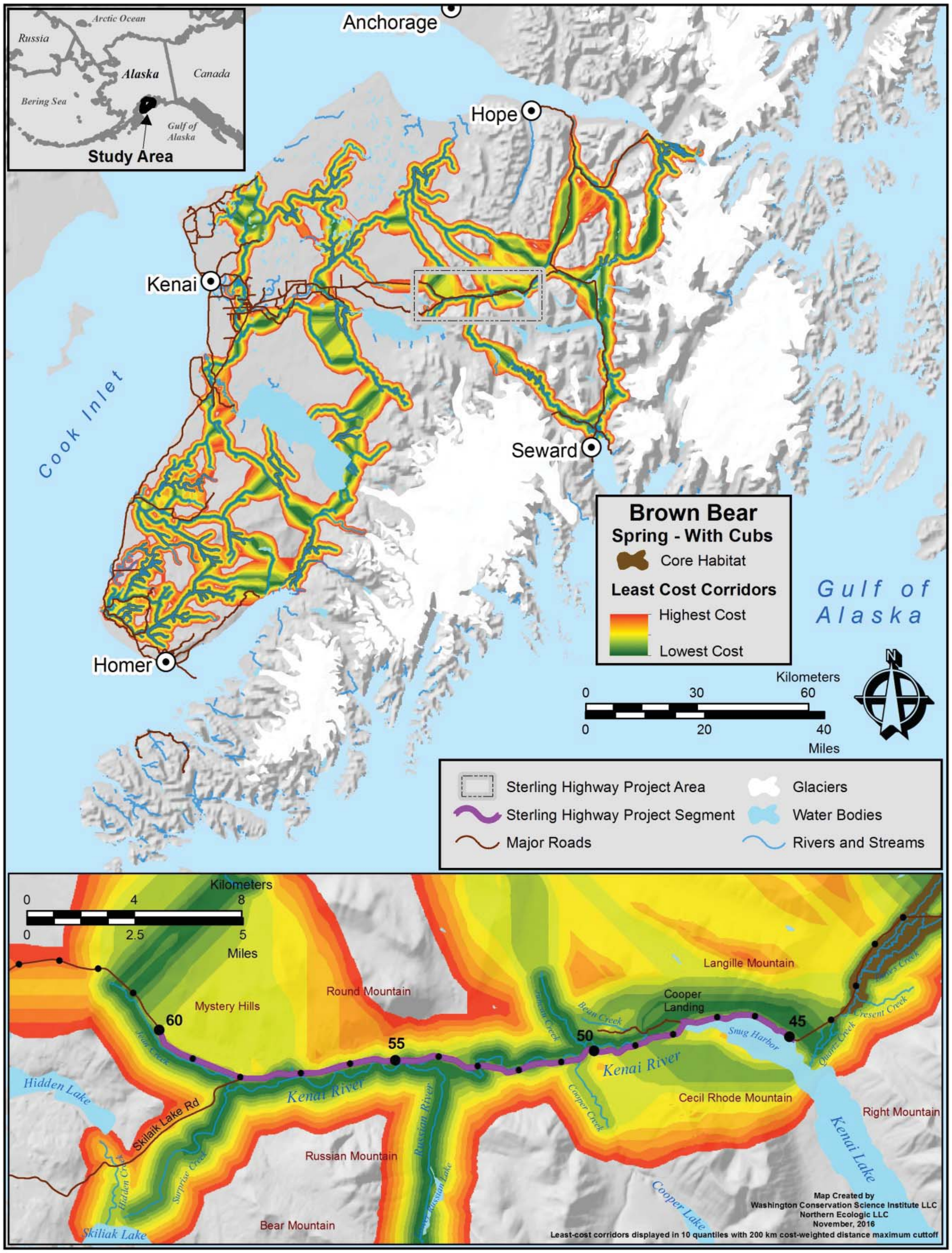


Figure 3-16. Least-cost corridors for movement of female brown bears in the spring with cubs within the Sterling Highway project area on the Kenai Peninsula, Alaska, USA.

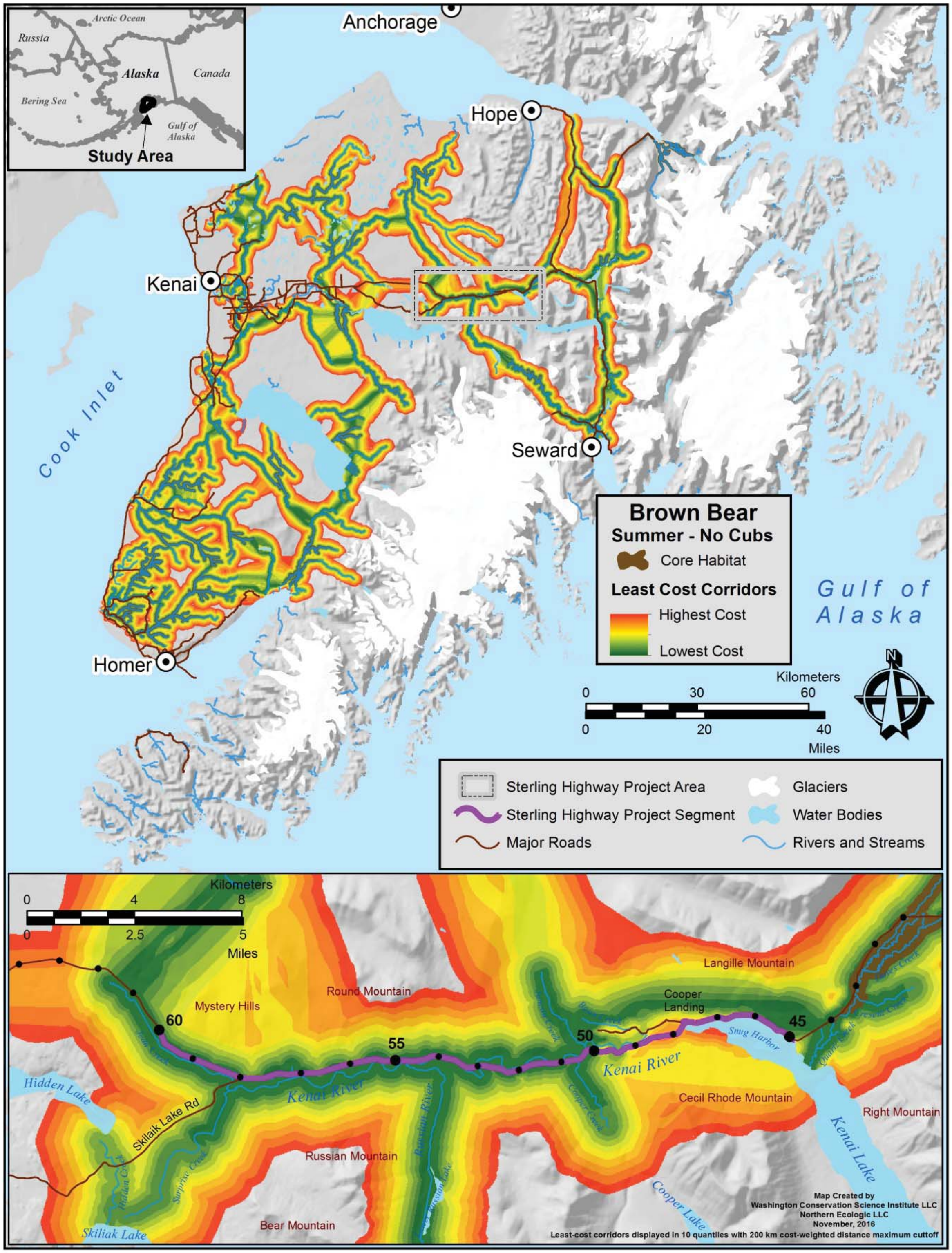


Figure 3-17. Least-cost corridors for movement of female brown bears in the summer without cubs within the Sterling Highway project area on the Kenai Peninsula, Alaska, USA.

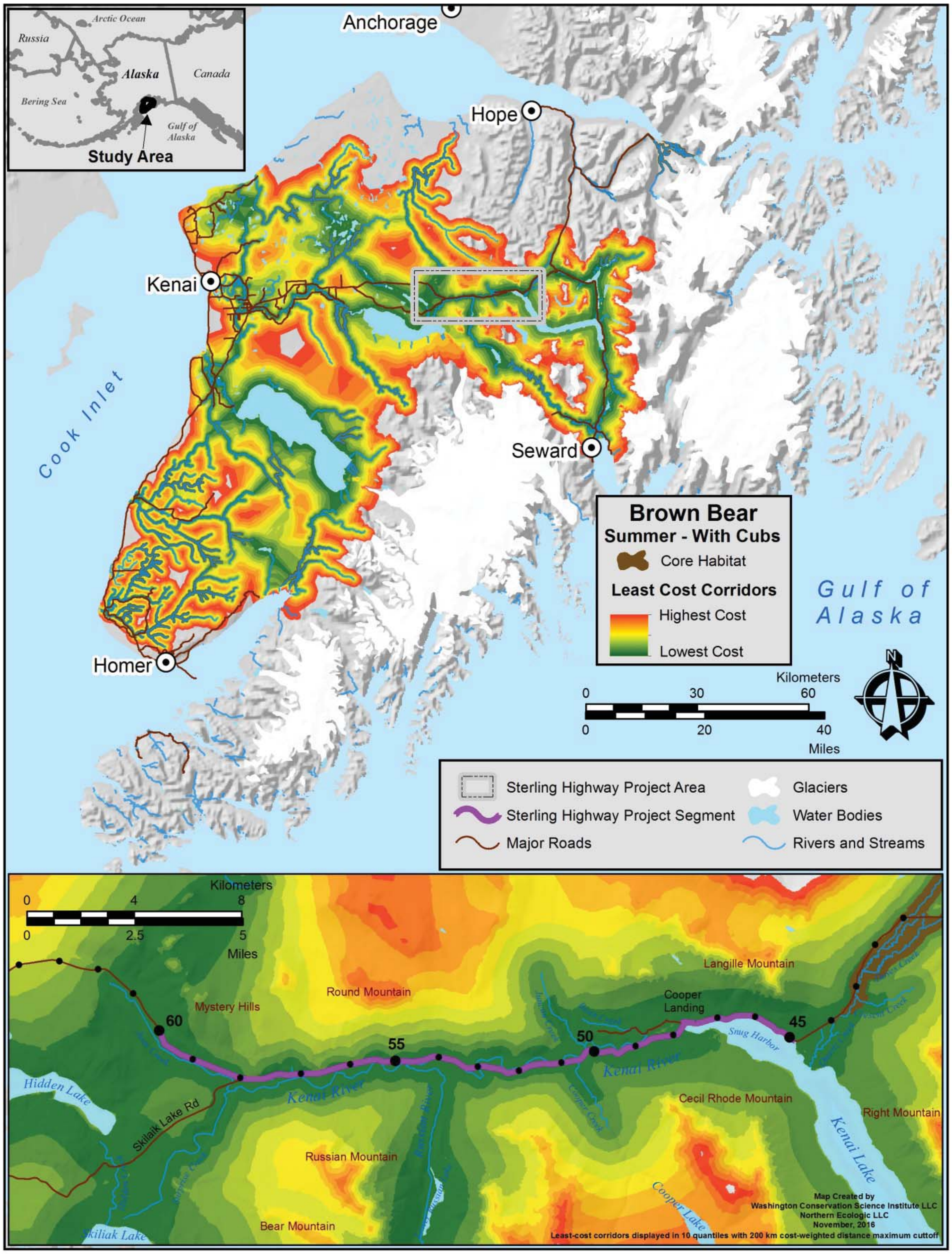


Figure 3-18. Least-cost corridors for movement of female brown bears in the summer with cubs within the Sterling Highway project area on the Kenai Peninsula, Alaska, USA.

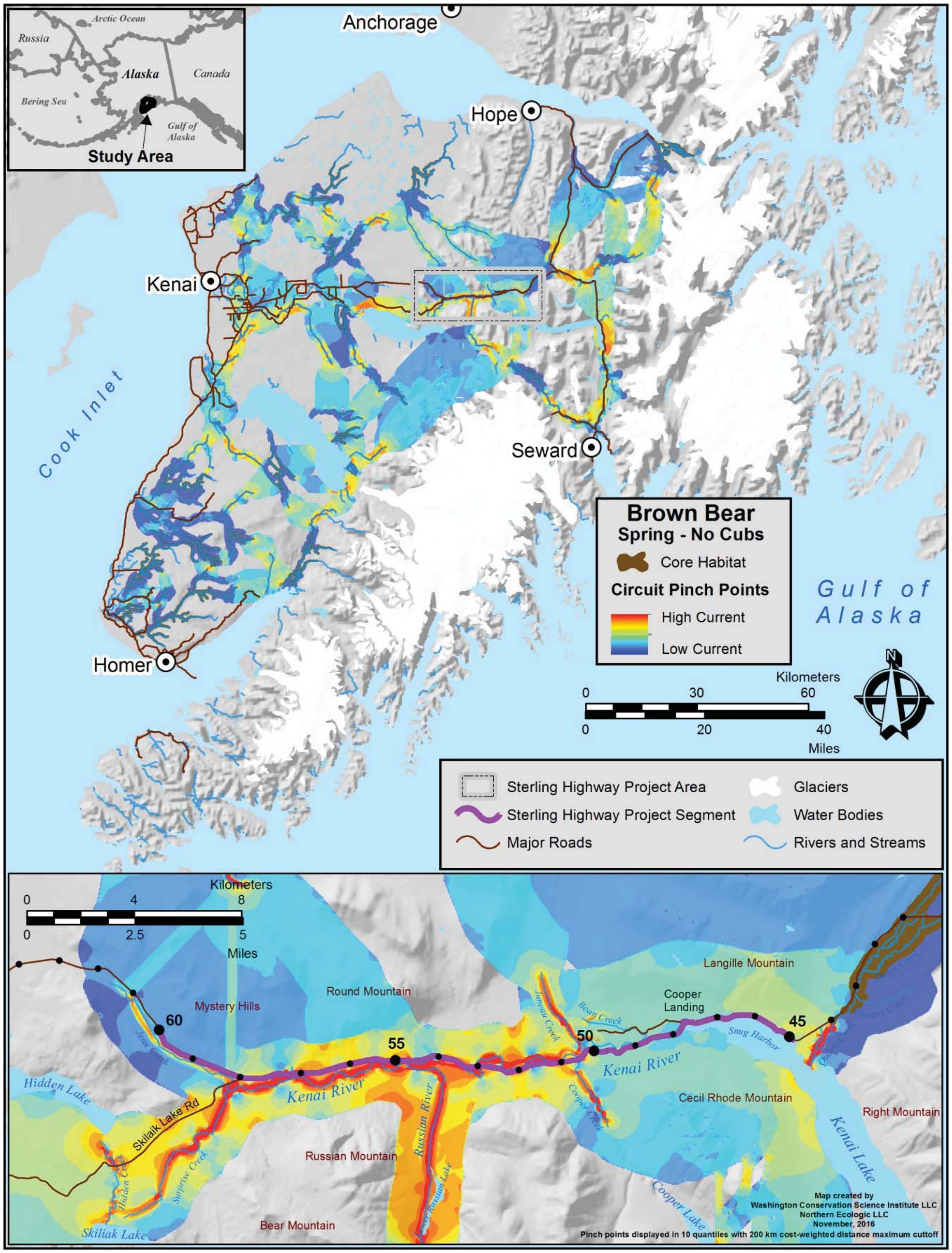


Figure 3-19. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female brown bears without cubs during spring.

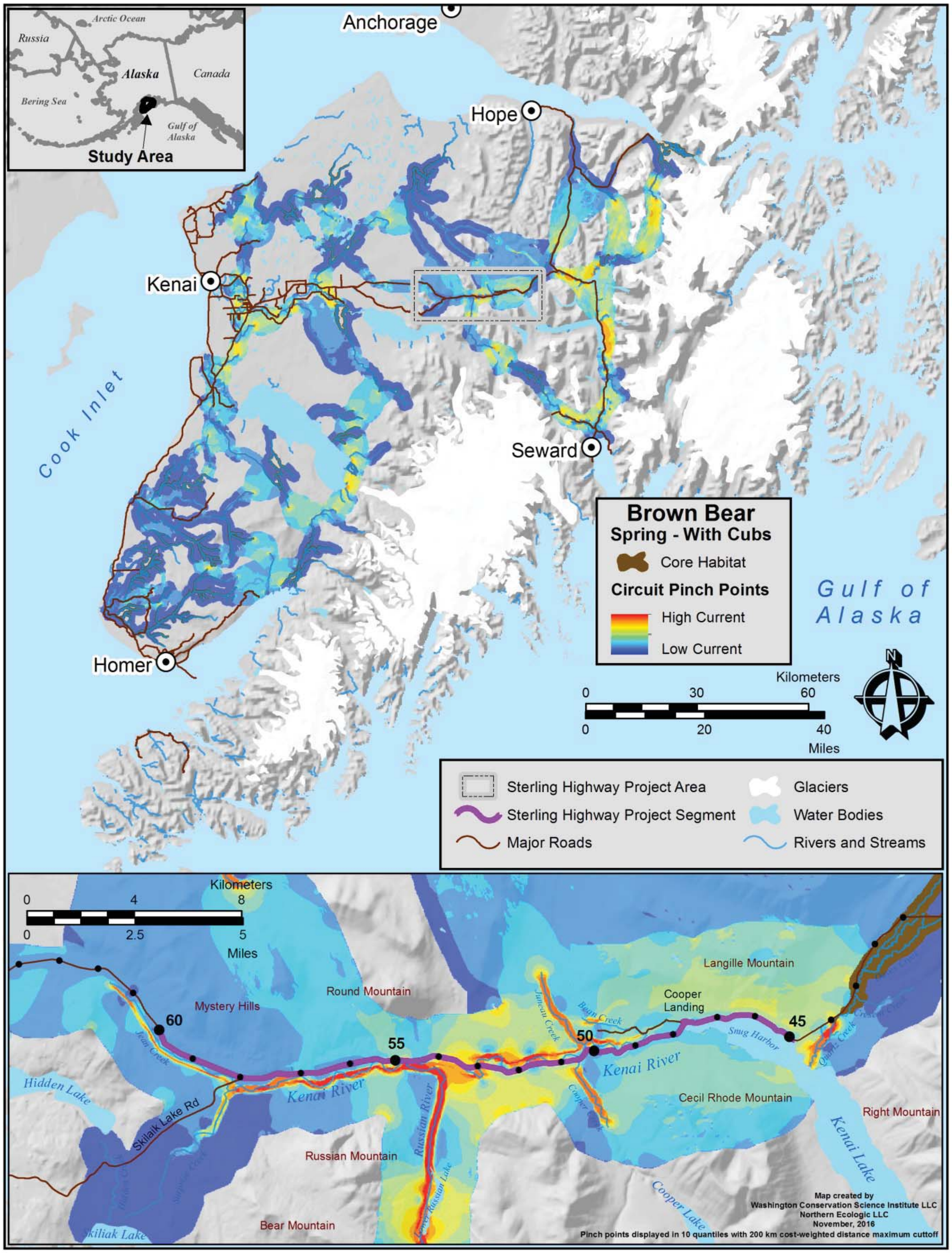


Figure 3-20. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female brown bears with cubs during spring.

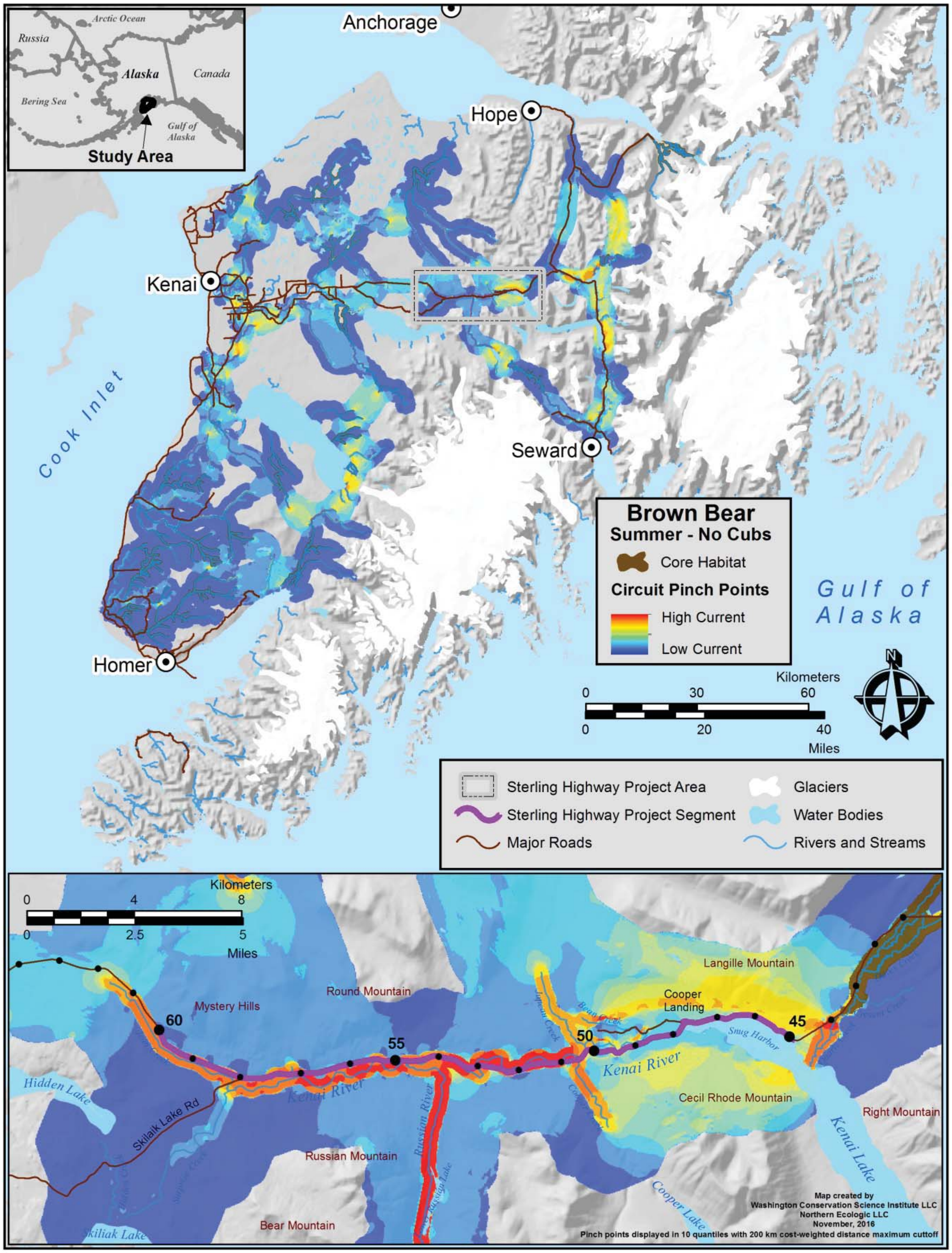


Figure 3-21. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female brown bears without cubs during summer.

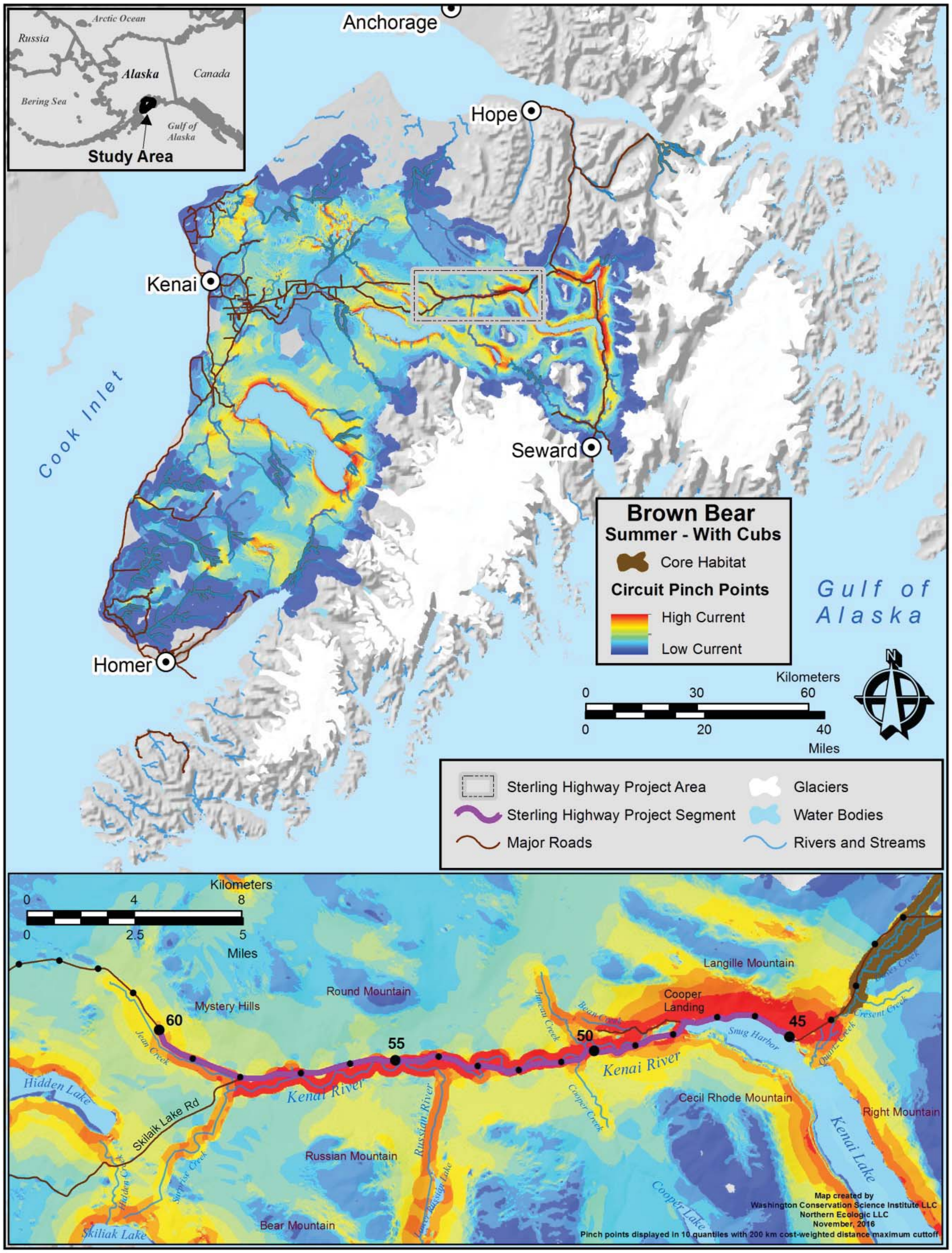


Figure 3-22. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female brown bears with cubs during summer.

Road crossings by brown bears were more likely to occur in areas where dense vegetation was adjacent to roads. Preference for proximity to cover when moving near or crossing roads has been observed elsewhere (McLellan and Shackleton 1989). Consequently, availability of cover may be an important requirement for attempting to cross roads and providing security from road-related disturbance. Additionally, Gibeau et al. (2001) reported that zones of high frequency road crossings by brown bears were characterized by lower total road density, proximity to a major drainage, rugged terrain, and high quality habitat indicating that the distribution of road-crossing corridors may be predictable.

The potential crossing areas identified for brown bears in our analysis were similar to those previously described in the literature for the Kenai Peninsula (Graves et al. 2006). Crossing roads at these areas on the Kenai Peninsula provided access to high-quality habitat and were generally associated with dense vegetation in major drainages. Brown bears on the Kenai Peninsula crossed the Sterling Highway at least partially to gain access to salmon resources (Graves et al. 2006).

Graves et al. (2006) evaluated the frequency and distribution of crossings of the Sterling Highway by brown bears from its intersection with the Seward Highway west to Soldotna, Alaska. This analysis was based on 171 highway-crossing locations by 15 monitored brown bears. Lone females and females with young >1 year old crossed the highway more frequently than females with cubs. Females with cubs also had a higher probability of crossing at nighttime. A road density of 2 km/km^2, equivalent to 2 parallel roads, was only 0.74 times as likely to be an actual brown bear crossing location as an area with a road density of 1 km/km^2 (i.e., as road density increased, brown bears were less likely to cross roads).

Graves et al. (2007) subsequently identified potential corridor locations based on the movement characteristics of brown bears on the Kenai Peninsula. They identified 4 areas with predicted high value seasonal habitat and low levels of human activities along the Sterling Highway that may be considered linkage zones (i.e., north of Skilak Lake near the East Fork of Moose River, north of Skilak Lake near Hidden Creek, west of Cooper Landing near Juneau Creek, east of Kenai Lake). These linkage zones correspond well with the crossing points we identified in our analysis (Figures 3-19, 3-20, 3-21, 3-22).

Multivariate analyses showed a preference of overpasses rather than underpasses as mitigation measures by brown bears (Clevenger and Waltho 2000, 2005). In pairwise comparisons of underpasses and overpasses <200 m (<656 ft) apart Clevenger et al. (2009) found that brown bears preferred overpass structures when there was an underpass nearby (<300 m [<984 ft] distance). While brown bears in Clevenger and Barrueto’s (2014) study area, especially males, appeared to have adapted to and eventually used all types of crossing structures, the smallest crossing structures remained virtually underutilized 17 years after construction. Sawaya et al. (2014) reported that female brown bears had a strong preference for overpasses and large underpasses. Structures similar to 4 by 7 m (13 by 23 ft) corrugated steel culverts and smaller were underutilized and appeared to be of little conservation value to brown bears (Clevenger and Barrueto 2014). Clevenger and Huijser (2011) indicated that brown bears tend to prefer large, open structures with good visibility. They recommended landscape bridges from 70–>100 m (230 ft–>328 ft) wide, wildlife overpasses 40–70 m (131–230 ft) wide, and viaducts or flyovers (Clevenger and Huijser 2011). They also indicated that large underpasses may be sufficient for brown bears if they are specifically adapted for their use. Although they recommend a minimum width of 12 m (39 ft) and minimum height of 4.5 m (14.7 ft), Clevenger and Huijser (2011) went on to say that these dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes.

Management Implications

The results of Graves et al. (2006) indicated that crossings of the Sterling Highway by brown bears may be restricted due to traffic volume and highway configuration. Potentially, connectivity may be decreased and highway mortality may be increased as a result of the Sterling Highway 45–60 Project. This could, in turn, exacerbate negative population-level effects on brown bears. The brown bear population on the Kenai Peninsula has been estimated to be 582 animals (Morton et al. 2016). With infrequent female bear immigration (Jackson et al. 2008); even a few annual highway mortalities could decrease the overall population viability. While populations are sensitive to the survival of breeding females, the subadult cohort is the future of any population. The 1st priority in conserving the brown bear population relative to roads should be reducing the highway mortality of breeding females. A 2nd priority should be to ensure the dispersal of subadults (and associated gene flow). Dispersal by young brown bears appears to be a gradual process over months or even years (McLellan and Hovey 2001) making these crossing areas potentially critical to the population. Graves et al. (2006) recommended maintaining or reducing current highway traffic volumes and developing and implementing measures to improve highway-crossing opportunities. The potential crossing points we identified would be appropriate areas to focus these, and other, highway mitigation efforts.

Previous efforts to maintain movement corridors for bears have concentrated on using crossing structures to facilitate movement across highways (e.g., McCoy 2005, Ford et al. 2009, Lewis et al. 2011). Those authors emphasized the use of crossing structures because they can be important in reducing highway mortalities and enhancing connectivity of subpopulations of bears. However, human developments were also closely associated with brown bear mortalities on the Kenai Peninsula (Suring and Del Frate 2002) and were the most important factor in affecting movement patterns in other populations of brown bears (Proctor et al. 2012). These findings suggest that management strategies to maintain movement patterns of brown bear on the Kenai Peninsula should consider reduction of mortality of brown bears from human conflict and minimization of human densities in movement corridors along with mitigation of mortalities associated with highway crossings. When primary movement corridors are near human settlement or developments, an effective strategy may be to include increased human-bear conflict management to reduce over-all risk of mortality (Proctor et al. 2015).

As suggested by Proctor et al. (2015), the value of identifying core habitats and movement corridors is to inform targeted management within the MP 45–60 study area. Delineation of core habitats does not mean that management to maintain brown bear populations should be limited to these areas. They merely represent areas identified that have higher-quality habitat that may change over time due to many factors (natural and human-induced). However, by focusing management efforts within the movement corridors, rather than along the full length of the highway and rather than within all human developments, there is likely to be a greater return on management actions and probability of success. Within movement corridors, in addition to mitigating highway crossing mortality, management actions should also be directed toward minimizing human-generated bear attractants, reducing human access to prime habitat, and minimizing human development (e.g., subdivisions) and densities (Proctor et al. 2008, 2012, 2015).

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Appendix – Brown Bear

Table 3A-1. Parameter values assigned in the core mapper software to identify core habitats for female brown bears on the Kenai Peninsula, Alaska, USA.

Analysis strata	Moving window radius (m)[a]	Minimum average probability of use[b]	Minimum probability of use per pixel[c]	Expand cores by this cost weighted distance (m)	Minimum size of core areas (ha)[d]
Female brown bears in spring with cubs	2500	50	98.5	5000	100
Female brown bears in summer with cubs	2500	50	98.5	0	100
Female brown bears in summer without cubs	2500	75	98.5	5000	100
Female brown bears in spring without cubs	2500	25	98.5	5000	100

[a] Smaller values result in larger numbers of more-detailed core areas.

[b] Average probability of use in the moving window around a pixel must be greater than this for the pixel to be considered 'core'.

[c] Pixel value must be greater than this to be 'core'.

[d] Core areas smaller than this will be eliminated at end of the run.

Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 4 – Habitat Use Patterns of Female Moose on the Kenai Peninsula, Alaska, USA

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Introduction

The moose population on the Kenai Peninsula is of considerable interest from both ecological and economic perspectives, and concerns have been raised about their long-term population viability (Bangs et al. 1989, Ernst et al. 2009, Morton 2012). Factors that have been identified that affect the moose population on the Kenai Peninsula include habitat quality and quantity, hunting, disturbance from recreation and other human activities, and wildlife-vehicle collisions (Bangs et al. 1989, Morton 2012, Harris et al. 2013). Over the last 30 years, the human population has doubled and the traffic volume on the Sterling Highway has quadrupled on the Kenai Peninsula (Morton 2012). Approximately 250 moose are killed in a typical year by collisions with vehicles on the Kenai Peninsula (Morton 2012).

The moose population on the eastern portion of the Kenai Peninsula (ADF&G Game Management Unit [GMU] 7) is at a low density when compared to the rest of the Peninsula (McDonough 2010). High mortality rates for moose in this area have been linked to consistent severe winters with heavy snowfall. On average, 30 (range 18–38) moose were harvested annually in GMU 7 from 2004–2009 (McDonough 2010). Hunters participating in the general moose season have had an average success rate of 9% (range 6–11). The average annual mortality of moose in GMU 7 as a result of wildlife-vehicle collisions (WVCs) from 2004–2009 was 25 moose (range 19–30) (McDonough 2010).

In areas with few anthropogenic affects, moose habitat selection is primarily influenced by the availability of browse and protective cover against predators and inclement weather (van Ballenberghe and Ballard 1998). However, studies have shown that human activities can modify how moose use landscapes (Laurian et al. 2008, Harris et al. 2013, Wilson et al. 2015). For example, Laurian et al. (2008) analyzed moose behavior at Laurentides Wildlife Reserve in Québec, which had only 2 single-lane highways running in a north–south direction and a few forest roads suitable for cars and trucks (0.16 km/km^2). Their results indicated that moose perceive road networks as a broad characteristic of the environment and moose usually avoided roads up to 500 m on each side. This led to an avoidance of crossing highways and forest roads (i.e., 16 and 10 times less than expected, respectively). In general, moose seem to modify their behavior around roadways by avoiding highways, forest roads, and associated roadsides (Yost and Wright 2001, Laurian et al. 2008). Laurian et al. (2008) demonstrated that moose with home ranges near highways avoided crossing those roads. One highway in their study area had estimated mean daily traffic of 1,460 vehicles; the other highway had estimated mean daily traffic of 2,800 vehicles. Almost half (19/45) of the moose marked at the edge of a paved highway never traversed the road and others crossed infrequently. As a result, moose home ranges were located primarily on 1 side of the highway because of their reluctance to cross the highway, limiting dispersion and use of available habitats (Laurian et al. 2008).

Harris et al. (2013) used resource selection functions (RSFs) to model moose habitat use and distribution during their study of the influence of winter recreation on habitat selection in Placer Valley and Juneau Creek on the Kenai Peninsula. They developed RSF models with moose location data obtained during the 2006-2007 winter. Moose data obtained during the 2007-2008 winter was used for model validation. They found that in areas without the influence of winter recreation, moose habitat selection was driven by the availability of forage and cover. However, moose were displaced from preferred areas by snowmobiles.

The objective of our study was to identify landscape characteristics that influenced resource selection by moose on the Kenai Peninsula, Alaska. We used results of the above described studies and a review of the literature to identify a set of abiotic (e.g., slope, elevation), biotic (e.g., vegetation cover types), and anthropogenic (e.g., roads, highways) variables that could be spatially represented and used to develop RSF models. Information on the influence of landscape features on the distribution of moose on the Kenai Peninsula was needed to facilitate habitat connectivity modeling and the identification of potential mitigation practices associated with the Sterling Highway Milepost (MP) 45–60 Project.

Methods

Telemetry Data

We used telemetry data acquired during studies described by Ernst et al. (2009) and Harris et al. (2013). Thirty adult cow moose were successfully captured and collared with GPS units in late October and early November 2005 (Ernst et al. 2009). GPS units were programed to record locations of moose every 30 m from October through March, then every 2 hr until collar release in July. Twenty-seven units were recovered with their data in July 2006. Two units were retrieved in fall 2006; 1 unit was not recovered. An additional 31 cow moose were successfully captured and collared with GPS units in late October and early November 2006. As in the previous year, GPS units were programed to record locations of moose every 30 m from October through March, then every 2 hr until collar release in summer. Thirty units were recovered with their data in July and August 2007; 1 unit was not recovered. A total of 558,239 locations were recorded from 59 moose with GPS units from 2005 through 2007 (Ernst et al. 2009).

The telemetry dataset was filtered to include only 3-D (4 satellites) GPS data points to increase location accuracy (Wyckoff et al. 2007). Typically, 3-D fixes have <20 m error (Di Orio et al. 2003). This resulted in a total of 528,399 locations to use in the analysis of resource selection (Table 4-1). We then assigned each location to 1 of 4 seasons, based on moose movement patterns and habitat use. We defined seasons similar to how other researchers have used them (e.g., Bangs et al. 1989, Cederlund and Sand 1994, Olsson et al. 2011, Laurian et al. 2012, Harris et al. 2013) and to account for peak months of moose crossings of the Sterling Highway reported by Ernest et al. (2009).

Spring – 1 May to 15 June, vernal re-vegetation and calving

Summer – 16 June to 31 July, well-developed and abundant vegetation

Autumn – 1 August to 31 October, vegetation quality and quantity decline, rut occurs

Winter – 1 November to 30 April, dormant vegetation and snow, peak moose crossings of Sterling Highway (Ernest et al. 2009), encompasses winter period used by Harris et al. (2013)

Table 4-1. Descriptions of variables used in candidate models to assess resource use by moose on the Kenai Peninsula (based on Chapter 2; Begley et al. 2017).

Variable	Description
Vegetation	
Deciduous forest	Trees generally >5 m tall, >20% of total vegetation, >75% of trees shed foliage
Mixed forest	Trees generally >5 m tall, >20% of total vegetation, mix of evergreen and deciduous
Evergreen forest	Trees >5 m tall, >20% of total vegetation, >75% maintain leaves all year.
Shrubland	Woody vegetation with aerial stems generally < 6 m tall, both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted.
Wetland	Forest or shrubland vegetation accounts for >20% of cover and soil is periodically saturated with or covered with

Table 4-1. Descriptions of variables used in candidate models to assess resource use by moose on the Kenai Peninsula (based on Chapter 2; Begley et al. 2017).

Variable	Description
	water
Cover	Forested upland
Forage	Shrubland, herbaceous upland, woody wetlands
Water/barren	Open water or permanent ice/snow cover; Bare rock, gravel, sand, silt, clay or other earthen material with little or no green vegetation present
Topography	
Elevation	Continuous variable
Slope	Continuous variable
Human activities	
Human development, low	Agriculture – Areas planted or intensively managed for food, feed or fiber, herbaceous vegetation accounts for 75-100% of the total. Developed, open – Most commonly included large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. Developed, low intensity – Commonly included single-family housing units, impervious surfaces 20-49% of total cover.
Human development, high	Developed, medium intensity – Commonly included single-family housing units, impervious surfaces 50-79% of total cover. Developed, high intensity – included apartment complexes, row houses, and commercial/industrial, impervious surfaces >80% total cover.
Distance to road	Distance to road, highway or freeway in m. Truncated at 3 km.

Table 4-1. Descriptions of variables used in candidate models to assess resource use by moose on the Kenai Peninsula (based on Chapter 2; Begley et al. 2017).

Variable	Description
Distance to trail	Distance to motorized or non-motorized trail in m. Truncated at 3km.
Distance to recreation site	Distance to trailhead, campground, etc. Truncated at 3km.

Resource Selection Modeling

We defined the study area by buffering all moose locations by 1 km and creating a single minimum convex polygon (Figure 4-1) (Sawyer et al. 2009, Harris et al. 2013). This was consistent with the McClean et al. (1998) recommendation that the population-level of habitat availability be based on the complete distribution of radio-collared animals.

We reviewed a considerable body of literature on moose resource selection and movement ecology (see Appendix A) to select a suite of variables potentially important as landscape predictors, and to inform the development of *a priori* resource selection models. The variables included various combinations of vegetation, topographical, and human use measures (Table 4-1). We then used these variables, in various combinations and based on our understanding of the ecological relationships of moose, to develop ecologically plausible *a priori* resource selection models. For example, several studies have shown the influence that vegetation, used for food or cover, can have on moose habitat selection (e.g., Seiler 2005, Danks and Porter 2010, Becker et al. 2011, Laurian et al. 2012). Topographic features, such as elevation and slope, have also been shown to influence how moose use landscapes (Becker et al. 2011, Laurian et al. 2012). Finally, human developments and activities such as roads, winter recreation, and housing developments have been shown in numerous studies to influence moose resource selection (Schneider and Wasel 2000, Yost and Wright 2001, Lykka et al. 2009, Shanley and Pyare 2011, Laurian et al. 2012, Harris et al. 2013). However, the influence of these variables can vary by study and study area. To account for this in our modeling approach, we used various combinations of the variables to determine what best described moose resource selection in our study area.

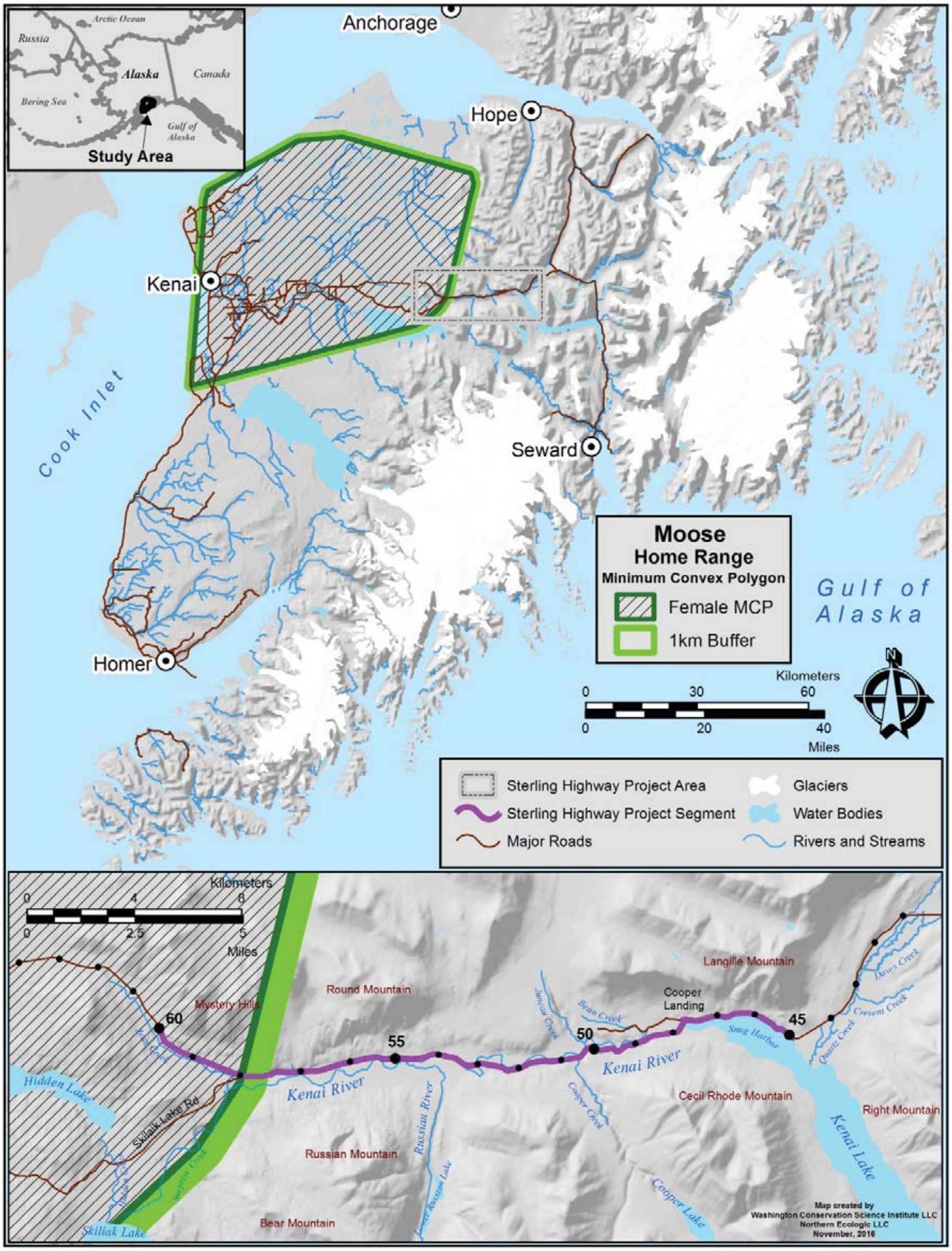

Figure 4-1. Composite minimum convex polygon multi-year home range and 1 km buffer for moose, Kenai Peninsula, Alaska, USA.

Our approach relied on fitting generalized linear models (GLM) to relate the probability of use by moose to habitat characteristics (Sawyer et al. 2009, Harris et al. 2013). The approach consisted of 4 steps: 1) we measured predictor variables as systematically selected circular sampling units, 2) the relative frequency of use in the sampling units for all collared moose was estimated, 3) we modeled the relative frequency of use by moose as a function of predictor variables, and 4) we retained 25% of the telemetry data to use in model evaluation. We treated individual radio-marked moose as the experimental unit to avoid pseudoreplication and to accommodate population-level inference (Otis and White 1999, Erickson et al. 2001).

We estimated the relative frequency of use for each GPS-collared moose by using a straightforward technique that involved counting the number of moose locations in sampling units across the study area. Sampling units within the assessment area for measuring habitat variables were circular with a 200 m radius. This size captured differences in relative frequency of use and matched the spatial heterogeneity of the landscape (Sawyer et al. 2007, Harris et al. 2013). Although the entire study area contained 26,445 circles, the RSF modeling technique we employed required a Poisson sampling approach and a negative binomial distribution, meaning our sample could not equate to the entire population. The sampling units were selected via a systematic sample with a random start to increase precision through more even coverage and more accurate representation of the study area (Nielson and Sawyer 2013, Manly 2009). As suggested by Manly (2007), we used bootstrapping to determine the appropriate sample size of circular units (n=21,155) to accurately represent each estimated habitat parameter on the landscape. The relative frequency of locations from GPS-collared moose found in each sampling unit provided an empirical estimate of the probability of use by that moose, and we used it as a continuous response variable in a GLM.

We compiled a variety of data layers to spatially represent variables used in our resource selection analyses (see Chapter 2; Begley et al. 2017) (Table 4-1). For each sample unit, we measured the average elevation (m), average slope (%), distance to roads (km), distance to highways (km), distance to trails (km), distance to recreation sites (km), percentage of area within human development, percentage of area in each vegetation cover type, and percentage of area in foraging or cover habitat (Table 4-2). We amalgamated National Land Cover Data vegetation cover types into habitat classes (e.g., forage and cover). Classes were lumped according to similarity of vegetation and associations relevant to moose (Table 4-1). The maximum distances to roads, highways, trails, recreation sites and human development was 3 km based on Harris et al. (2013). Previous studies for other mammals including elk (Rowland et al. 2000), caribou (Preisler et al. 2006), and mule deer (Sawyer et al. 2006, 2009) have seen maximum effects at distances <3 km. Therefore, we truncated our distance values to ≤3 km.

Table 4-2. Candidate models used to develop Resource Selection Functions for female moose on the Kenai Peninsula, Alaska, USA.

Model Name	Variables
Vegetation	Deciduous forest + Mixed forest + Evergreen forest + Shrubland + Wetlands + Water/barren
Habitat	Cover + Forage + Other (barren, snow, ice, water)
Topography	Elevation + Slope
Human activities	Human development + Roads + Motorized trails + Non-motorized trails
Vegetation-Human activities	Vegetation model + Human activities model
Habitat-Human activities	Habitat model + Human activities model
Topography-Human activities	Topography model + Human activities model
Global model A	Vegetation model + Topography model + Human activities model
Global model B	Habitat model + Topography model + Human activities model

We addressed correlations among covariates by removing variables with a high degree of correlation (r>0.70). We developed 9 *a priori* ecologically plausible models with the remaining variables (Table 4-2) to describe resource selection. To determine which model best approximated the structure of our dataset, we used Bayesian Information Criterion (BIC) instead of Akaike Information Criterion (AIC) (Burnham and Anderson 2002) because AIC values tend to be minimal for most complex models when sample sizes are high (Schwarz 1978, Boyce et al. 2002). We calculated means and 90% confidence intervals for each independent variable in the best model as a means of assessing the influence of the variable on the overall model.

Population-level RSFs were used to develop population-level moose predictive maps (Becker et al. 2011; Sawyer et al. 2007, 2009). We obtained a population-level model for each season by first estimating coefficients for each GPS-collared moose. The coefficients for individual moose were averaged and variance estimated using equations 3, 4 in Sawyer et al.

(2007). We estimated coefficients for the population-level model for each seasonal period by using:

$$ß_k = 1/n \sum ß_{kj}$$

Where $ß_{kj}$ was the estimate of coefficient k for individual j ($j = 1, \ldots, n$). We estimated the variance of each population-level model coefficient by using the variation between GPS-collared moose and the equation:

$$\mathrm{Var}(ß_k) = 1/n\text{-}1 \sum (ß_{kj} - ß_k)^2$$

This method of estimating population-level coefficients has been used to evaluate habitat selection patterns of Stellar's jay (Marzluff et al. 2004), mule deer (Sawyer et al. 2006), and elk (Sawyer et al. 2007). Population-level inferences using these equations are unaffected by auto- or spatial correlation, because temporal autocorrelation between locations of an individual moose or spatial autocorrelation between habitat units does not bias model coefficients for the individual radiomarked moose models (McCullagh and Nelder 1989, Neter et al. 1996).

We mapped predictions of the population-level models for each season across the Kenai Peninsula by scaling the RSF values from high to low use following procedures similar to those described in Sawyer et al. (2007). For a final display of the seasonal RSF population-level maps, we first made water and icefields zero, and then scaled the remaining areas into 10 equal quantiles based on our population-level model coefficients. We scaled these values from 0.1 to 100 to show areas ranging from relatively low-use to relatively high-use by moose (Figures 4-2a-d).

We used the remaining 25% of the telemetry locations to evaluate the seasonal population-level predictive maps by calculating the proportion of locations that occurred within each of 10 equal resource selection categories with water and ice classified as zero (Laurian et al. 2012, Sawyer et al. 2007). Spearman rank correlation was used to compare predicted use with actual use. When an RSF model reliably reflects the relative probability of use of resource units, Spearman rank correlation should be high (>0.75) with significant *P* values (Sawyer et al. 2009, Coe et al. 2011, Laurian et al. 2012).

Results

Resource Selection Model

The number of telemetry locations available for each season to develop RSF models ranged from a low of 6,955 in autumn to a high of 474,629 in winter (Table 4-3), for a total of 528,399 relocations.

Table 4-3. Summary of the telemetry data used to develop Resource Selection Functions for female moose on the Kenai Peninsula, Alaska, USA.

Season/year		Total number of collared moose	Total number of relocations
Spring			
2006		29	15,297
2007		34	18,569
	Total		33,866
Summer			
2006		28	6,728
2007		34	6,221
	Total		12,949
Autumn			
2005		25	3,652
2006		14	3,303
	Total		6,955
Winter			
2005		29	219,615
2006		35	255,014
	Total		474,629

Correlation tests indicated that slope and elevation were highly correlated ($r^2 = 0.80$) as were Habitat-cover and Habitat-forage ($r^2 = 0.70$). As such they were not used together in subsequent models, yielding a suite of 16 models. The results of our resource selection modeling showed that the global model (Table 4-2, Global Model A) that included abiotic (elevation, slope), biotic (vegetation cover types), and anthropogenic (distance to road, trail or recreation site) variables (Table 4-4) provided the best fit to the structure of our dataset. BIC results indicated that no other model fit the data structure as well as this global model (Table 4-4.).

Table 4-4. BIC scores for candidate models used to describe resource selection by female moose on the Kenai Peninsula, Alaska, USA. Lowest BIC score for each seasonal model is in bold.

Model name	BIC scores by season			
	Spring	Summer	Autumn	Winter
Vegetation	188,483	82,569	42,389	1,416,454
Habitat[a]				
Cover	197,115	86,277	43,611	1,552,540
Forage	197,185	86,331	43,657	1,552,111
Topography[a]				
Elevation	199,477	86,564	45,364	1,642,168
Slope	202,095	86,242	44,954	1,624,003
Human activities	168,609	75,248	39,536	1,365,092
Vegetation – Human activities	150,265	68,004	36,279	1,178,881
Habitat – Human activities				
Habitat (cover) + Human activities	159,264	72,156	37,792	1,287,932
Habitat (forage) + Human activities	159,309	72,191	37,832	1,287,767
Topography – Human activities				
Elevation + Human activities	161,032	72,170	39,783	1,350,812
Slope + Human activities	163,734	72,533	39,267	1,345,557
Global model A				
Vegetation + Elevation + Human activities	**145,437**	**65,814**	35,712	1,163,507
Vegetation + Slope + Human activities	149,234	67,225	**35,446**	**1,134,093**
Global model B				
Habitat (cover) + Elevation + Human activities	153,825	69,739	37,985	1,278,659

Table 4-4. BIC scores for candidate models used to describe resource selection by female moose on the Kenai Peninsula, Alaska, USA. Lowest BIC score for each seasonal model is in bold.

	BIC scores by season			
Model name	Spring	Summer	Autumn	Winter
Habitat (cover) + Slope + Human activities	155,260	69,904	37,316	1,267,014
Habitat (forage) + Elevation + Human activities	153,877	69,766	38,030	1,278,516
Habitat(forage) + Slope + Human activities	155,307	69,934	37,361	1,266,858

[a] Cover/forage and elevation/slope were correlated and were not included together in same model.

The anthropogenic variables exerted the greatest influence on moose habitat selection across all seasons (Table 4-5) based on the variable coefficients (ß) and parameter confidence intervals calculated across individual moose. During all seasons, the probability of moose use of an area was positively associated with increasing distance from human activities, whether the activity was a recreation site, road, or trail, with the exception of a slight negative relationship with Distance to Road in autumn.

During the spring, autumn, and winter periods, areas with the highest probability of use were characterized by female moose selection of vegetation types that provided both cover (mixed and evergreen forests) and forage (shrublands, wetlands) that were away from a recreation site, road, or trail. During the summer period, moose resource selection was largely influenced by human activities, with increased probability of use as distance to human activity increased and a greater use of vegetation types that provided cover (mixed and evergreen forests). We used the model parameters (Table 4-5) to construct population level seasonal RSFs that were extrapolated to the entire Kenai Peninsula (Figures 4-2a-d). We scaled the model results from 0.00 to 1.00 to show the relative probability of use as an index of habitat quality.

Table 4-5. Parameter estimates, standard error (SE), 90% lower (CILL) and upper (CIUL) confidence intervals for variables included in seasonal population-level models with the most support that were used to assess resource use by female moose on the Kenai Peninsula, Alaska, USA.

	Season									
	Spring					Summer				
Parameter	Estimate	SE	CILL	CIUL	P value	Estimate	SE	CILL	CIUL	P value
(Intercept)	-1663.91	331.12	-2217.55	-1110.27	0.00	-2189.50	357.65	-2787.86	-1591.13	0.00
Deciduous forest	10.94	1.35	8.69	13.19	0.00	-91.43	68.39	-205.86	22.99	0.19
Mixed forest	12.12	1.46	9.68	14.56	0.00	7.24	1.55	4.65	9.83	0.00
Evergreen forest	11.11	1.75	8.19	14.03	0.00	7.86	2.12	4.32	11.40	0.00
Shrubland	5.68	2.08	2.20	9.17	0.01	-44.85	50.46	-129.28	39.57	0.38
Wetland	12.35	1.45	9.91	14.78	0.00	-30.06	40.24	-97.38	37.27	0.46
Water/barren	-140.48	71.95	-260.78	-20.17	0.06	-541.49	128.68	-756.78	-326.20	0.00
Elevation	-0.02	0.01	-0.03	-0.01	0.00	--	--	--	--	--
Slope	--	--	--	--	--	-0.35	0.08	-0.48	-0.22	0.00
Distance to recreation site	215.76	63.01	110.41	321.12	0.00	371.97	76.49	244.00	499.93	0.00
Distance to road	168.52	52.37	80.96	256.09	0.00	206.30	57.52	110.06	302.53	0.00
Distance to trail	162.77	53.98	72.51	253.04	0.00	143.33	47.87	63.23	223.43	0.00

Table 4-5. Parameter estimates, standard error (SE), 90% lower (CILL) and upper (CIUL) confidence intervals for variables included in seasonal population-level models with the most support that were used to assess resource use by female moose on the Kenai Peninsula, Alaska, USA.

	Season									
	Autumn					Winter				
Parameter	Estimate	SE	CILL	CIUL	P value	Estimate	SE	CILL	CIUL	P value
(Intercept)	-2927.61	518.29	-3806.38	-2048.83	0.00	-146.32	-85.25	288.85	-30.79	0.09
Deciduous forest	-55.44	80.34	-191.66	80.77	0.50	12.64	1.45	10.22	15.68	0.00
Mixed forest	23.76	3.69	17.50	30.01	0.00	11.27	1.27	9.15	13.39	0.00
Evergreen forest	-76.15	102.58	-250.07	97.77	0.46	12.33	1.21	10.31	14.34	0.00
Shrubland	29.31	3.10	24.06	34.56	0.00	14.91	1.57	12.29	17.53	0.00
Wetland	-149.46	122.75	-357.58	58.66	0.23	12.08	1.16	10.13	14.23	0.00
Water/barren	-1770.69	156.51	-2036.05	-1505.33	0.00	-0.98	2.55	-5.25	3.28	0.71
Elevation	--	--	--	--	--	--	--	--	--	--
Slope	-0.22	0.07	-0.34	-0.09	0.01	-0.13	0.01	-0.15	-0.11	0.00
Distance to recreation site	345.26	99.33	176.83	513.68	0.00	20.74	20.66	-13.81	55.29	0.32
Distance to road	-0.22	0.11	-0.40	-0.04	0.05	19.87	19.97	-13.51	53.26	0.32
Distance to trail	619.17	98.81	451.63	786.70	0.00	0.69	0.12	0.50	0.88	0.00

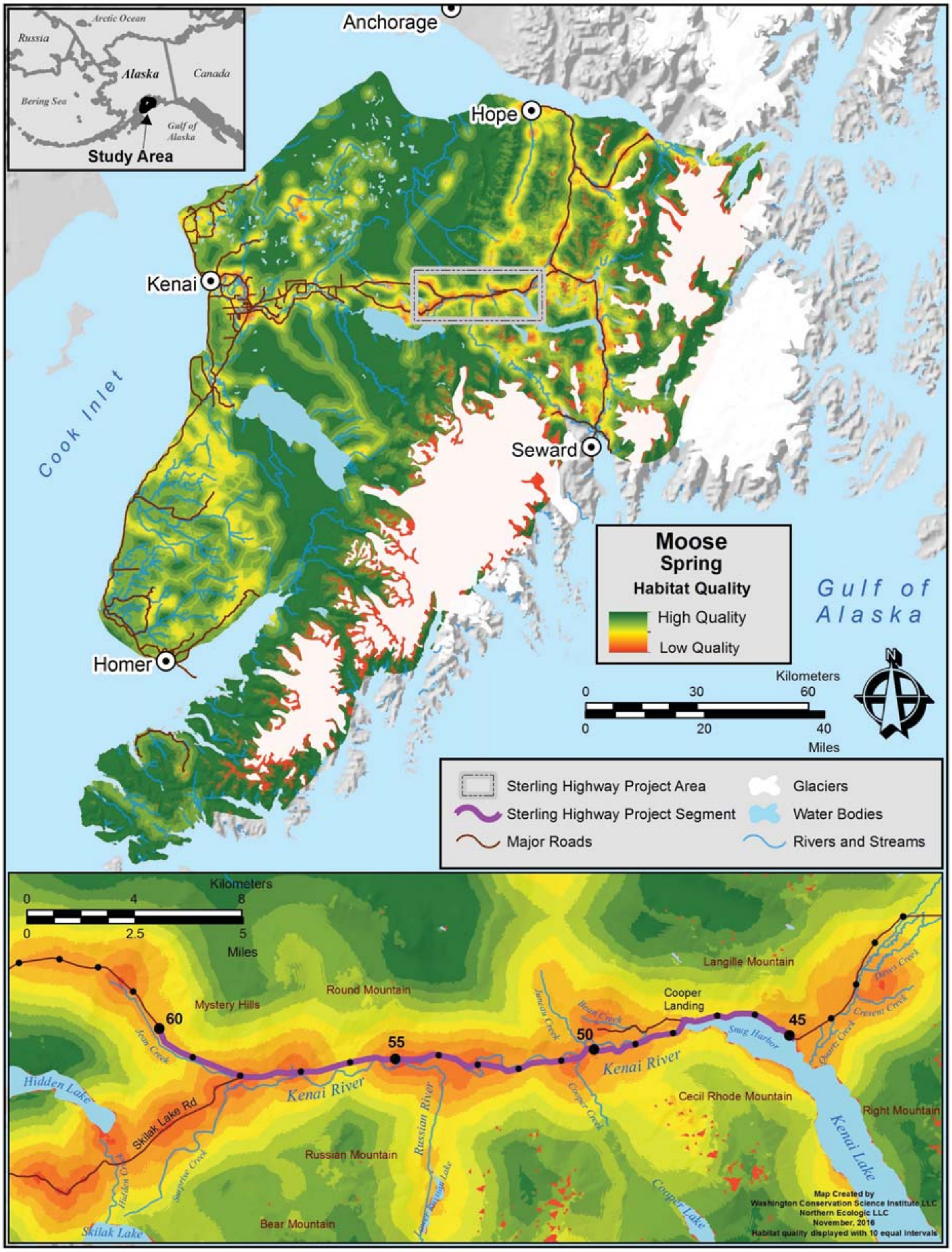

Figure. 4-2a. Habitat quality for female moose in the spring on the Kenai Peninsula, Alaska, USA.

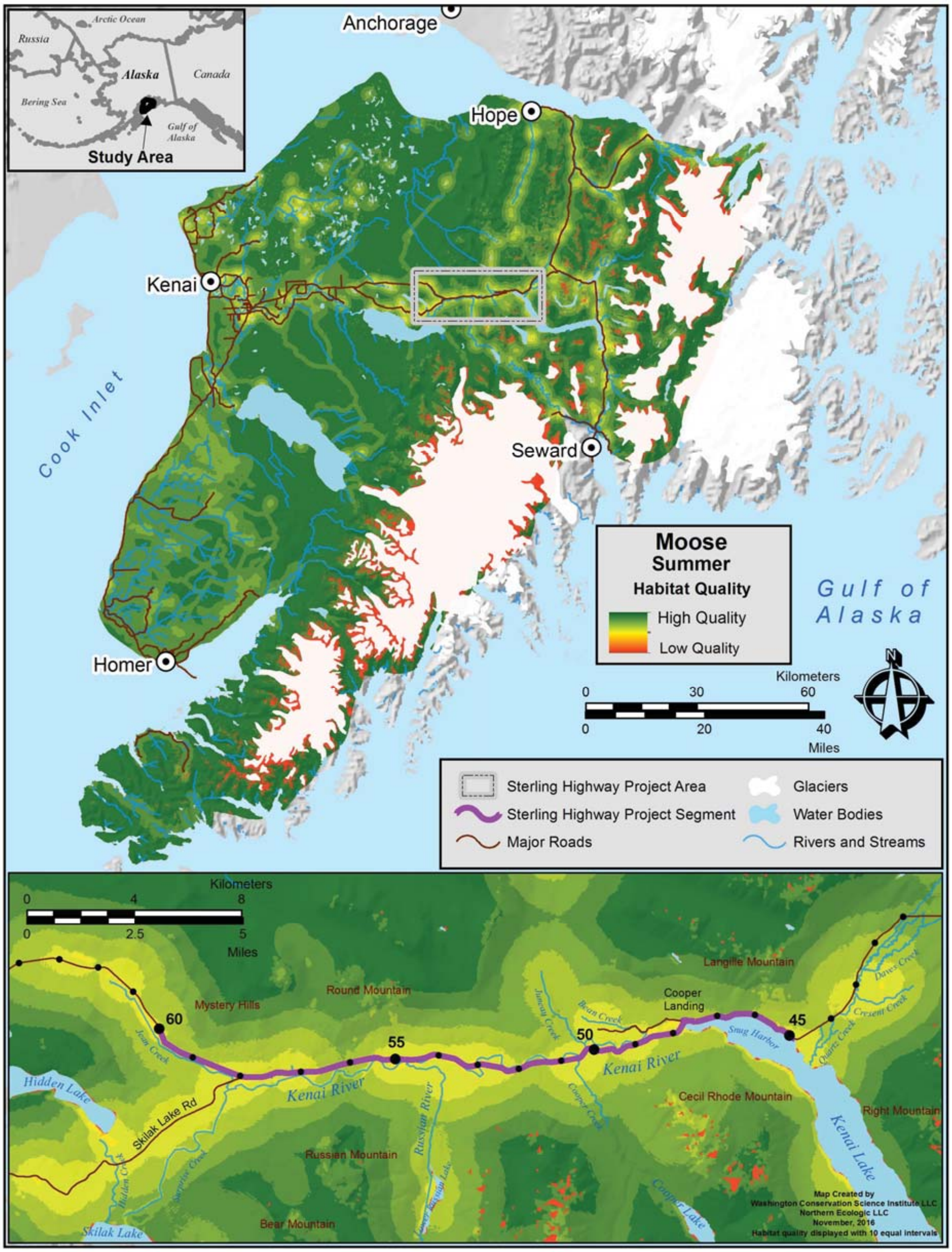

Figure 4-2b. Habitat quality for female moose in the summer on the Kenai Peninsula, Alaska, USA.

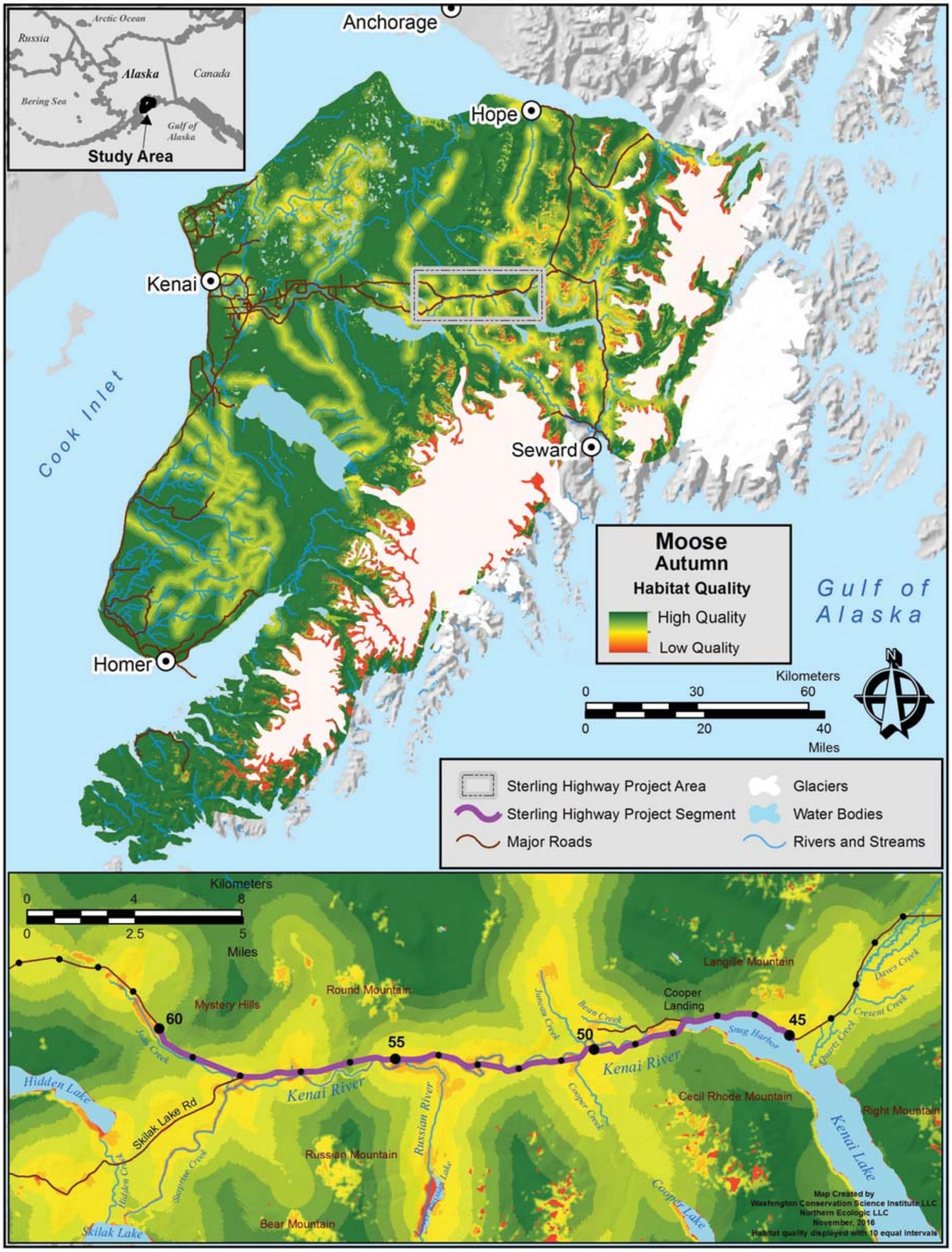

Figure 4-2c. Habitat quality for female moose in autumn on the Kenai Peninsula, Alaska, USA.

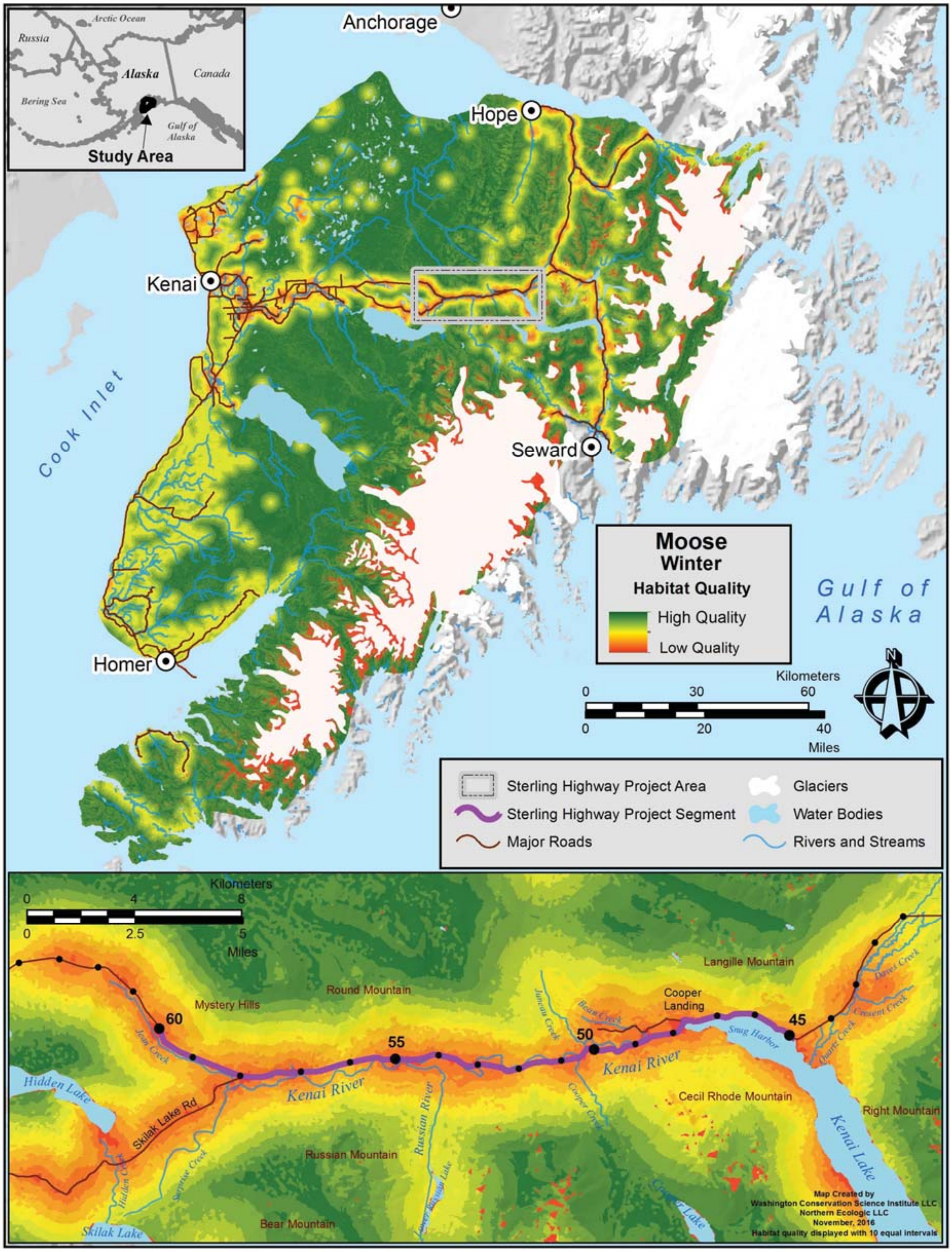

Figure 4-2d. Habitat quality for female moose in the winter on the Kenai Peninsula, Alaska, USA.

Our evaluation of the seasonal moose population-level models showed high rho **(r_s)** values, suggesting that all 4 models effectively predicted the distribution of a reserved (*test*) set of moose locations (Table 4-6). Based on these results, we assumed that we had a robust set of seasonal RSF models for describing probability of use by female moose across the landscape of the Kenai Peninsula.

Table 4-6. Results of evaluation of the seasonal moose population Resource Selection Function models, Kenai Peninsula, Alaska, USA.

Season	Spearman rank correlation (rho, r_s)	P-value
Spring	0.9151	0.0004
Summer	0.8441	0.0043
Autumn	0.8773	0.0020
Winter	0.8875	0.0015

Discussion

As in other studies of habitat selection of moose, our results suggested a combination of vegetative characteristics and human activities affect moose habitat selection. Several studies have shown moose habitat selection to be largely associated with vegetation types that provide either food resources or cover, and that use of these resources varies across seasons and by sex (Oehlers et al. 2011). Availability and selection can also be influenced by other external elements. The availability of food and cover resources, and their spatial arrangement can be greatly influenced by fire, especially in boreal forest ecosystems (Loranger et al. 1991, Maier et al. 2005, Weixelman et al. 1998), and by forest management (Bjorneraas et al. 2011, Courtois et al. 2002, McLaren et al. 2000). Moose habitat selection can also be influenced by predator avoidance (Dussault et al. 2005a, Kunkel and Pletscher 2000). For example, moose may select their home ranges to avoid wolves (Dussault et al. 2005a) but within home range habitat selection may be more influenced by the availability of vegetation types that provide food resources and cover (Dussault et al. 2005a,b; Leptich and Gilbert 1989).

Laurian et al. (2012) found that resource selection by female moose was positively associated with vegetation types with high food availability during all seasons except spring. During spring and autumn, areas providing cover (coniferous forest) on the Kenai Peninsula were used either greater than or in proportion to availability. Shanley and Pyare (2011) found that female moose habitat selection was associated with willow (forage), edge (cover and forage), and streams during the summer and fall seasons at a variety of spatial scales. Our winter

RSF model results indicated that moose habitat selection was positively associated with deciduous forest, shrublands, and wetlands. Similarly, female moose habitat selection in Wyoming (Becker et al. 2011) and Labrador (Jung et al. 2009) during the winter was associated with a high proportion of riparian areas and hardwood forests.

Human activities that occur on roads and recreation routes play an important role in determining resource selection by moose across a variety of study locations throughout their distribution (Beyer et al. 2013, Laurian et al. 2008, McLoughlin et al. 2011), including areas in Alaska (Harris et al. 2013, Shanley and Pyare 2011, Yost and Wright 2001). In addition, human activity levels associated with housing developments resulted in moose avoidance of these areas (Lykka et al. 2009, however see Schneider and Wasel 2000). We found human activity variables to be key factors in moose resource selection across all seasons, but were especially influential during the summer season when human activities in moose habitat would likely be the most intense and extensive.

Management Implications

The impacts of human activities, in combination with specific vegetation types, influenced moose resource selection on the Kenai Peninsula. These results are similar to other studies from a broad array of geographic areas (Loranger et al. 1991, Maier et al. 2005, Oehlers et al. 2011, Weixelman et al. 1998). Moose resource selection can be especially influenced by the availability of deciduous forest, shrublands, and wetlands during the winter (Becker et al. 2011, Jung et al. 2009, Shanley and Pyare 2011), while recreational activities exerted a strong influence during the summer. Harris et al. (2013) suggested that the extent of the area influenced by recreation had a greater influence on moose resource selection than the intensity of recreation. This suggests that managers will need to balance the amount of area designated for human recreation and development with the need to provide habitats free of human disturbance in order to maintain populations of moose.

Previous studies have identified the need to reduce moose-vehicle collisions along the Sterling Highway to improve human safety and reduce moose mortalities (Ernest et al. 2009, McDonough 2010). Efforts to delineate movement corridors for moose will need to include variables that incorporate the role that human activities play in determining moose habitat use and movement ecology. For example, roads can have a variety of effects on the movement of large ungulates such as moose. These effects include displacement from important habitats or mortality as a result of moose-vehicle collisions (Bangs et al. 1989, Ernst et al. 2009, Laurian et al. 2008). The behavioral influences that human activities, including those associated with roads, exert on moose habitat selection provide strong inference that human activities increase the resistance to moose movement across landscapes.

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Appendix – Moose

Table 4-A1. Variables used in previous studies of moose to evaluate resource selection (RSF), moose-highway crossing (MHC) sites, or moose-vehicle collision (MVC) sites.

Variable	Description	References	Study type
Vegetation			
Riparian-deciduous shrub		Becker et al. 2011	RSF
Mixed conifer		Becker et al. 2011	RSF
Aspen		Becker et al. 2011	RSF
Habitat diversity		Becker et al. 2011	RSF
Conifer/forest cover		Becker et al. 2011, Seiler 2005	RSF, MVC
Regenerating forest	<30 years post-disturbance	Danks and Porter 2010	MVC
Closed canopy forest, dense coniferous shelter		Danks and Porter 2010, Dussault et al. 2007	MVC, MHC
Food density	Density of deciduous stems 50-300 cm above ground	Dussault et al. 2006	MHC
Habitat interspersion	Food and cover	Dussault et al. 2006	MHC
Forest edge		Seiler 2005	MVC
Landcover type		Hurley et al. 2009	MVC
Physical			
Brackish pool		Dussault et al. 2005, Dussault et al. 2007	MVC, MHC

Table 4-A1. Variables used in previous studies of moose to evaluate resource selection (RSF), moose-highway crossing (MHC) sites, or moose-vehicle collision (MVC) sites.

Variable	Description	References	Study type
Wetland, Water, River, Stream	Distance to variable	Hurley et al. 2007, Hurley et al. 2009, Leblanc and Montel 2005	MVC, MVC, MVC
Snow depth		Rolandsen et al. 2011	MVC
Winter temperature		Rolandsen et al. 2011	MVC
Moose habitat			
Winter range		Ernest et al. 2009	MHC
Moose habitat	None, low, moderate, high based on Parks Canada ecological classification	Hurley et al. 2009	MVC
Moose habitat	Food, shelter, food-shelter, other	Laurian et al. 2012	RSF
Forage habitat quality		Leblanc and Montel 2005	MVC
Moose Demographics			
Density/abundance	Related to habitat quality	Joyce and Mahoney 2001, Rolandsen et al. 2011, Seiler 2005	MVC, MVC, MVC
Male vs. female	RSFs for each sex	Laurian et al. 2012	RSF

Table 4-A1. Variables used in previous studies of moose to evaluate resource selection (RSF), moose-highway crossing (MHC) sites, or moose-vehicle collision (MVC) sites.

Variable	Description	References	Study type
Topography			
Elevation or Altitude		Becker et al. 2011, Laurian et al. 2012	RSF, RSF
Slope or slope complexity		Becker et al. 2011, Hurley et al. 2007, Laurian et al. 2012, Leblanc and Montel 2005	RSF, MVC, RSF, MVC
Valley in proximity to road		Dussault et al. 2005, Dussault et al. 2007	MVC, MHC
Human activities			
Prescribed burns		Ernest et al. 2009	MHC
Salt ponds		Grossman et al. 2009, Laurian et al. 2008	MVC, RSF
Highway	Distance to variable	Laurian et al. 2012	RSF
Forest road/rural road	Distance to variable	Laurian et al. 2012, Shanley and Pyare 2011, Yost and Wright 2001	RSF, RSF, RSF
Steep road-cut banks	>3 meter high	Leblanc and Montel 2005	MVC
Traffic volume/speed		Rolandsen et al. 2011, Seiler 2005	MVC, MVC
Occurrence of fences		Seiler 2005	MVC

Table 4-A1. Variables used in previous studies of moose to evaluate resource selection (RSF), moose-highway crossing (MHC) sites, or moose-vehicle collision (MVC) sites.

Variable	Description	References	Study type
OHVs/snowmobiles		Shanley and Pyare 2011, Harris et al. 2013	RSF, RSF
X-C skiing /snowshoeing		Harris et al. 2013	RSF
Temporal			
Night vs diurnal	Higher MVCs at night	Joyce and Mahoney 2001	MVC
Month	June during calving and December - February	Joyce and Mahoney 2001, Beyer et al. 2013	MVC, RSF
Season	In some studies RSF higher in winter	Beyer et al. 2013, Laurian et al. 2012	RSF, RSF

Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 5 – Movement Patterns and Potential Habitat Linkages for Moose on the Kenai Peninsula, Alaska, USA

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Introduction

The largest impacts on the moose population on the Kenai Peninsula are considered to be declining habitat quality, predation, and mortality caused by moose vehicle collisions (MVCs) (Selinger 2010). Over the last 30 years, the human population on the Kenai Peninsula has doubled and the traffic volume on the Sterling Highway has quadrupled (Morton 2012). An average of nearly 250 moose are killed by collisions with vehicles on the Kenai Peninsula each year, and up to 90% of the moose killed by MVCs are cows (38%) and calves (55%) (Ernst et al. 2009, Morton 2012). Bangs et al. (1989) reported that MVCs were the largest source of mortality for mature female moose on the Kenai National Wildlife Refuge. Mortality of mature female moose from MVCs is likely to be additive (Gasaway et al. 1983, Bangs et al. 1989, Loranger 1991). The spatial and temporal distributions of MVCs are not random (e.g., Seiler 2005; Dussault et al. 2006, 2007). Primary factors in MVCs on the Kenai Peninsula were increasing traffic volume and increasing traffic speeds on the Sterling Highway (Del Frate and Spraker 1991). Traffic-related covariates that best predicted MVCs in Maine included traffic volume and speed limit (Danks and Porter 2010). For each additional 500 vehicles/day, odds of a location with a MVC increased by 57%. For each 8-km/hr increase in speed limit, odds of a MVC increased by 35%. Evaluation of MVC risk relative to environmental characteristics can help managers plan road alignments and help determine the need and location of mitigation measures to maintain movement patterns of moose and to reduce MVCs (Finder et al. 1999, Malo et al. 2004, Hurley et al. 2007).

Monitoring has shown that mitigations such as crossing structures (under and over passes), fencing, and lighting can be used to successfully reduce MVC's involving moose and provide safe crossing opportunities, but must be carefully designed and placed so as not to negatively impact moose movements and potential gene flow (McDonald 1991, Dussault et al. 2007, Olsson and Widen 2008, Laurian et al. 2012, Wilson et al. 2015). Our objectives were to identify potential locations along the Sterling Highway important for moose crossings, using moose resource selection functions (RSFs) (Chapter 4; Gaines et al. 2017) to inform the development of habitat connectivity models. This analysis serves as a basis for determining potential locations along the Sterling Highway Milepost (MP) 45–60 on the Kenai Peninsula suitable for mitigations that might reduce MVCs and promote genetic continuity.

Habitat Connectivity Modeling

We used existing tools to develop models of habitat connectivity. This approach involved the following steps:1) development of a resistance surface, 2) identification of core areas of high quality habitat, 3) identification of potential habitat linkages between core areas across the Sterling Highway. We completed steps 1 and 2 using RSF maps for each of 4 seasons (Chapter 4; Gaines et al. 2017). We aggregated the results of the linkage assessments across all seasons to identify a complete, year-round set of potential linkages for moose.

Resistance Surface

We used the tools in CoreMapper (Shirk and McRae 2013) and the results of RSF modeling (Gaines et al. 2017) to develop resistance surfaces for each of 4 seasons: spring (1 May-15 June), summer (16 June-31 July), autumn (1 August-31 October), and winter (1 November-30 April). In general we followed the process outlined in Beier et al. (2007) to develop resistances surfaces from our seasonal RSFs. The following considerations were used to develop the resistance surface from the RSFs:

- Variable combinations that resulted in high RSFs by moose were assigned low resistance values.
- Conversely, variable combinations that resulted in low RSFs by moose were assigned higher resistance values.
- Human features on the landscape (e.g., highways, housing development) that resulted in negative correlations with habitat quality for moose and had high variable weights (high correlations) were assigned the highest resistance values.

Core Areas

We mapped core areas to identify relatively large patches of high quality habitat and to identify areas between which we evaluated patterns of habitat connectivity. Core areas are significant habitat areas that are expected or known to be important for moose based on the RSF models for each season. We used CoreMapper (Shirk and McRae 2013) and the RSF models to identify core areas for each season using a 200-m moving window radius. The minimum average habitat value (based on all pixels within the moving window) ranged from 89.9-97.2 within the window for a pixel to be assigned as core area, depending on the season. The minimum habitat value for any individual pixel to be assigned as core area ranged from 76.0 to 87.0, depending on the season. We used a minimum core area size of 10 km^2 (based on process described in WHCWG

2010). This resulted in a map of relatively large concentrations of high quality habitat, or core areas, that we used to model connectivity.

Potential Habitat Linkages

We identified potential habitat linkages or movement paths using the resistance surfaces and core areas described above. Cost-weighted distance approaches to estimate movement paths of animals represent the least accumulative cost required to move between a specified source and a specified destination (Beier et al. 2007). The cost accumulated by moving through each intermediate cell is equal to the cell‘s resistance value multiplied by the cell size (30-m in the case of this study). The central concept in these analyses is that the cost distance from a source to a cell increases as the resistance of the intervening landscape (measured along the most efficient path from the source to the target cell) increases. While the shortest-path, or least-cost, methods have been used to develop empirical models of habitat connectivity (Schwartz et al. 2009, Richard and Armstrong 2010), predictions from current flow-based models (e.g., circuit theory) have been highly correlated with observed genetic distance in several plant and animal populations and may better reflect actual animal movement ecology (McRae et al. 2008, Lee-Yaw et al. 2009, Shirk et al. 2010).

Circuit theory assumes a random walk dispersal behavior (least-cost assumes an animal has perfect knowledge of landscape resistance), simultaneously integrates the contribution of all possible pathways to gene flow, and attributes greater resistance to narrow corridors than wide corridors (McRae 2006). This may explain why landscape distances derived from circuit theory have been more strongly correlated with genetic distance in both simulated and real landscapes than least-cost (McRae 2006, McRae and Beier 2007).

To identify potential movement corridors, we used a combination of least-cost modeling and circuit theory using the Linkage Mapper Toolkit (McRae and Kavanagh 2011) in ArcGIS 10.3. We then applied circuit theory through the program Circuitscape (McRae and Shah 2009) using the Pinchpoint Mapper module (McRae 2012). Once potential linkages were mapped using Linkage Mapper, Pinchpoint Mapper ran Circuitscape (McRae and Shah 2009) within the resulting corridors. This produced current maps that identified and mapped pinch points (i.e., constrictions, bottlenecks, choke points) in the linkage network. It also provided effective resistance values for each linkage, a measure of connectivity that complements least-cost distances.

Results

Core Areas

The number of core areas varied by season from 24 in spring to 46 in autumn. Across all seasons they were widely distributed across the Peninsula (Table 5-1, Figures 5-1–5-4). The core areas varied in size from 10.1 to 1,710.9 km^2. The average sizes of the core areas ranged from 72.8 to 186.3 km^2. There were fewer (24) but larger ($\overline{x}$=186.3 km^2) core areas in spring. Conversely, there were more (46) and smaller ($\overline{x}$=72.8 km^2) core areas in autumn.

Table 5-1. A summary of the moose core areas by season used in the connectivity assessment for the Kenai Peninsula, Sterling Highway Project.

Season	Number of core areas	Total area in core (km^2)	Mean core area size (km^2)	Range of core area sizes (km^2)
Spring	24	4,472.2	186.3	11.7-1,604.5
Summer	29	3,947.7	136.1	10.2-1,224.1
Autumn	46	3,349.0	72.8	10.2-513.6
Winter	25	4,433.0	177.3	10.1-1,710.9

Potential Habitat Linkages

Based on our analysis, we identified 5 primary north-south habitat linkages across the Sterling highway for moose based on an aggregation of all 4 seasonal linkage models (Figures 5-5–5-8). Several habitat linkages were identified across multiple seasons despite differences in resistance surfaces, however the degree that the linkages were constrained (based on the pinch-point analyses) varied by season (Figures 5-9–5-12). In general, linkages were most highly constrained during autumn (Figure 5-11) and least constrained during spring (Figure 5-9).

Linkage at MP 48-49

Starting at the eastern end of our study area, there was a linkage near MP 48-49 west of Kenai Lake near Cooper Landing (Figures 5-6, 5-7). This linkage was most constrained during the autumn (Figure 5-11). There was a considerable amount of human development in this area.

Linkage at MP 52-53

There was a linkage near MP 52-53 that occurred in spring, summer, and winter seasonal assessments (Figures 5-5, 5-6, 5-8), but not in the autumn linkages (Figures 5-7, 5-11). This linkage occurred west of the confluence of Cooper Creek and the Kenai River and east of the

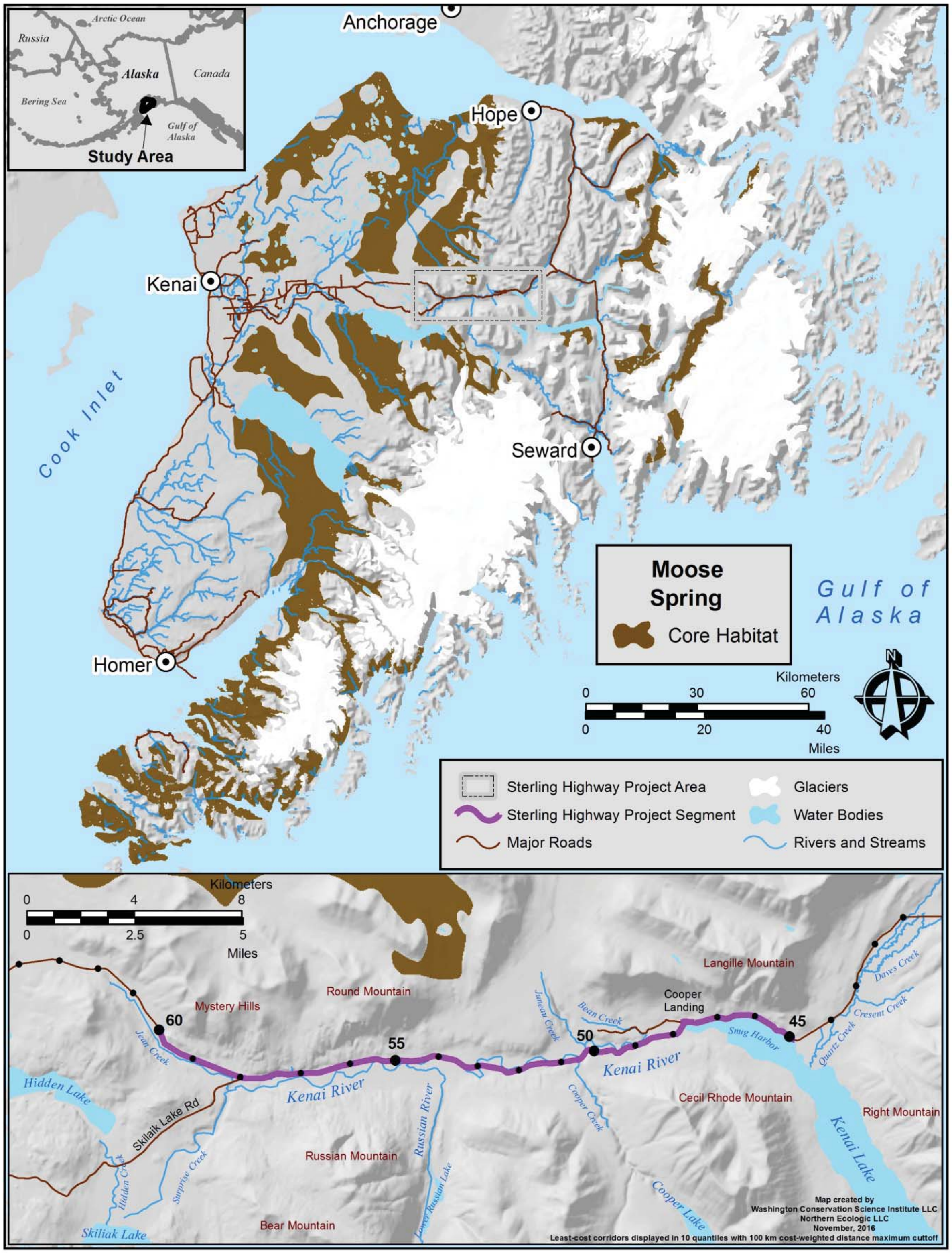


Figure 5-1. Core areas for female moose during spring on the Kenai Peninsula, Alaska, USA

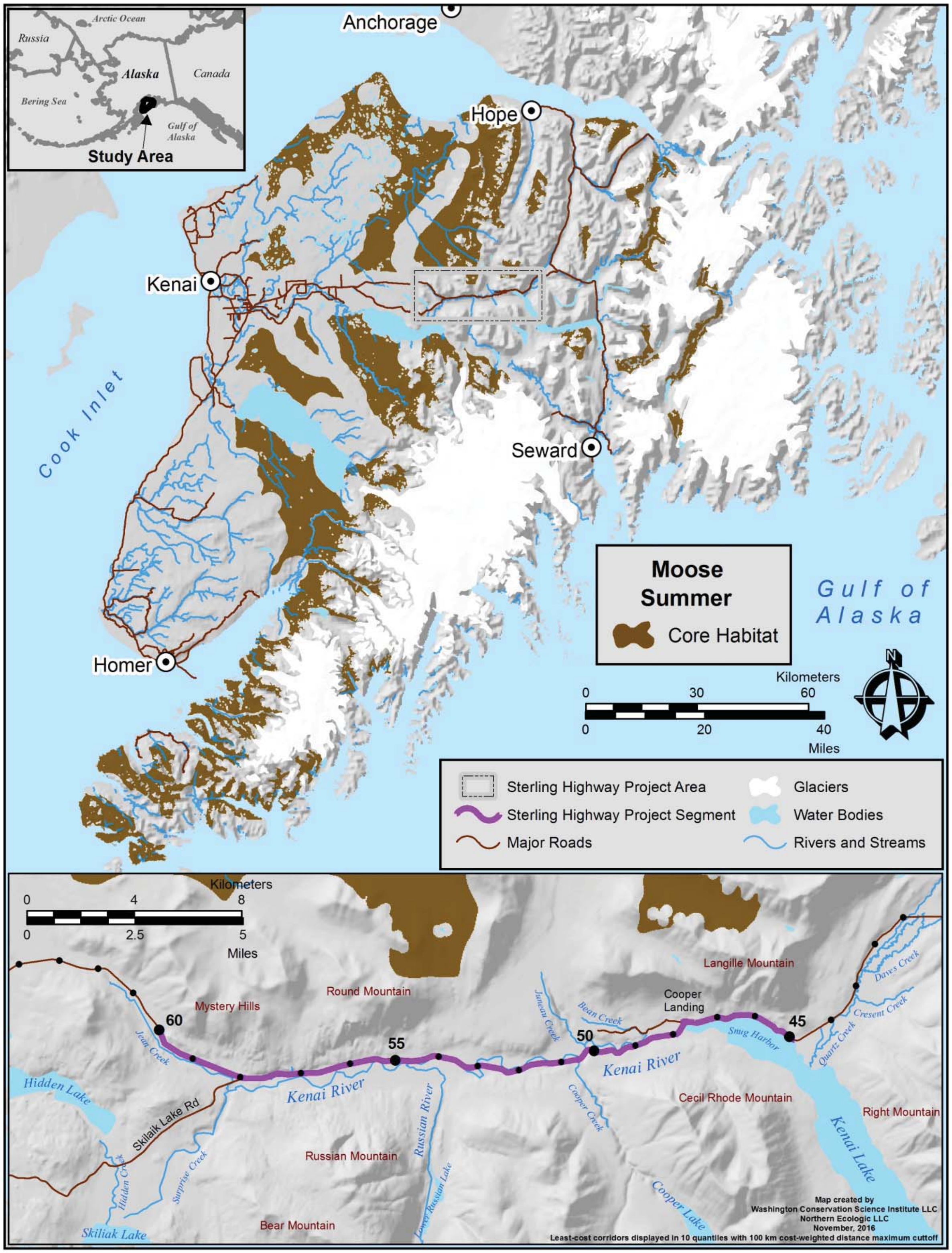


Figure 5-2. Core areas for female moose during summer on the Kenai Peninsula, Alaska, USA

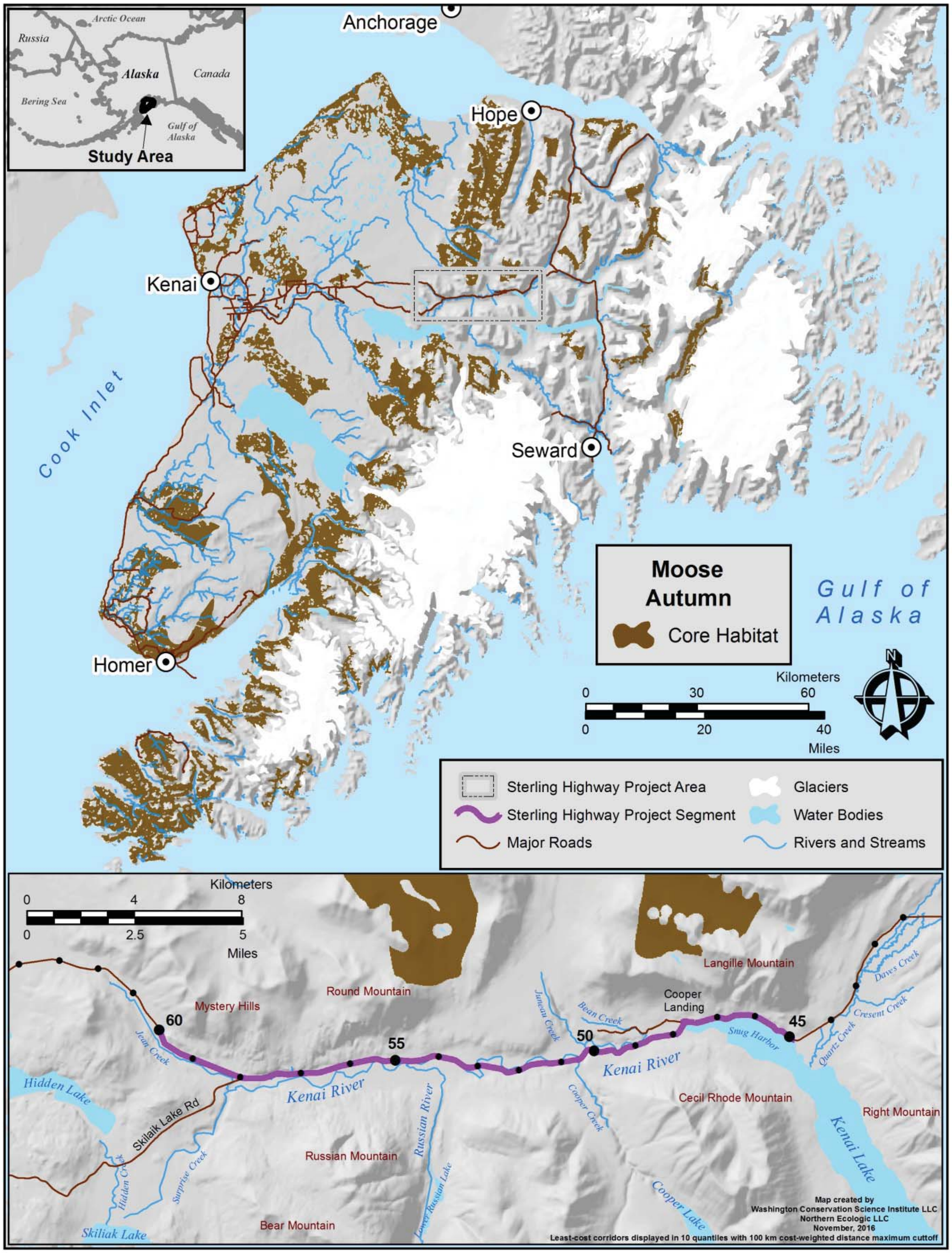


Figure 5-3. Core areas for female moose during autumn on the Kenai Peninsula, Alaska, USA

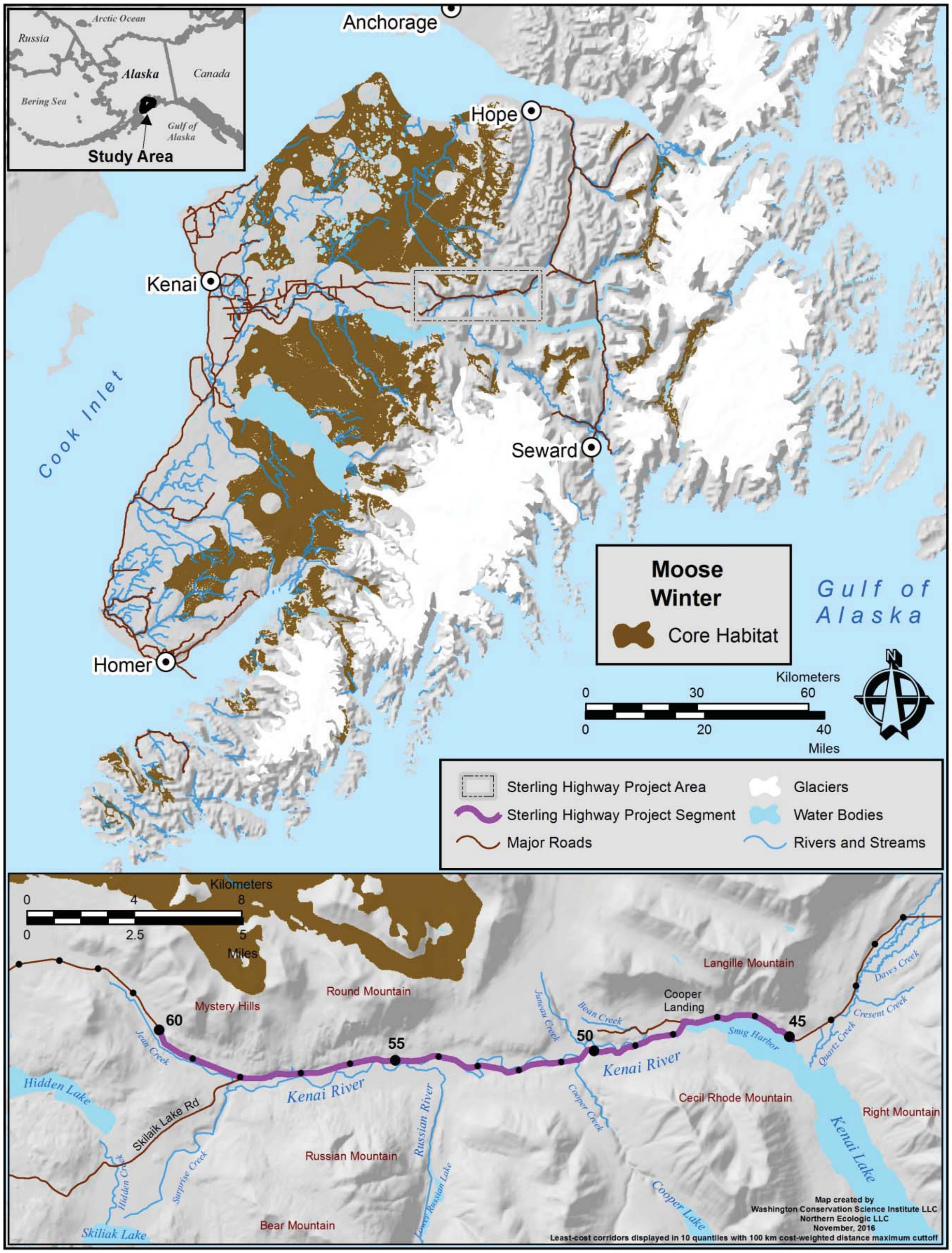
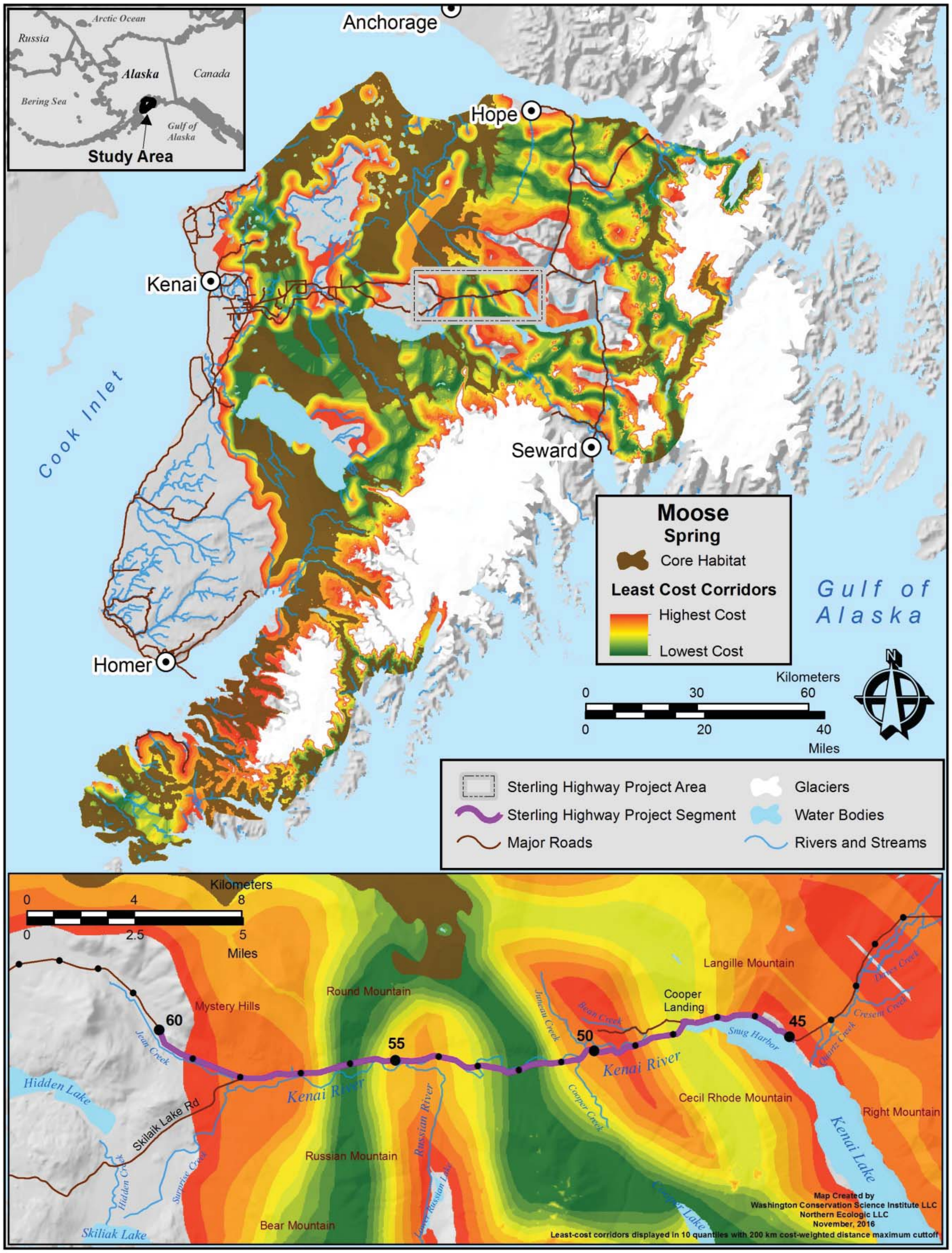


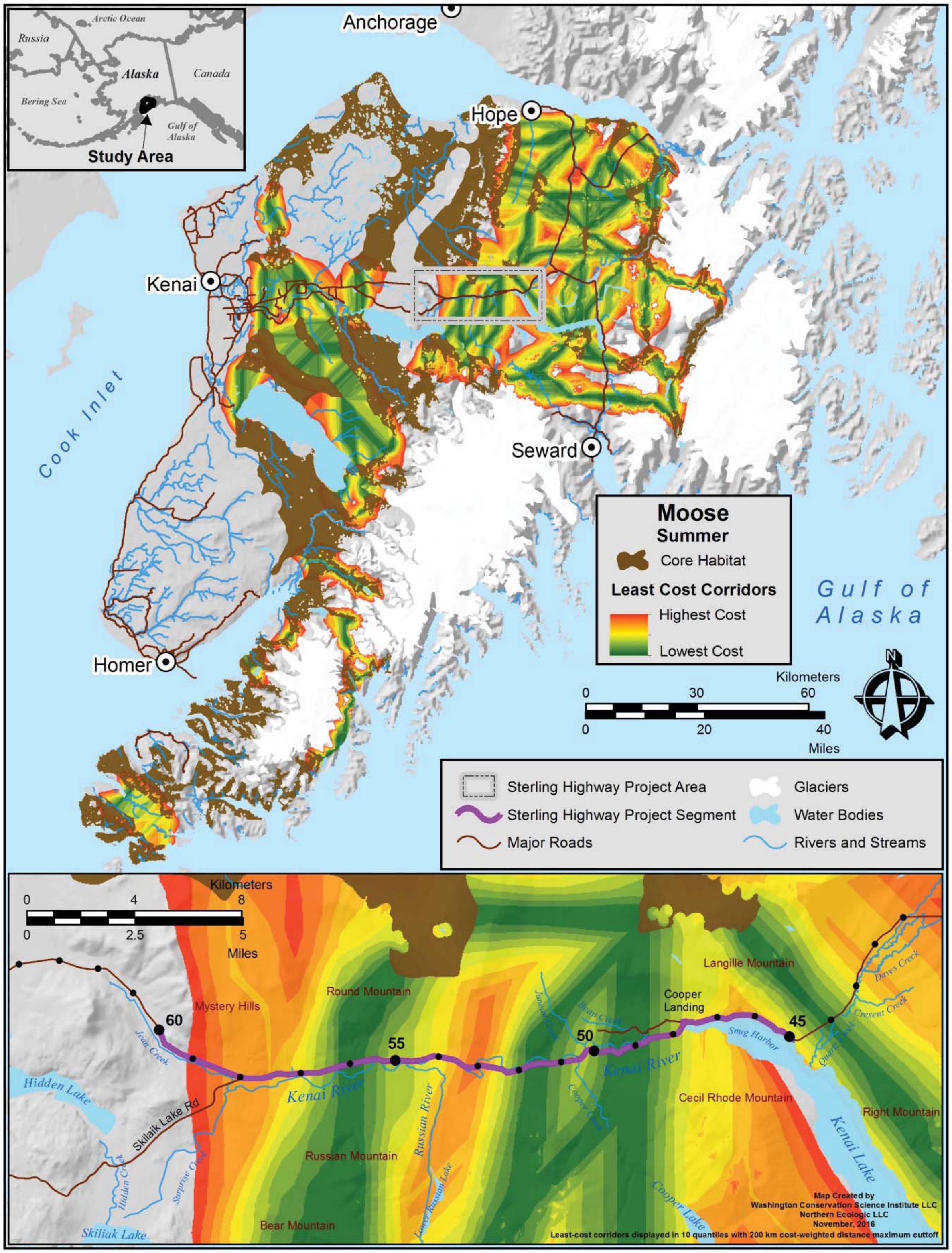
Figure 5-4. Core areas for female moose during winter on the Kenai Peninsula, Alaska, USA



Map Created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016

Least-cost corridors displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 5-5. Least-cost corridors for movement of female moose in the spring on the Kenai Peninsula, Alaska, USA.



Map Created by
Washington Conservation Science Institute LLC
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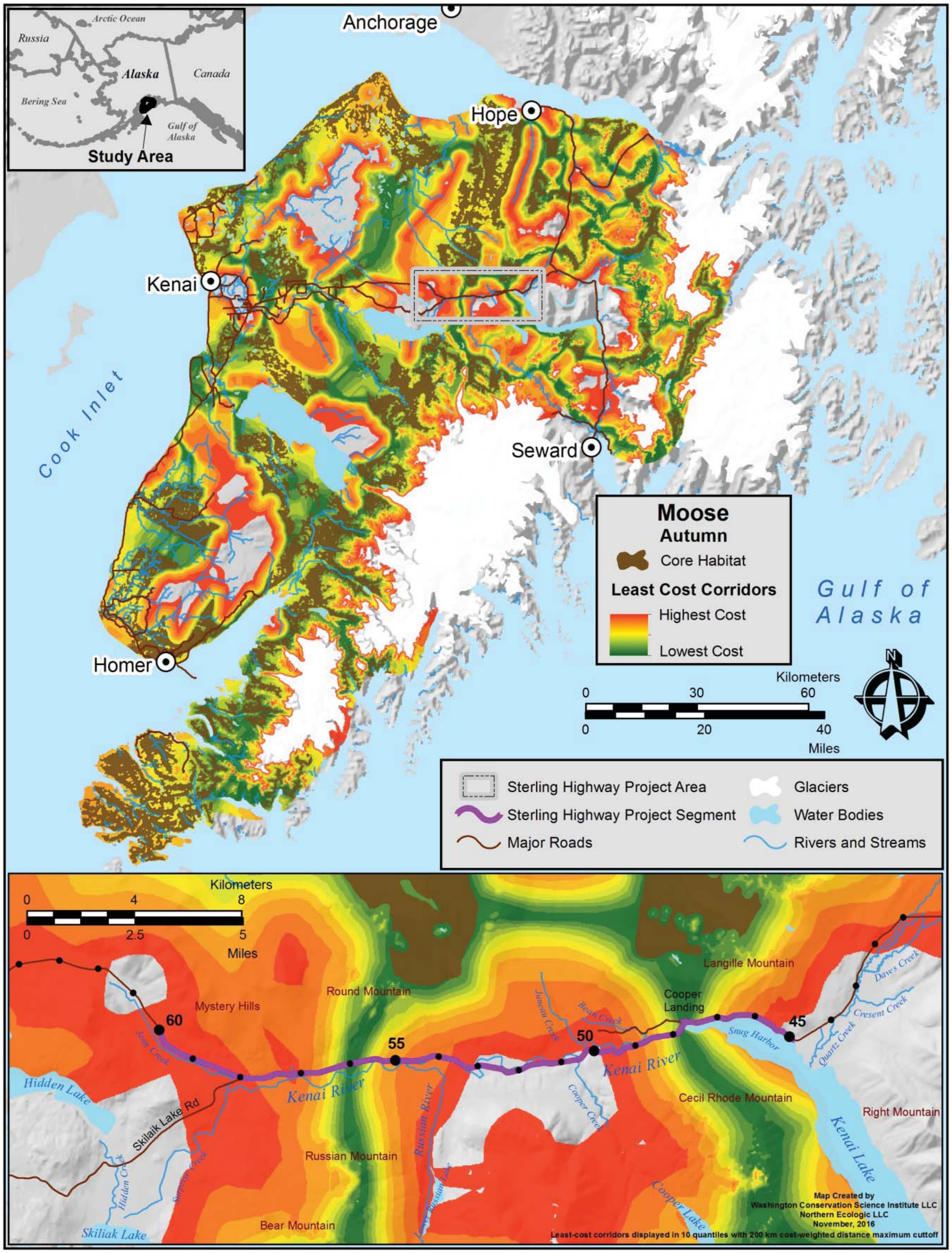
November, 2016

Least-cost corridors displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 5-6. Least-cost corridors for movement of female moose in the summer on the Kenai Peninsula, Alaska, USA.



Map Created by
Washington Conservation Science Institute LLC
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November, 2016

Least-cost corridors displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 5-7. Least-cost corridors for movement of female moose in the autumn on the Kenai Peninsula, Alaska, USA.

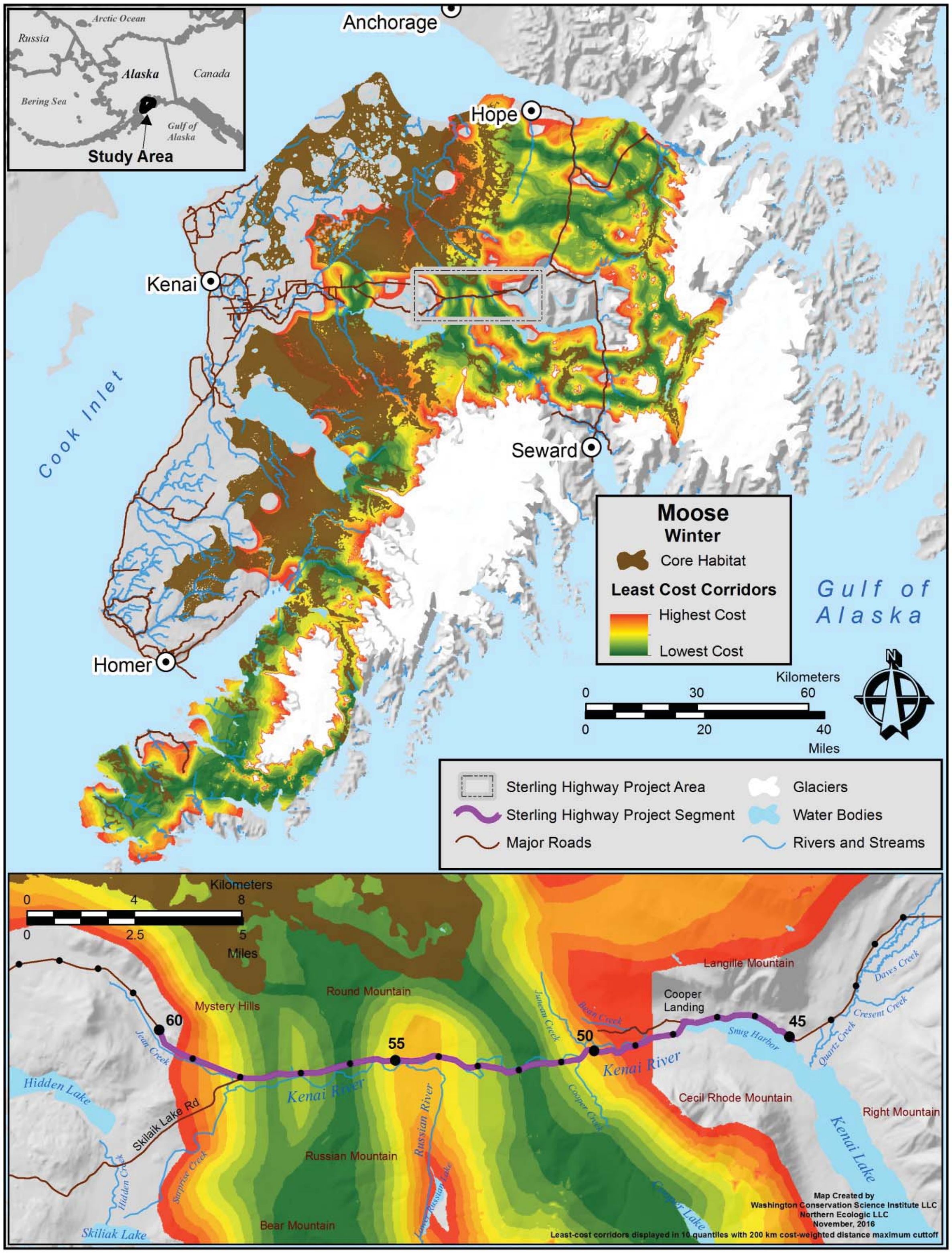

Figure 5-8. Least-cost corridors for movement of female moose in the winter on the Kenai Peninsula, Alaska, USA.

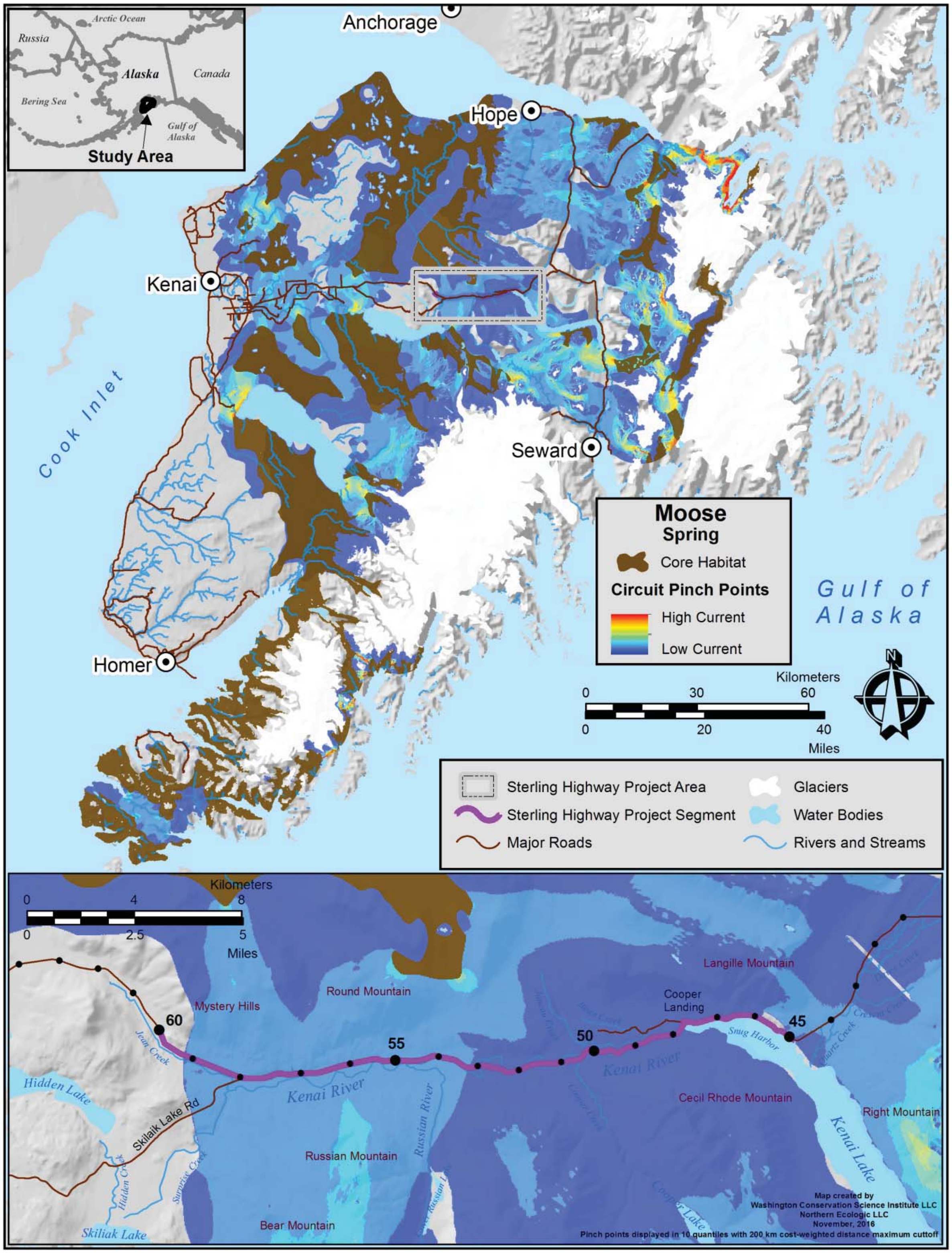

Figure 5-9. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female moose during spring.

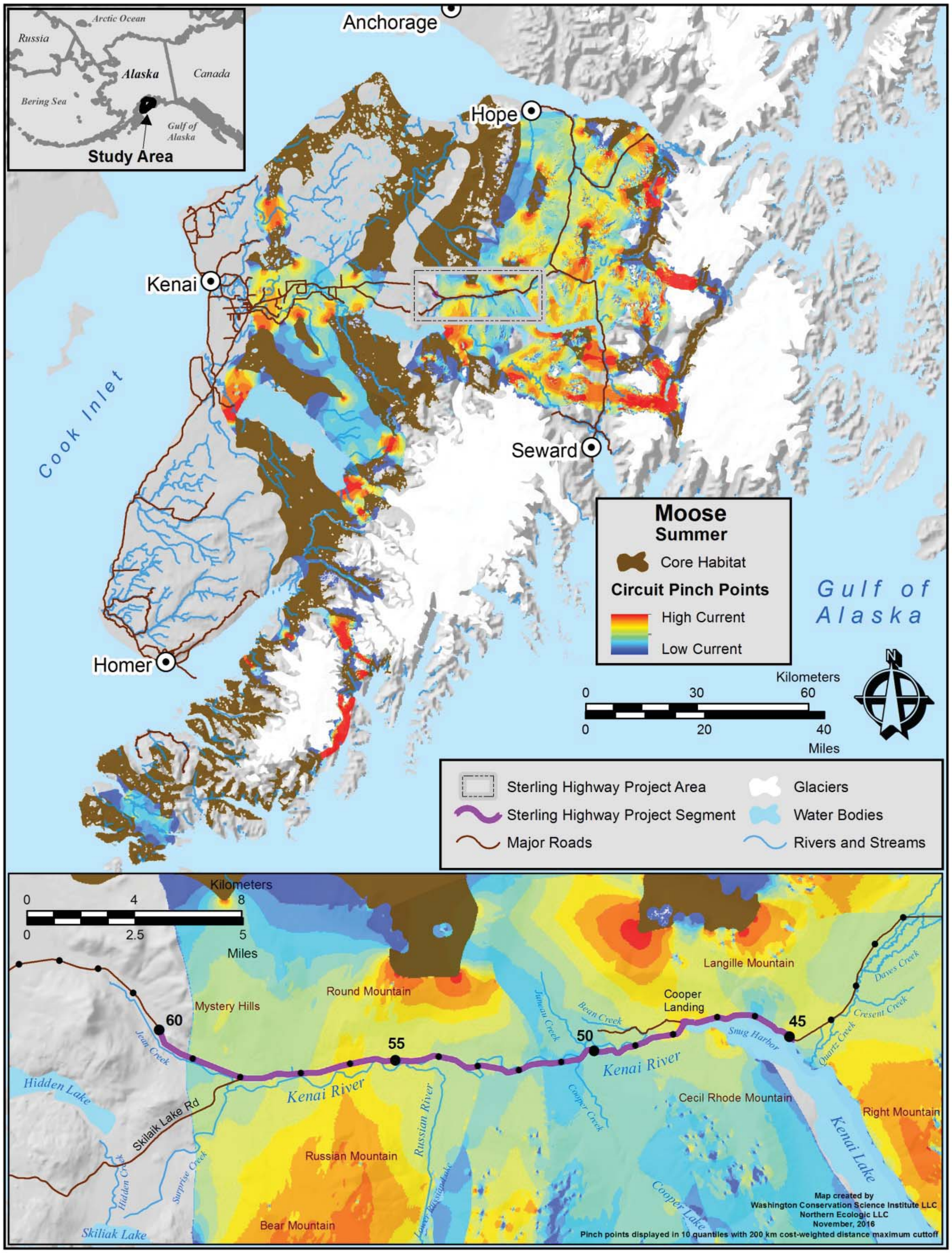

Figure 5-10. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female moose during summer.

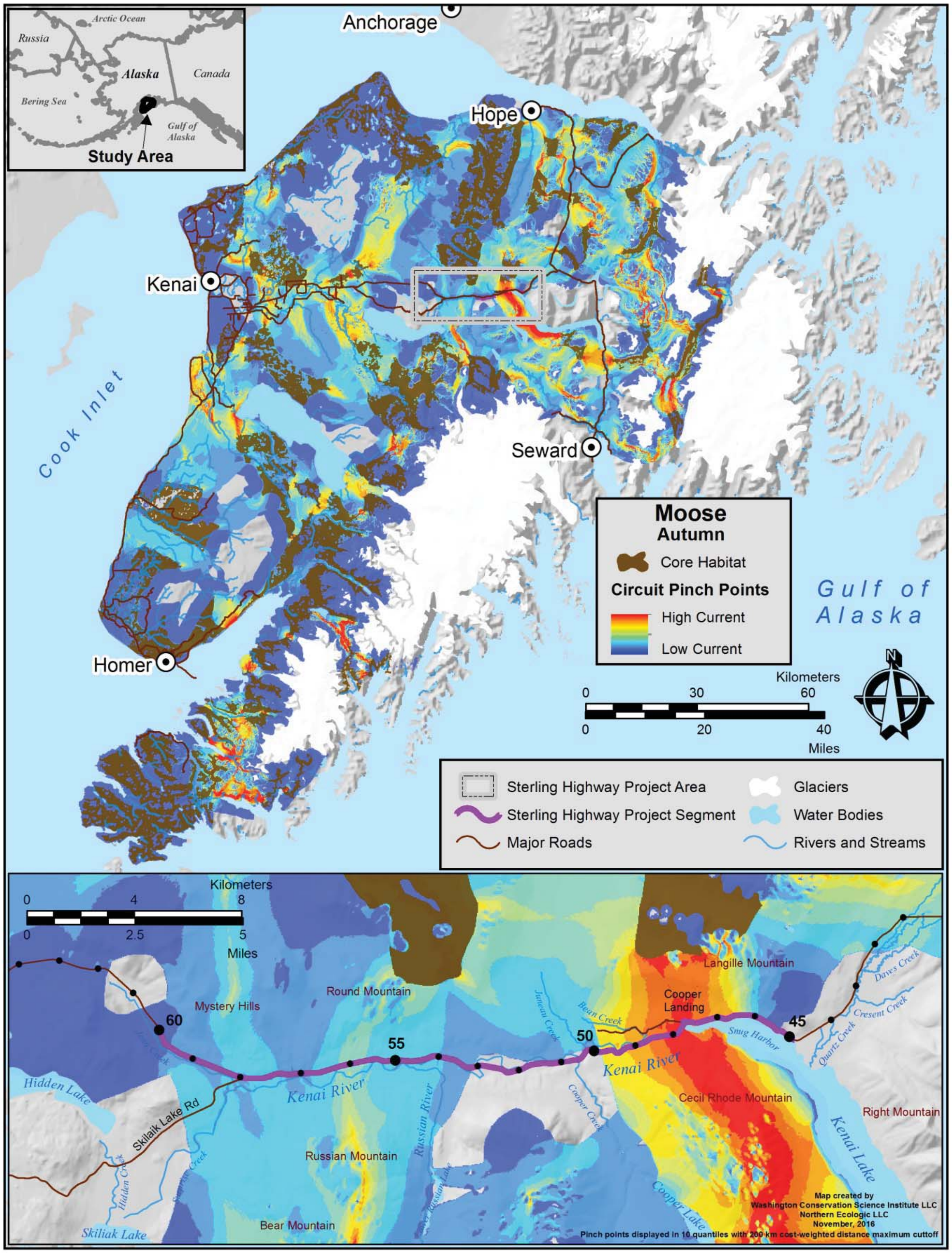

Figure 5-11. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female moose during autumn.

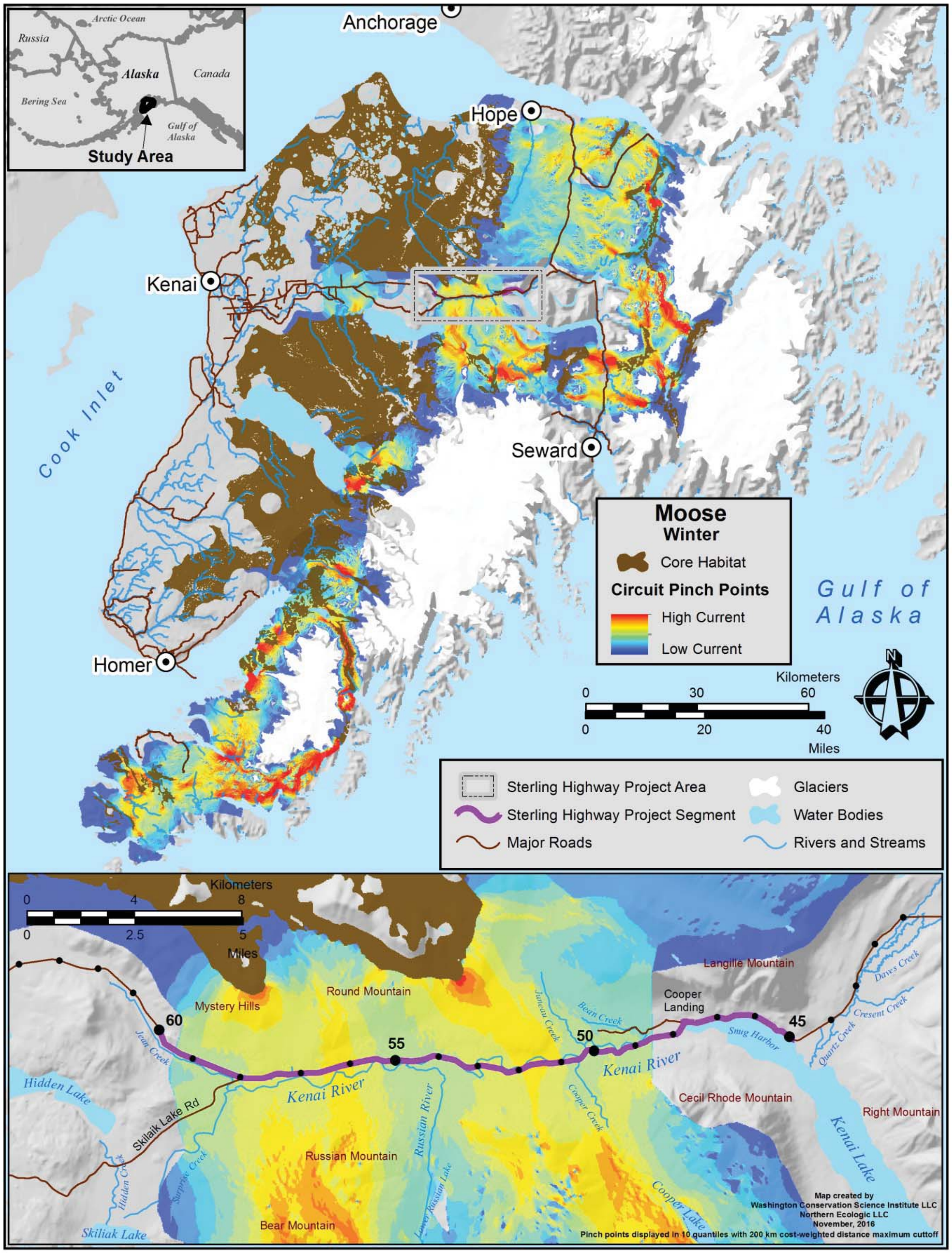

Figure 5-12. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female moose during winter.

confluence of the Russian and Kenai rivers, where the Kenai River has several large meanders that created considerable wetland habitats.

Linkage at MP 56-57

West of the confluence with the Russian River and east of the intersection with the Skilak Lake Road there was a linkage that shows in the all of the seasonal linkage assessments (Figures 5-5 thru 5-8), but was most highly constrained during the winter period (Figure 5-12). This area was a relatively broad river valley with multiple river channels and little human development.

Discussion

There are currently several million cervid-vehicle collisions each year around the world (Conover et al. 1995, Groot Bruinderink and Hazebroek 1996, Romin and Bissonette 1996), and MVCs along the Sterling Highway pose serious safety issues for people and impact moose populations (Bangs et al. 1989, Ernst et al. 2009, Morton 2012). In most cases, it appeared that the spatial and temporal distributions of accidents with wildlife are not random (Nielsen et al. 2003, Malo et al. 2004, Seiler 2005, Dussault et al. 2006, Becker et al. 2011). Modeling of animal movements and habitat use relative to environmental characteristics, such as presented in our study, will help managers determine the location and design of mitigation measures (Finder et al. 1999, Malo et al. 2004, Becker et al. 2011). Previous studies have used RSF modeling to inform where wildlife cross roads (Becker et al. 2011, Squires et al. 2013, Proctor et al. 2015), however, our approach was novel in that we combined seasonal RSF modeling with recently developed habitat linkage identification techniques to identify potential crossing locations for moose.

Several studies have characterized the landscape conditions that increase the probability of highway crossings by moose. The variables that influence where moose cross highways can vary greatly across studies, but generally include valley bottoms and trees that provide cover. For example, Dussault et al. (2007) characterized sites where radio-collared moose crossed highways in the Laurentides Wildlife Reserve, Quebec. They found moose crossings to be associated with valley bottoms, areas with brackish pools, and dense coniferous cover. Becker et al. (2011) found moose crossings in Wyoming were associated with landscape features such as relatively flat, low elevation habitats dominated by deciduous shrubs/trees interspersed with conifers. Similarly, during the autumn and winter periods when potential habitat linkages across the Sterling highway are most constrained, we found moose resource selection to be positively associated with vegetation types that provide cover (e.g., deciduous forest, mixed forest, and evergreen forest) and was negatively associated with increasing slope steepness (Chapter 4; Gaines et al. 2017).

MVCs have been used to identify sites where moose interact most with roads. Several studies have used spatial and temporal variables to characterize MVC sites to better develop and design mitigation strategies. For example, Danks and Porter (2010) found that MVCs in western

Maine were associated with the amount of regenerating forest and closed canopy forest, along with traffic volume and speed. Seiler (2005) studied MVCs in Sweden and found that the risk of a MVC was associated with traffic volume, vehicle speed, fences, forest cover, forest edge, and moose abundance. Dussault et al. (2006) analyzed MVCs within the Laurentides Wildlife Reserve, Quebec, Canada, and found that the presence of a brackish pool, a valley on either side of the road, time of day, and traffic volume all influenced the probability of a moose-vehicle accident. Hurley et al. (2007) developed predictive models using MVCs from Mount Revelstoke and Glacier national parks in Canada. They found that distance to wetland and slope within 500 m of a collision point provided the best coarse-scale predictor variables. Ernest et al. (2009) studied MVCs between MP 58 and 79 along the Sterling Highway and found that the highest MVCs occurred at MP 74 and 75. This area also coincides with the best moose winter range in their study area, and the highest crossings by radio-collared moose (Ernst et al. 2009).

Management Implications

A number of mitigations have been recommended to reduce the risk of wildlife-vehicle collisions. In a few cases, some of these mitigations have been implemented and studies conducted to assess their effectiveness. Olsson and Widen (2008) evaluated the effects of fencing and crossing structures on MVCs and moose crossings in Sweden. They found that while fencing and the construction of 3 crossing structures effectively reduced MVCs, they also significantly reduced moose crossing. Conversely, McDonald (1991) studied the effects of moose-proof fencing, a moose underpass, 1-way gates, and highway lighting that were included in widening of the Glenn Highway near Anchorage, Alaska. He found that moose mortality caused by vehicle collisions was reduced by 70%, yet at the time of his analysis there was no decline in the number of moose crossings (but see Wilson et al. 2015). Ernst et al. (2009) recommended fencing and the installation of wildlife crossing structures to reduce MVCs and provide for moose crossings along the Sterling Highway within their study area between MPs 58-79. Our analyses generally support these recommendations, and provide additional details as to the best locations for crossing structures. In addition, our evaluation encompasses a considerably larger section of highway than that addressed by Ernst et al. (2009). Our evaluation of potential moose crossing sites, when considered with key crossing areas of other focal wildlife species, and once field evaluated, should allow managers to develop and refine mitigation strategies to reduce MVCs while providing for the connectivity of important wildlife habitats.

As part of an effort to minimize MVCs, an underpass designed for moose passage (3 m wide by 3.2 m high [9.8 ft by 10.5 ft]) was installed on an 11.5 km section of the Glenn Highway, north of Anchorage, Alaska. Although McDonald (1991) noted evidence of use of the underpass (i.e., tracks), Wilson et al. (2015) reported a subsequent genetic discontinuity in moose on either side of the highway. They attributed this to restrictions in gene flow due to alterations to the highway (e.g. moose resistant fencing with 1-way gates) and a significant increase in traffic volume over the past 30 years. Although these alterations appear to have been effective in reducing road mortality (McDonald 1991), the sole underpass to facilitate wildlife movement across the highway was drastically undersized for moose and was rarely used (Farley et al. 2012).

The width and height of underpasses were more important than length in predicting the number of crossings by moose through conventional bridges and culverts in Sweden (Olsson and Seiler 2012). They estimated that underpasses wider than 23 m (75.5 ft) were likely to be used by moose at the same frequency with which they were detected on reference track beds close to the underpass. Clevenger and Huijser (2011) indicated that moose tend to prefer large, open structures with good visibility and vertical clearance in areas with little human disturbance. They recommended landscape bridges from 70–>100 m (230–>328 ft) wide, wildlife overpasses 40–70 m (131–230 ft) wide, and viaducts or flyovers (Clevenger and Huijser 2011). They also indicated that large underpasses may be sufficient for moose if they are specifically adapted for their use. Although they recommended a minimum width of 12 m (39.4 ft) and minimum height of 4.5 m (14.8 ft), Clevenger and Huijser (2011) went on to say that these dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes.

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Appendix – Moose

Table 5A-1. Parameter values assigned in the core mapper software to identify core areas for female moose on the Kenai Peninsula, Alaska, USA.

Analysis strata	Moving window radius (m)	Minimum average probability of use	Minimum probability of use per pixel	Expand cores by this cost weighted distance (m)	Minimum size of core areas (ha)
Spring	100	0.93	0.76	0	1000
Summer	100	0.95	0.80	0	1000
Autumn	100	0.99	0.80	0	1000
Winter	100	0.96	0.83	0	1000

Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 6 – Habitat use patterns of black bears on the Kenai Peninsula, Alaska, USA

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Introduction

Selection of areas used by black bears to obtain resources is often affected by many factors, which are often related to physical attributes of habitat. Habitat attributes usually include resources, such as abundance and distribution of forage, that influence how areas used are selected. Non-habitat factors typically affect how an individual black bear uses resources. These factors can significantly affect habitat effectiveness (Gaines et al. 2005). A variety of human activities can displace black bears in their normal day-to-day activities (e.g., Ayers et al. 1986). Although selection of areas used by black bears has been linked to food productivity (Powell et al. 1997), other features may make some areas less effective for black bears. For example, brown bears may displace black bears from high quality habitat (Aune 1994, Belant et al. 2010). Consequently, black bears often restrict their selection of use areas to secure sites that may be less productive. Lindzey and Meslow (1977) reported that female black bears in Washington State used areas where food productivity was limited because these areas were more secure.

The objective of our study was to identify landscape characteristics that affected selection of use areas by black bears on the Kenai Peninsula, Alaska at 2nd and 3rd orders of habitat selection (Johnson 1980). We hypothesized that black bears would select use areas that would provide necessary food resources but preclude contact with brown bears. We further postulated that female black bears would exhibit habitat selection patterns that separated them from dominate males (Lindzey and Meslow 1977). We employed multivariate analyses to derive a probabilistic resource-selection function (Manly et al. 2002). Our goal was to describe and predict black bear distribution based on meaningful variation among our variables. Information on the influence of landscape features on the distribution of black bears on the Kenai Peninsula was needed to facilitate description of movement corridors and to support development of potential mitigation practices associated with the Sterling Highway Milepost (MP) 45–60 Project.

Methods

Capture and Immobilization

Schwartz and Franzmann (1991) captured 167 individual black bears that were used in this analysis a total of 308 times from 1977–1985. Capture methods included snares (1.6%), barrel traps (41.6%), darting from helicopter (27.3%), and immobilization in winter dens (29.5%). Black bears were immobilized with phencyclidine hydrochloride and promazine hydrochloride following the recommendations of Seal et al. (1970) or with etorphine hydrochloride and diprenorphine hydrochloride as an antagonist (Miller and Will 1974). Additional details are provided in Schwartz and Franzmann (1991).

Radio Telemetry

Schwartz and Franzmann (1991) fitted female (n = 72) and resident male (n = 62) black bears with radio-transmitter collars (680 g; Telonics., Inc., Mesa, Arizona, USA). Subadult black bears (n = 77) were fitted with break-away collars (390 g; Telonics., Inc., Mesa, Arizona, USA). These collars were replaced each year in the case of females or until the black bear dispersed in the case of males.

Virtually all location data (92.5% of 5,258 locations) for black bears came from aerial fixes using a Piper Super Cub (PA-18) (Schwartz and Franzmann 1991). The remaining 7.5% of locations came from capture locations, location at death, and ground observations. Black bears were radio tracked from 1978–1987 with most observations made from 1978–1985. Tracking flights occurred every 3–10 days beginning in early spring prior to den emergence until after den entry in the early winter. Tracking flights occurred throughout the day with the majority in midmorning. Whenever a radio signal was detected from a marked black bear Schwartz and Franzmann (1991) circled the area in an attempt to locate the animal and to pinpoint its location on a 1:63,360 scale map. Numerous lakes and ponds in the study area facilitated accurate plotting of aerial locations. Accuracy was confirmed by their ability to locate dens on the ground from aerial locations. Although Schwartz and Franzmann (1991) did not measure location error, they believed it was small. Individual locations of black bears were digitized by hand from the 1:63,360 scale maps into GIS databases.

Delineation of Use Areas

Our primary objective in our investigation of the 3rd order of habitat use of black bears was to determine characteristics of habitat patches intensively used by an animal. Therefore, we used the fixed-kernel method provided in the RANGES V program (Kenward and Hodder 1996) to establish use areas for black bears on the Kenai Peninsula since it reduces the inclusion of unused areas (Girard et al. 2002). The kernel method (Worton 1989) not only gives the circumference of an animal's range, but calculates the use areas on the basis of the intensity of use within their range (Worton 1987, Harris et al. 1990). Degree of utilization is important in calculating use areas because it provides an accurate depiction of the frequency with which an individual uses each point in the habitat (Seaman and Powell 1996, Worton 1989). Fixed-kernel estimators use a distribution function to calculate density of space use (Van Winkle 1975; Worton 1987, 1989) in which boundaries are built by joining sites with equal density. Fixed-kernel analyses are affected by the choice of a smoothing parameter, which is estimated by assuming a normal distribution of the locations (Harris et al. 1990, Seaman and Powell 1996). The smoothing parameter used in this analysis was estimated for each data set by Least Squares Cross Validation (Worton 1989, Powell 2000, Kenward 2001) because it gives area estimates with very little bias (Horne and Garton 2006).

We defined use areas following the long-standing definition of home ranges by Burt (1943):

> "that area traversed by the individual in its normal activities of food gathering, mating and caring for young. Occasional sallies outside the area, perhaps exploratory in nature, should not be considered as in part of the home range."

Therefore we estimated the 95% use area size (Worton 1989, Seaman and Powell 1996). The 95% value is commonly employed to eliminate the most distant locations, which may greatly increase the estimated use area. We compared the estimated size of male and female annual use areas using a 1-way ANOVA at the 95% significance level.

Statistical Analysis

This analysis focused on 2 spatial scales of habitat selection as described by Johnson (1980):

- 2nd order selection of multi-year, annual use within the landscape, and
- 3rd order selection of habitats within multi-year, annual use areas of each of the black bears.

Analysis strata

Black bear food habits and resulting patterns of resource use varied seasonally on the Kenai Peninsula (Schwartz and Franzmann 1991). As a result, this analysis was designed to evaluate resource use patterns separately for 2 seasons; spring (den emergence—31 July) and summer (1 August—den entrance). In addition, female and male black bears have been reported to use habitat differently (Young and Beecham 1986, Clark et al. 1993) and to differ in home range size (Powell et al. 1997). Consequently, analyses were conducted separately for 4 strata based on temporal and spatial use patterns: 1) female black bears in spring, 2) male black bears in spring, 3) female black bears in summer, and 4) male black bears in summer.

Relocation points falling in the Water landcover class and the Other landcover class were removed from the datasets. All but 1 of the relocation points that appeared to be from the same location (e.g., same landscape variable values, same date) were also removed from the dataset. These points were almost always from early spring or late fall and were likely locations of the animal at the den site. After this censoring exercise, black bears with ≥20 relocations by stratum were included in the analysis (Seaman and Powell 1996, Mitchell and Powell 2007). Data sets were created for each analysis strata for individuals across the landscape and within use areas: spring males, summer males, all males, spring females, summer females, all females.

Initially, 500 random points were placed within use areas for each black bear. After random points falling in the Water landcover class and the Other landcover class were removed, the total number of points with in each use area ranged from 434 to 497 (Table 6-1). Initially, 3,150 random points were placed across the landscape. After random points falling in the Water landcover class and the Other landcover class were removed, the total number of points available for analysis was 3,041 (Table 6-1).

Table 6-1. Black bear relocation points and random points by sampling strata used for the analysis of habitat use on the Kenai Peninsula, Alaska.

	Black bears					
	Males			Females		
	Spring	Summer	Combined	Spring	Summer	Combined
Across the study area						
Individual study animals	14	7	20	34	23	42
Range of number of relocations per animal	20-85	25-46	21-131	20-118	20-73	20-189
Mean number of relocations per animal	40	32	52	50	36	69
Within use areas						
Individual study animals	13	7	18	33	15	38
Range of number of relocations per animal	20-84	22-45	22-129	22-105	23-52	20-156
Mean number of relocations per animal	40	30	51	46	33	64
Random points across use areas						
Individual use areas	58					
Range of number of random points per use area	434-497					
Mean number of random points per use area	473					
Random points across study area	3041					

Land cover preference

Use of 6 land cover designations by black bears was estimated by calculating selection ratios at 2 spatial scales: within each of the sampling strata across the landscape and within use areas for individual black bears. Evaluation of habitat use often includes the development or calculation of indices of use by wildlife species of the land cover classes of interest (Morrison et al. 2006:336-337). Many indices have been used to describe degree of selection or preference of habitats by animals (e.g., Ivlev 1961, Krueger 1972, Cock 1978, Lechowicz 1982, Alldredge et al. 1998). However, none is generally superior to the rest and none is without bias and increasing error at small proportions (Chesson 1978, Strauss 1979). These indices and their variations have several short comings including non-linearity, bias to rare habitats, increasing confidence intervals with increasing heterogeneity, being unbound or undefined, and lacking symmetry between selected and rejected values (Jacobs 1974). Confidence intervals also become excessive for proportions below about 10% (Strauss 1979). However, there are methods that minimize these biases (Krebs 1989). We chose a version of Ivlev's (1961) electivity index as modified by Reynolds-Hogland and Mitchell (2007) to minimize these biases.

Ivlev's electivity index has had numerous applications to describe preference and avoidance of habitats by wildlife (e.g., Schoen et al. 1994, Yeo and Peek 1992, Doerr et al. 2005, Garneau et al. 2008). It is a dimensionless number that compares the proportion of a land cover class used by an animal to the proportion available in a specified area of study. Reynolds-Hogland and Mitchell's (2007) modification makes the index symmetrical with respect to zero:

$$E_i = \frac{2 \text{ x } (\text{proportion of habitat } i \text{ used} - \text{proportion of habitat } i \text{ available})}{1 + (\text{proportion of habitat } i \text{ used} + \text{proportion of habitat } i \text{ available})},$$

where E_i is an index of preference for habitat i. They modified Ivlev's electivity index ((use of habitat i – availability of habitat i)/(use of habitat i + availability of habitat i)) because it overestimates E_i when use and availability of habitat i are very low. For example, E_i based on the Ivlev's electivity index equals 0.33 when use of habitat $i = 0.02$ and availability of habitat $i = 0.01$. Alternatively, E_i using the modified Ivlev's electivity index equals 0.019, which is more representative. Values of E_i can range from – 1 to + 1 where negative values suggest avoidance and positive values suggest selection with larger absolute values indicating a higher degree of preference or avoidance for each land cover class (Reynolds-Hogland and Mitchell 2007). Electivity indices were calculated using the mean proportions of habitats at relocation points for each black bear with the mean proportion of habitats available from the random locations within individual use areas and across the landscape. Simultaneous Bonferroni confidence intervals ($\alpha = 0.05$) were also calculated to determine whether preference or avoidance responses associated with land cover classes were statistically significant (Byers et al. 1984, White and Garrott 1990).

The percentage of each land cover used by each black bear was determined by noting the land cover associated with each relocation. The percentage of each land cover available was determined by noting the land cover associated with each of 3,041 random points across the landscape and each of 434–497 random points within each black bear's use area. Points that fell on ice, snow, or lakes were excluded from the analysis. Indices were calculated for each black bear from relocation and random points within individual use areas and from relocation and random points across the landscape. Index values were averaged across all black bears in each analysis stratum.

Univariate analysis

Importance of resources to black bears is contingent on selection of resources being related to their life history and fitness requirements and ultimately demography of the population (Johnson and Seip 2008, Hodder et al. 2014). Twenty-one physical habitat and human development variables were reviewed for potential inclusion in multiple regression models of landscape use by black bears (Table 6-2). Variables selected for consideration were previously identified as variables that influenced distribution and fitness of black bears (Table 6-2) and had spatial databases available describing their distribution across the Kenai Peninsula (Chapter 2; Begley et al. 2017).

Table 6-2. Variables available for modeling resource selection by black bear and for developing habitat quality models on the Kenai Peninsula, Alaska, USA. Distances were in m and densities were in m per km^2.

Variable	Description	Source
Buildings		
DEVELOP_KM	Density of human developments	Clark et al. 1993, Van Mannen and Pelton 1997, Mitchell et al. 2002, Carter et al. 2010
DEVELOP_D	Distance to human developments	Bowman 1999
Roads		
LOW_ROADS_KM	Density of low use roads	Gaines et al. 2005, Carter et al. 2010
HIGH_ROADS_D	Distance to high-use roads	Clark et al. 1993, Mitchell et al. 2002, Gaines et al. 2005
LOW_ROADS_D	Distance to low-use roads	Kasworm and Manley1990, Clark et al. 1993, Mitchell et al. 2002, Gaines et al. 2005
KEN_ROADS_D	Distance to all roads	Kasworm and Manley1990, Clark et al. 1993, Mitchell et al. 2002, Gaines et al. 2005
Trails		

Table 6-2. Variables available for modeling resource selection by black bear and for developing habitat quality models on the Kenai Peninsula, Alaska, USA. Distances were in m and densities were in m per km^2.

Variable	Description	Source
K_TRAILS_KM	Density of recreation trails	Kasworm and Manley1990, Kasworm and Their 1994
HIGH_TRAILS_D	Distance to high-use trails	Kasworm and Manley1990, Kasworm and Their 1994
LOW_TRAILS_D	Distance to low-use trails	Kasworm and Manley1990, Kasworm and Their 1994
ALL_TRAILS_D	Distance to all trails	Kasworm and Manley1990, Kasworm and Their 1994
Recreation sites		
ALL_SITES_KM	Density of recreation sites	Goodrich and Berger. 1994, Chi and Gilbert 1999, Nellemann et al. 2007
LOW_SITES_D	Distance to low-use recreation sites	Goodrich and Berger. 1994, Chi and Gilbert 1999, Nellemann et al. 2007
ALL_SITES_D	Distance to all recreation sites	Goodrich and Berger. 1994, Chi and Gilbert 1999, Nellemann et al. 2007
Topography		
ELEVATION	Elevation	Clark et al. 1993, Clevenger et al. 2002
ASPECT	Aspect	Clark et al. 1993, Clevenger et al. 2002

Table 6-2. Variables available for modeling resource selection by black bear and for developing habitat quality models on the Kenai Peninsula, Alaska, USA. Distances were in m and densities were in m per km^2.

Variable	Description	Source
Vegetation		
COVER_D	Distance to forest or shrub cover	McCollum 1973, Mitchell et al.2002
LCOVER	Land cover category	Rogers and Allen 1987, Clark et al. 1993, van Mannen and Pelton 1997, Gaines et al. 2005
Streams/salmon		
HIGH_STM_D	Distance to high potential salmon spawning stream	Frame 1974, Clark et al. 1993, Clevenger et al. 2002
LOW_STM_D	Distance to low potential salmon spawning stream	Frame 1974, Clark et al. 1993, Clevenger et al. 2002,
HIGH_STM_KM	Density of high potential salmon spawning streams	Frame 1974, Sadeghpour and Ginnett 2011
LOW_STM_KM	Density of low potential salmon spawning streams	Frame 1974, Sadeghpour and Ginnett 2011

Landscape use by black bears and availability of habitat characteristics, as described by the physical habitat and human development variables, were evaluated at 2 spatial scales (i.e., landscape-wide and within individual use areas) and at the 4 strata. Comparisons were made between values of variables at relocation (i.e., used) points and at random (i.e., available) points at both spatial scales. Averages of each variable were compared over all relocation points for an individual black bear to averages of the same variables at 3,041 points randomly selected across the landscape and ~500 additional points randomly selected across each use area for individual black bears. Following an examination of the data for deviation from normality (using the Shapiro-Wilks test) we used a Wilcoxon rank-sum test to evaluate differences between used and available averages (paired by black bear) at each spatial scale and for each stratum. These comparisons enabled us to screen variables for their potential utility in predicting resource selection with multivariate models at the study-area and use-area scales. Since samples of values of variables available to black bears were large, and they were selected across each stratum, the available averages were considered constants. We further evaluated the utility of these variables for this analysis through a preanalysis correlation screen to identify multicollinearities (Neter et al. 1985) in the data and removed correlated variables ($r > 0.6$).

Resource selection

Empirically-based resource selection functions (RSFs) identify the strength of animal-resource (i.e. habitat) relationships where strong selection or suitability is indicated by high RSF values (Hodder et al. 2014). A RSF produces a series of coefficients that quantify the strength of avoidance or selection for specific habitat covariates. We examined habitat use using the exponential form of the RSF: $w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k)$, where $w(x)$ was the relative probability of selection at location x and $x_1, \ldots, x_k$ were covariates we measured at each telemetry location for models with $\beta_{1,\ldots,}\beta_k$ estimated parameters (Manly et al. 2002).

RSFs can be used to describe and map suitable habitat of a species based on predicted probability of use (Meyer and Thuiller 2006). We used a use-available design based on black bear radio telemetry locations and random points to estimate the coefficients of an exponential RSF with logistic regression (Johnson et al. 2006, Lele and Kiem 2006). We developed separate models for 2nd order selection of habitats within the landscape and for 3rd order selection of habitats within use areas of each of the black bears. Because the telemetry data that we used in this analysis only detected the presence of black bears, absence was not evaluated. Rather than relate model covariates to the presence and absence of black bears, we compared the presence of black bears to randomly generated ‘‘available’’ locations across the landscape and within each black bear’s 95% kernel density estimated use area. Within the landscape, 3,041 random points were generated to characterize habitat available to back bears; ~500 additional points were randomly selected across each use area for individual black bears to describe habitat available within use areas.

In such use–availability study designs, RSFs are interpreted as a ratio of density functions for used and available resource units rather than a probability of use (Seber 1984, Keating and Cherry 2004). We sampled a large number of possible available locations within the landscape and within use areas, and presumably a relatively small number of sites used by black bears but not identified by radio telemetry. This ensured that contamination of available locations with sites actually used but unknown by us was likely low, that the probability of use by black bears of any single point in the landscape was very small, and that the argument of the exponential function was negative (Manly et al. 2002, Johnson et al. 2006). All used and available locations were attributed with a suite of previously identified continuous and categorical environmental variables (Table 6-2).

We developed a series of RSF models that served as ecologically plausible hypotheses for explaining the distribution of black bears across the landscape on the Kenai Peninsula. We based these hypotheses on information available in the literature and our understanding of the ecological relationships in the landscape. Our working premise was that habitat selection by black bears was a function of them responding to combinations of functional variables: We developed candidate models a priori for the landscape analysis based on 5 categories of covariates: 1) recreation, 2) roads, 3) streams, 4) vegetation cover, and 5) terrain (elevation). A priori candidate models for the use-area analysis were based on 4 categories of covariates: 1) recreation, 2) human development, 3) streams, and 4) vegetation cover. We compared 19 models for the landscape analysis and 8 models for the use area analysis containing combinations of their respective categories. We ranked candidate models by change in Akaike's Information Criterion (AIC) corrected for small sample sizes (AIC_c) and selected top models (i.e., models with ΔAIC_c, values ≤ 2.0; Burnham and Anderson 2002). We computed Akaike model weights (w_i), to determine the strength of each model compared to other competing models. Model averaging methods were used when appropriate. If a single candidate model for either analysis had ΔAIC_c, values ≤ 2.0, it was considered the best model; otherwise model averaging theory (Burnham and Anderson 2002) was applied to the highest ranking models whose ΔAIC_c, values ≤ 2.0 (Lesmerises et al. 2012). Model averaging is commonly used to address model uncertainty among a set of models estimating habitat selection (e.g., Arnold 2010). This approach minimizes the effect of uninformative parameters among individual models, particularly if covariates are included in 1 model and not in another (Burnham and Anderson 2002). Model averaging can result in greater precision and reduced bias relative to the single best model, and this approach is appropriate where prediction is the primary objective (Anderson et al. 2000, Anderson and Burnham 2002). When model averaging was applied, we averaged those models that constituted 95% of the AIC_c weights (w_i) across the full suite of models.

To create a map of predicted habitat use patterns, the final model was displayed in a GIS using the exponential relationship: $w(x) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k)$ where $w(x)$ represents a RSF for predictor variables, x_i, with associated selection coefficients, β_i. We generated an output surface map of relative probability of selection using the coefficients of factors included in the final model. The RSF score predictions were normalized from 1–100 and then binned into 5 quantile classes with the following upper limit values: none (0) low (21), low-moderate (79), moderate-high (91), and high (100).

We evaluated how well our habitat selection models predicted the use of black bears within the landscape (i.e., 2nd order selection of habitats). We mapped probability of use of black bears across the landscape using the RSF with ΔAIC_c, value ≤ 2.0. We then determined probability of use of black bears at each of 678 telemetry locations of black bears that were not used in the development of the RSFs from that map and sorted the results into 4 quartile bins based on the RSF values. We also determined probability of use of black bears at each of 3,144 random locations across the landscape from this map and sorted them into the same 4 quartile bins. We compared the proportion of telemetry locations with the proportion of random locations in each bin using a Pearson's chi-squared test of goodness of fit (χ^2). Results indicated how well the model predicted probability of use by black bears.

We used the map of probability of use of black bears on the Kenai Peninsula to evaluate the quality of habitat within use areas and to compare the quality of habitats within male black bear use areas with female black bear use areas. Five-hundred random points were established in each of 18 use areas for males and 37 use areas for females. Probability of use was recorded at each of the 500 random points for each black bear and a mean probability was calculated for each use area. Probability of use was also recorded at each of 3,144 random points across the landscape. A two-sample *t*-test with a significance level of 0.05 was used to compare the mean probability across all black bears in the sample with the landscape mean and to compare the mean probability across male black bears with the mean probability across female black bears.

Results

Delineation of Use Areas

We had a sample of observations available that was adequate to estimate the size of multi-year annual use areas for 19 male and 39 female black bears using fixed-kernel analyses. Mean size of annual male use area was 366.0 ± 36.3 km^2, which was 6.1 times larger than the female use area size of 60.1 ± 5.3 km^2 ($F_{1,56}$= 129.0, $P < 0.01$) (Table 6-3). The number of locations used to estimate size of use areas was not correlated to the estimated sizes of use areas for male or female black bears (males: $r = 0.295$, $t = 1.273$, $P = 0.220$; females: $r = 0.119$, $t = 0.729$, $P = 0.471$; all black bears: $r = -0.055$, $t = -0.412$, $P = 0.682$).

Table 6-3. Estimates of the size of use areas of black bears generated with 95% fixed kernel density estimates with least-squares cross-validation on the Kenai Peninsula, Alaska, USA.

Sex	*n*	$\overline{x}$ ± SE	Range	Median
Male	19	366.0 ± 36.3	51.4 – 600.6	340.8
Female	39	60.1 ± 5.3	17.0 – 191.1	50.8
All bears	58	160.3 ± 27.5	17.0 – 600.6	69.3
M:F ratio		6.1:1		

Correlation Among Variables

The results of correlation analyses across all variables associated with relocations of black bears indicated that density of all salmon streams on the Kenai Peninsula (KENAI_STM_D) was correlated ($r = 0.65$) with the distance a location was to a stream with high potential for spawning salmon (HIGH_STM_D) (Table 6-4). HIGH_STM_D was retained in the analysis. The density at a location point of all streams with spawning salmon (KENAI_STM_KM) was correlated ($r = 0.82$) with the density of streams with high potential for spawning salmon on the

Kenai Peninsula (HIGH_STM_KM). HIGH_STM_KM was retained in the analysis. The density at a location point of all recreation sites on the Kenai Peninsula (ALL_SITES_KM) was correlated with the density of high-use recreation sites (HIGH_SITES_KM) ($r = 0.67$) and the density of low-use recreation sites (LOW_SITES_KM) ($r = 0.74$). ALL_SITES_KM was retained in the analysis. The density at a location point of all recreation trails on the Kenai Peninsula (K_TRAILS_KM) was correlated with the density of high-use trails (H_TRAILS_KM) ($r = 0.78$) and the density of low-use trails (L_TRAILS_KM) ($r = 0.61$). K_TRAILS_KM was retained in the analysis. The density at a location point of all roads on the Kenai Peninsula (KEN_ROADS_KM) was correlated with the density of low-use roads (LOW_ROADS_KM) ($r = 0.99$). LOW_ROADS_KM was retained in the analysis.

Land Cover Preference

Analysis of the use of 6 land cover designations by black bears showed consistent patterns across and among strata at both the landscape and use area scales (Tables 6-5 and 6-6). Within the landscape males selected land cover classes during spring that were predominately forested. During summer, selection of land cover classes showed preference for shrubs, deciduous forest, and mixed forest. Females avoided conifer forests during all seasons, selected forb and shrub land cover classes during spring, shrubs during summer, and showed preference for deciduous forest and mixed forest during spring and summer. However, all patterns of selection of land cover classes at the landscape level were not statistically significant.

Within use areas, males and females showed preference for deciduous forest and mixed forest during spring and summer. Males and females also avoided the shrub cover class during spring but selected it during summer. Again, all patterns of selection of land cover classes at the use area level were not statistically significant.

Landscape Variables

Univariate analyses of the effects of landscape variables on habitat use patterns of black bears across the landscape on the Kenai Peninsula indicated that there were very few differences across analysis strata (Table 6-7). As a result all observations were combined across all strata for subsequent analyses of use patterns at the study-area level.

Resource Selection

Landscape

Male and female black bears were combined across seasons for the analysis of RSF models across the landscape. We evaluated a suite of 19 potential models that included topographic features and landscape characteristics that we believed were important to habitat selection by black bears (Table 6-8). The most parsimonious model within that suite of models consisted of covariates for low-use and high-use roads, low-potential and high-potential salmon streams,

Table 6-4. Coefficients of correlation of variables describing characteristics of the landscape at relocation points of black bears on the Kenai Peninsula, Alaska, USA.

Variable	Coefficient of correlation by variable						
	HIGH_STM_D	HIGH_STM_KM	HIGH_SITES_KM	LOW_SITES_KM	H_TRAILS_KM	L_TRAILS_KM	LOW_ROADS_KM
KENAI_STM_D	0.65						
KENAI_STM_KM		0.82					
ALL_SITES_KM			0.67	0.74			
K_TRAILS_KM					0.78	0.61	
KEN_ROADS_KM							0.99

Table 6-5. Selection of land cover classes by black bears across the landscape by sex and season on the Kenai Peninsula, Alaska, USA.

Land cover class[1]	Males			Females			All bears		
	Spring	Summer	All seasons	Spring	Summer	All seasons	Spring	Summer	All seasons
Barren	-	-	-	-	-	-	-	-	-
Forb	-	-	-	+	-	-	-	-	-
Shrub	-	+	+	+	+	+	+	+	+
Conifer	+	-	-	-	-	-	-	-	-
Deciduous	+	+	+	+	+	+	+	+	+
Mixed	+	+	+	+	+	+	+	+	+

[1] See Chapter 2; Begley et al. 2017

Table 6-6. Selection of land cover classes by black bears within use areas by sex and season on the Kenai Peninsula, Alaska, USA.

Land cover class[1]	Males			Females			All bears		
	Spring	Summer	All seasons	Spring	Summer	All seasons	Spring	Summer	All seasons
Barren	-	-	-	-	-	-	-	-	-
Forb	-	-	-	-	-	-	-	-	-
Shrub	-	+	+	-	+	-	-	+	+
Conifer	-	-	-	-	-	-	-	-	-
Deciduous	+	+	+	+	+	+	+	+	+
Mixed	+	+	+	+	+	+	+	+	+

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[1] See Chapter 2; Begley et al. 2017

Table 6-7. T-test p values associated with comparisons of the effect of landscape variables on black bears across analysis strata on the Kenai Peninsula, Alaska, USA (bold indicates a statistically significant difference).

Variables	Male/female			Spring/summer		
	Spring	Summer	All seasons	Male	Female	All animals
LOW_SITES_D	0.250	0.764	0.246	0.709	0.584	0.761
HIGH_SITES_D	0.237	0.348	0.124	0.561	0.643	0.530
ALL_SITES_D	0.232	0.549	0.466	0.391	0.340	0.620
ALL_SITES_KM	0.757	0.328	0.841	0.177	0.805	0.981
LOW_TRAILS_D	0.058	0.011	**0.003**	0.101	0.610	0.413
HIGH_TRAILS_D	0.850	0.656	0.878	0.533	0.210	0.158
ALL_TRAILS_D	0.745	0.798	0.662	0.790	0.865	0.787
K_TRAILS_KM	0.871	0.923	0.846	0.998	0.984	0.977
LOW_ROADS_D	0.264	0.968	0.325	0.424	0.899	0.544

Table 6-7. T-test p values associated with comparisons of the effect of landscape variables on black bears across analysis strata on the Kenai Peninsula, Alaska, USA (bold indicates a statistically significant difference).

	Male/female			Spring/summer		
Variables	Spring	Summer	All seasons	Male	Female	All animals
HIGH_ROADS_D	0.107	0.172	**0.036**	0.737	0.764	0.796
KEN_ROADS_D	0.268	0.969	0.329	0.427	0.899	0.546
LOW_ROADS_KM	0.169	0.796	0.596	0.525	0.861	0.721
HIGH_ROADS_KM	0.186	0.217	0.106	0.289	--	0.305
DEVELOP_D	**0.015**	0.082	**0.003**	0.703	0.422	0.484
DEVELOP_KM	0.246	0.356	0.164	0.505	--	0.539
LOW_STM_D	**0.020**	0.057	**0.003**	0.813	0.671	0.781
HIGH_STM_D	0.280	0.307	0.109	0.885	0.534	0.466
LOW_STM_KM	0.595	0.165	0.186	0.895	0.198	0.252
HIGH_STM_KM	0.218	0.413	0.114	0.882	0.458	0.440
ASPECT	0.297	0.535	0.489	0.057	0.648	0.237
ELEVATION	0.304	0.100	0.819	0.129	0.220	0.660

Table 6-8. Models with topographic and landscape features potentially affecting habitat selection by black bears across the landscape on the Kenai Peninsula, Alaska, USA.

Model		
Elements	Number	Variables
Recreation sites	1	ALL_SITES_KM
Recreation trails	2	K_TRAILS_KM
Recreation	3	ALL_SITES_KM + K_TRAILS_KM
Roads	4	LOW_ROADS_KM + HIGH_ROADS_KM
Streams	5	LOW_STM_KM + HIGH_STM_KM
Cover	6	COVER_D
Topography	7	ELEVATION
Recreation + Cover	8	LOW_ROADS_KM + HIGH_ROADS_KM + COVER_D
Roads + Cover	9	LOW_ROADS_KM + HIGH_ROADS_KM + COVER_D
Human effects	10	ALL_SITES_KM + K_TRAILS_KM + LOW_ROADS_KM + HIGH_ROADS_KM
Human effects + Cover	11	ALL_SITES_KM + K_TRAILS_KM + LOW_ROADS_KM + HIGH_ROADS_KM + COVER_D
Streams + Cover	12	HIGH_STM_KM + LOW_STM_KM + COVER_D
Topography + Cover	13	ELEVATION + COVER_D
Human effects + Streams + Cover	14	ALL_SITES_KM + K_TRAILS_KM + HIGH_ROADS_KM + LOW_ROADS_KM + HIGH_STM_KM + LOW_STM_KM + COVER_D
Global	15	ALL_SITES_KM + K_TRAILS_KM + HIGH_ROADS_KM + LOW_ROADS_KM + HIGH_STM_KM + LOW_STM_KM + COVER_D + ELEVATION

Table 6-8. Models with topographic and landscape features potentially affecting habitat selection by black bears across the landscape on the Kenai Peninsula, Alaska, USA.

Model		
Elements	Number	Variables
Trails + Roads + + Streams + Cover + Elevation	16	K_TRAILS_KM + HIGH_ROADS_KM + LOW_ROADS_KM + HIGH_STM_KM + LOW_STM_KM + COVER_D + ELEVATION
Roads + Streams + Cover + Elevation	17	HIGH_ROADS_KM + LOW_ROADS_KM + HIGH_STM_KM + LOW_STM_KM + COVER_D + ELEVATION
Trails + Roads + Streams + Cover	18	K_TRAILS_KM + HIGH_ROADS_KM + LOW_ROADS_KM + HIGH_STM_KM + LOW_STM_KM + COVER_D
Roads + Streams + Cover	19	HIGH_ROADS_KM + LOW_ROADS_KM + HIGH_STM_KM + LOW_STM_KM + COVER_D

distance to cover, and elevation (Table 6-9). All other candidate models had ΔAIC_c, values >2.0. However, an AIC_c w_i of 0.58 for the top model suggested some model selection uncertainty.

Table 6-9. AIC*c* scores, as well as differences in AIC*c* scores (Δ) and AIC*c* weights (*wi*) within a set of resource selection function models representing factors affecting the location of black bears across the landscape on the Kenai Peninsula, Alaska, USA.

Model elements	Model number	AIC_c	ΔAIC_c	w_i
Roads + Streams + Cover + Elevation	17	995.3	0.0	0.5811
Trails + Roads + + Streams + Cover + Elevation	16	997.3	2.0	0.2133
Global	15	999.1	3.8	0.0867
Topography	7	999.9	4.6	0.0593
Topography + Cover	13	1000.3	5.0	0.0472
Roads + Streams + Cover	19	1005.7	10.5	0.0031
Roads + Cover	9	1006.4	11.1	0.0023
Roads	4	1006.7	11.4	0.0020
Trails + Roads + Streams + Cover	18	1007.8	12.5	0.0011
Streams + Cover	12	1008.5	13.2	0.0008
Cover	6	1008.9	13.6	0.0006
Streams	5	1009.0	13.7	0.0006
Human effects + Streams + Cover	14	1009.5	14.2	0.0005
Human effects + Cover	11	1009.9	14.6	0.0004
Human effects	10	1010.1	14.8	0.0003
Recreation trails	2	1011.1	15.8	0.0002
Recreation sites	1	1011.3	16.0	0.0002
Recreation + Cover	8	1012.6	17.3	0.0001
Recreation	3	1013.1	17.8	0.0001

There was evidence that black bears avoided areas with greater densities of roads (density of low capacity roads β = -0.001, 95% CI = -0.003 – 0.001; density of high capacity roads β = -0.006, 95% CI = -0.016 – 0.004) (Figure 6-1), avoided areas with greater densities of salmon streams (density of low potential salmon streams β = -0.003, 95% CI = -0.007 – 0.001; density of high potential salmon streams β = -0.001, 95% CI = -0.003 – 0.001) (Figure 6-2), avoided areas further from cover (distance to cover β = -0.003, 95% CI = -0.011 – 0.005) (Figure 6-3), and avoided areas with higher elevation (elevation β = -0.003, 95% CI = -0.005 – -0.001) (Figure 6-4). This model had good predictive accuracy ($\chi^2 = 29.42$; $p < 0.001$) (Table 6-10).

We mapped the resulting output surface depicting relative probability of selection of habitats on the Kenai Peninsula by black bears (Figure 6-5). Within the mapped area, 23 percent was in the quantile bin without habitat value (i.e., water, snow fields, ice), 7 percent had low habitat value, 22 percent had low-moderate habitat value, 26 percent had moderate-high habitat value, and 22 percent had high value.

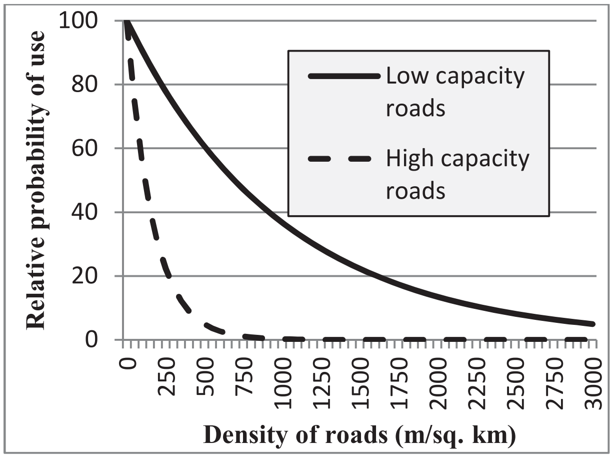

Figure 6-1. Effect of density of roads on the relative probability of use of black bears across the landscape on the Kenai Peninsula, Alaska, USA.

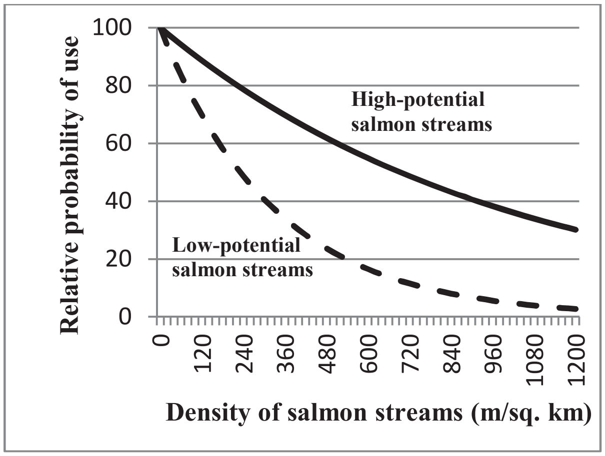

Figure 6-2. Effect of density of salmon streams on the relative probability of use of black bears across the landscape on the Kenai Peninsula, Alaska, USA.

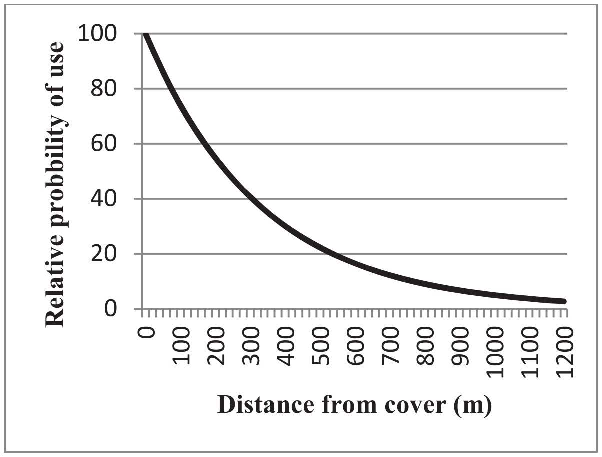

Figure 6-3. Effect of distance from cover on the relative probability of use of black bears across the landscape on the Kenai Peninsula, Alaska, USA.

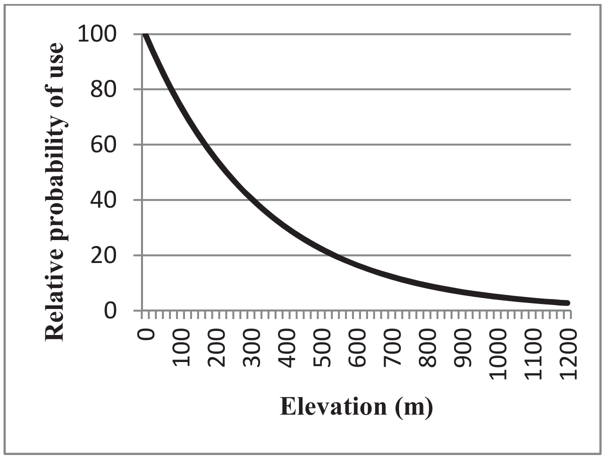

Figure 6-4. Effect of elevation on the relative probability of use of black bears across the landscape on the Kenai Peninsula, Alaska, USA.

Table 6-10. Evaluation of the selected RSF model for predicting probability of use of black bears across the landscape on the Kenai Peninsula, Alaska, USA ($\chi^2 = 29.42$; $p < 0.001$).

Quantiles	RSF value range	Number of telemetry locations	Percent of telemetry locations	Number of random points	Percent of random points
1	0-21	7	1.0	220	7.0
2	22-79	57	8.4	646	20.6
3	80-91	72	10.6	603	19.2
4	92-100	542	79.9	1,675	53.3
		678	100.0	3,144	100.0

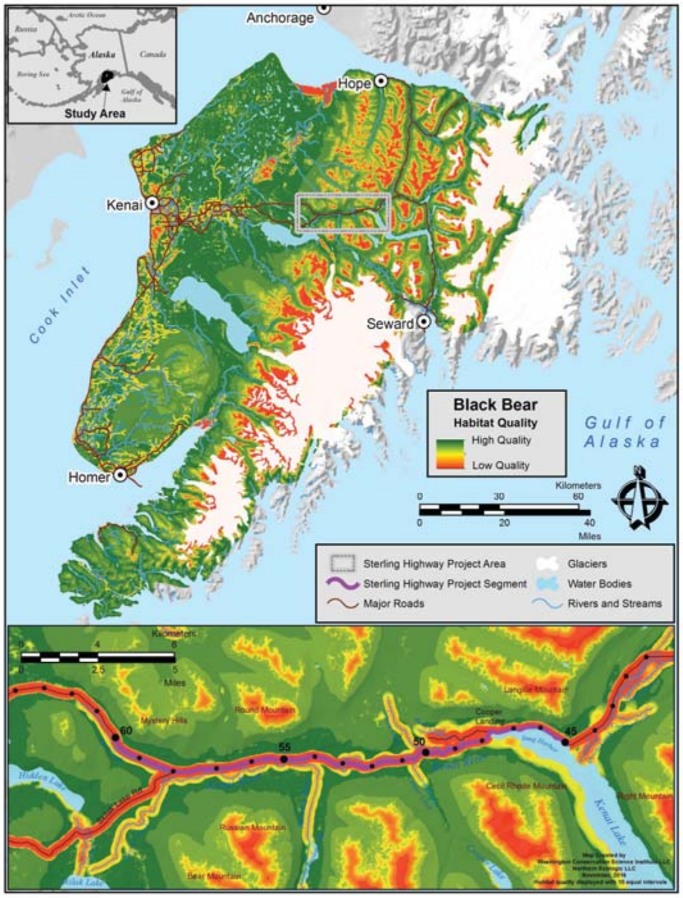

Figure 6-5. Probability of use of black bears on the Kenai Peninsula, Alaska, USA.

Use areas

Male and female black bears were combined across seasons for the analysis of RSF models within use areas. We evaluated a suite of 8 potential models that included recreation and human development features and landscape characteristics that we believed were important to habitat selection by black bears (Table 6-11). The top 4 candidate models had ΔAIC_c, values ≤ 2.0 (Table 6-12). Multi-model inference from model averaging suggested that within their use areas black bears avoided areas with greater densities of recreation sites (density of recreation sites β = -5.648, 95% CI = -48.098 – 36.803) (Figure 6-6), avoided areas with greater densities of trails (density of recreation trails β = -0.005, 95% CI = -0.019 – 0.009) (Figure 6-7), avoided areas with greater densities of human developments (density of human developments β = -4.733, 95% CI = -15.397 – 5.931) (Figure 6-8), avoided areas with greater densities of salmon streams (density of low potential salmon streams β = -0.004, 95% CI = -0.022 – 0.014) (Figure 6-9), and avoided areas further from cover (distance to cover β = -0.119, 95% CI = -0.209 – -0.029) (Figure 6-10).

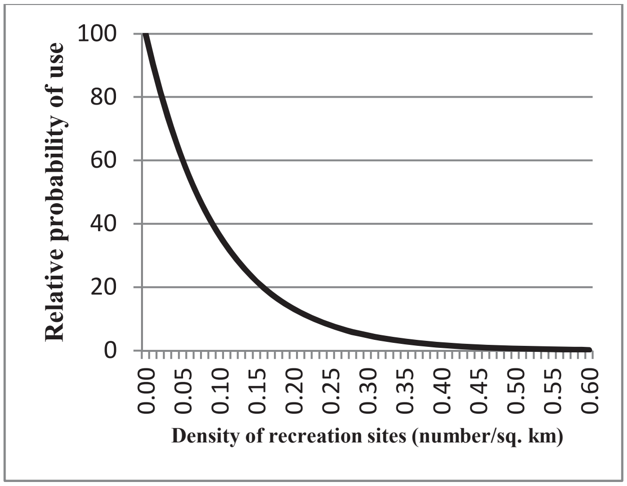

Figure 6-6. Effect of density of recreation sites on the relative probability of use of black bears within use areas on the Kenai Peninsula, Alaska, USA.

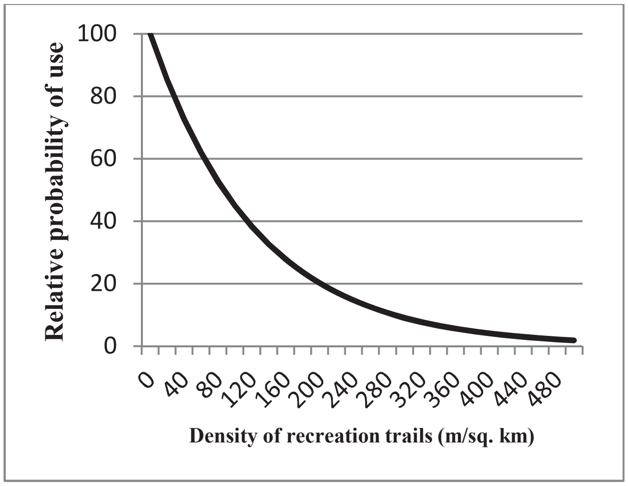

Figure 6-7. Effect of density of recreation trails on the relative probability of use of black bears within use areas on the Kenai Peninsula, Alaska, USA.

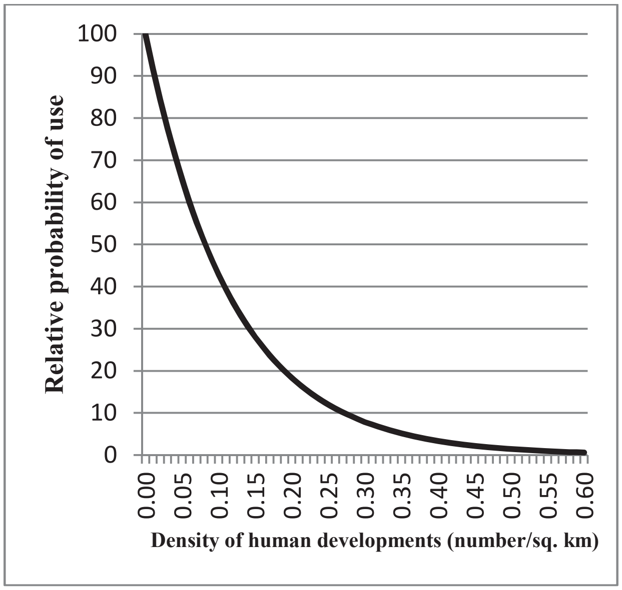

Figure 6-8. Effect of density of human developments on the relative probability of use of black bears within use areas on the Kenai Peninsula, Alaska, USA.

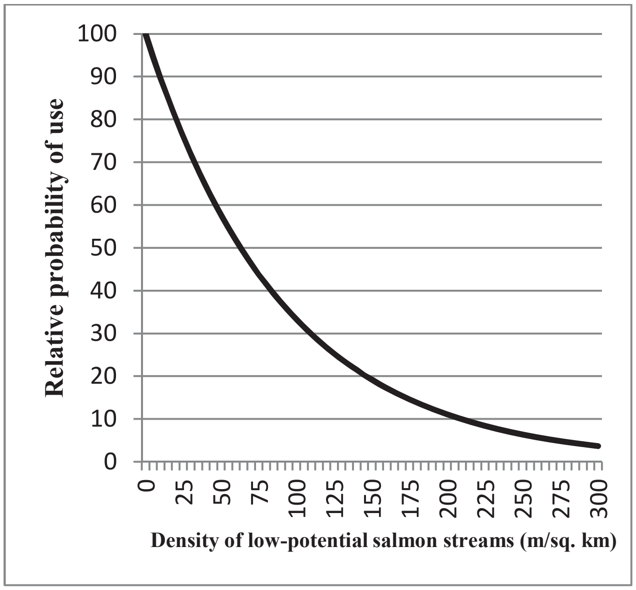

Figure 6-9. Effect of density of low-potential salmon streams on the relative probability of use of black bears within use areas on the Kenai Peninsula, Alaska, USA.

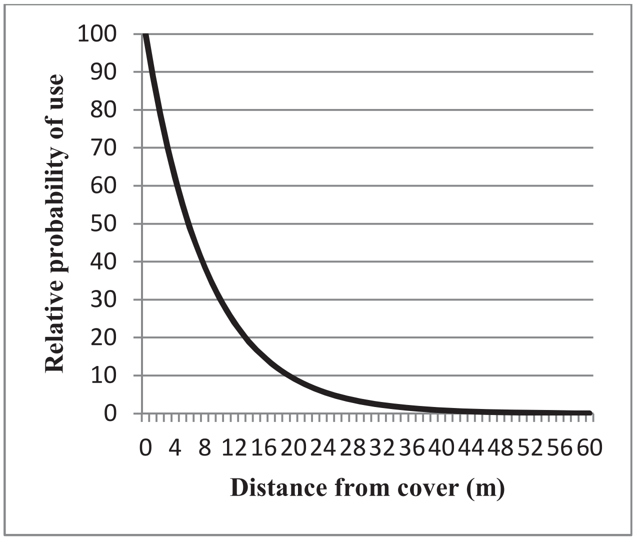

Figure 6-10. Effect of distance from cover on the relative probability of use of black bears within use areas on the Kenai Peninsula, Alaska, USA.

Table 6-11. Models with recreation, human development, and landscape features potentially affecting habitat selection by black bears within use areas on the Kenai Peninsula, Alaska, USA.

Model		
Elements	Number	Variables
Recreation	1	ALL_SITES_KM + K_TRAILS_KM
Development	2	DEVELOP_KM
Streams	3	LOW_STM_KM
Cover	4	COVER_D
Human effects	5	ALL_SITES_KM + K_TRAILS_KM + DEVELOP_KM
Human effects + Cover	6	ALL_SITES_KM + K_TRAILS_KM + DEVELOP_KM + COVER_D
Streams + Cover	7	LOW_STM_KM + COVER_D
Global	8	ALL_SITES_KM + K_TRAILS_KM + DEVELOP_KM + LOW_STM_KM + COVER_D

Table 6-12. AIC*c* scores and differences in AIC*c* scores (Δ) and AIC*c* weights (*wi*) within resource selection function models representing factors affecting the location of black bears within use areas on the Kenai Peninsula, Alaska, USA.

Model elements	Model number	AIC$_c$	ΔAIC$_c$	w_i
Recreation sites + Trails + Development + Cover[a]	6	154.6	0.0	0.3208
Cover[a]	4	154.8	0.2	0.2951
Global[a]	8	154.4	0.8	0.2157
Streams + Cover[a]	7	156.4	1.8	0.1292
Development	2	159.2	4.6	0.0315
Recreation sites + Trails + Development	5	163.1	8.5	0.0045
Streams	3	164.4	9.8	0.0023
Recreation sites + Trails	1	166.6	12.0	0.0008

[a] Models that were entered into the multi-model through model averaging.

The mean probability of use at 3,144 random points across the landscape ($\overline{x} = 80.9$) was significantly different than the mean probability of use within black bear use areas ($\overline{x} = 89.0$) ($t_{126} = 10.10$, $P = <0.0001$). The mean probability of use within use areas for male black bears ($\overline{x} = 85.3$) was significantly different than the mean probability of use within use areas for female black bears ($\overline{x} = 90.8$) ($t_{39} = -4.99$, $P = <0.0001$).

Discussion

Nondispersing black bears on the Kenai Peninsula have well-defined use areas selected within the context of a larger landscape that are consistent in size within sex classes, as reported elsewhere by Powell et al. (1997). These black bears live in a landscape of heterogeneous, patchy habitats and move among patches containing varying food resources on a daily and seasonal basis, but have annual use areas that are generally stable from year to year (similar to those reported by Powell et al. 1997). Vegetation composed the majority of the diet of black bears on the Kenai Peninsula (Smith 1984, Schwartz and Franzmann 1991). The almost complete absence of salmon in the assimilated diets of black bears on the Kenai Peninsula led to their being largely herbivorous and frugivorous (i.e., 83.6% plant matter in their diet) (Fortin et al. 2007). As a result, food availability and acquisition were likely major limiting factors, so black bears likely structured selection of their use areas according to the productivity of food resources and security (e.g., Amstrup and Beecham 1976; Alt et al. 1977; Young and Ruff 1982; Powell 1987; Powell et al. 1997; Mitchell et al. 2002).

Food Resources and Distribution of Black Bears

The composition of forest understory vegetation is likely more important than the overstory in describing the quality of habitat for black bears (Grenfell and Brody 1986). However, information available to us for describing characteristics of vegetation on the Kenai Peninsula (Begley et al. 2017) did not provide sufficient detail to define locations and densities of preferred understory food items (e.g., lowbush cranberries (*Vaccinium vitis-idaea*), American devilsclub (*Oplopanax horridus*) [Smith 1984, Schwartz and Franzmann 1991]). We were able to describe use of land cover classes by black bears; these classes were primarily described from characteristics of the vegetation overstory on the Kenai Peninsula.

The results of our analysis of the use of land cover class by black bears on the Kenai Peninsula were not statistically significant. However examination of the patterns of use by black bears within land cover classes can reveal important habitat associations (Rice et al. 2008). Our analysis described patterns of habitat use by land cover classes that were expected considering the reliance of black bears on vegetation and berries as food (Tables 6-5 and 6-6). Patterns of habitat use across the landscape showed a preference for the forb land cover class by females in the spring that contained new growth of vegetation as described by Smith (1984) and Schwartz and Franzmann (1991). Shrub land cover classes were preferred during spring and summer at the landscape scale and during summer at the use-area scale indicating use of persistent berries (e.g., lowbush cranberries) during spring and current year's production of berries during summer, prior to denning (Suring et al. 2006, 2008).

During all seasons black bears avoided the conifer forest cover class and selected the deciduous forest and mixed forest cover types. Despite the potential security value of conifer forests, black bears may have limited their use of this cover class because they provided limited food. Deciduous forest and mixed forest cover types apparently offered a combination of light-dependent food plants (primarily berries) with the security of tree cover. Occurrence of American devilsclub and lowbush cranberries, the primary food items of black bears on the Kenai Peninsula (Smith 1984, Schwartz and Franzmann 1991) was reported greater in forests with moderate to open overstories (e.g., deciduous forest and mixed forest cover types) than in forests with closed overstories (e.g., conifer forest cover class) (Reynolds 1990, Roorbach 2000, Hanley et al. 2014, Burton and Burton 2015).

Security and Distribution of Black Bears

Landscape

The variables that entered into our models describing probability of use by black bears at the landscape scale consistently described security for black bears rather than productivity of food resources. RSFs developed at this scale for black bears indicated that black bears selected use areas within the landscape based on densities of roads, densities of salmon streams (high salmon potential and low salmon potential), distance to cover, and elevation (Table 6-9).

Roads.–Human activities in wildlife habitat for resource extraction or recreation are often concentrated on roads. Subsequently, as road density on the Kenai Peninsula increased, the potential for black bears to encounter human activity increased leading to an avoidance of areas with higher densities of roads. While density of both high-capacity and low-capacity roads influenced use of black bears, high-capacity roads had a substantially greater effect (Figure 6-1); this relationship was also reported by Beringer et al. (1990). As observed by Brody and Pelton (1989) elsewhere, black bears on the Kenai Peninsula appeared to established use areas so as to keep road density or traffic volume below threshold levels.

This represents a common ecological tradeoff, in which bears are forced to choose between access to vital resources and mortality risk (Abrams 1991, Werner and Anholt 1993, Frid and Dill 2002). Density and use of roads on the Kenai Peninsula may have required black bears to use the landscape in a manner that minimized risks associated with roads while still achieving and maintaining necessary body condition (Elowe and Dodge 1989, Stringham 1990).

Salmon streams.–Brown bears and black bears coexist spatially on the Kenai Peninsula. Potential competition for the same resources (e.g., spawning salmon) appeared to cause the realized niches of black bears relative to use of the salmon resource to differ from their potential fundamental niche. Interference competition (Case and Gilpin 1974) is most common among bears when the social dominance of larger brown bears coincides with food sources (i.e., salmon) that are limited and spatially defendable at streams (Herrero 1978, McLellan 1993, Mattson et al. 2005). Fortin et al. (2007) established that the presence of brown bears on salmon streams on the Kenai Peninsula is sufficient to virtually eliminate association of black bears with salmon streams and their use of salmon. An observational study of sympatric brown and black bears on the Alaska Peninsula also showed that black bears moved through areas associated with salmon streams very quickly and captured <1% of all fish taken by bears (Tollefson et al. 2005). Additionally, areas with large densities of brown bears are avoided by black bears because brown bears prey on both cubs and adult black bears and pose a potential threat (Miller 1985, Mattson et al. 1992).

Black bears on the Kenai Peninsula appeared to established use areas within the landscape in a manner to minimize density of low- and high potential salmon streams (and associated conflict with brown bears) despite the availability of salmon, a high-value food source (Hilderbrand et al. 1999) (Figure 6-2). This pattern of habitat selection is in contrast with other areas in Alaska that have salmon available but do not have brown bears present (e.g., Frame 1974) or where brown bears are temporally precluded from fishing sites (e.g., Chi and Gilbert 1999). While increasing density of both of low- and high-potential salmon streams influenced use of black bears on the Kenai Peninsula, the effect of low-potential streams was substantially greater than high-potential salmon streams. Black bears may occasionally undertake the risk of encountering a brown bear at high-potential salmon streams because the high-quality food reward may be worth it (e.g., MacHutchon et al. 1998) but we found, that as a general pattern, black bears avoided salmon streams.

*Distance to Cover.–*Black bears are susceptible to attack from brown bears where they coexist and must temper their selection for habitats offering food resources with requirements for security cover. Lindzey and Meslow (1977) reported that black bears in Washington State used areas with more security habitat even though these areas had less food productivity. Davis et al. (2006) considered an ideal habitat configuration for black bears to include low horizontal visibility. The proximity of cover to forage has also been reported to influence habitat selection in other studies (Grenfell and Brody 1986, Vander Heyden and Meslow 1999, Lyons et al. 2003, Gaines et al. 2005). This aspect of habitat use was also evident in our findings related to habitat use by black bear at the landscape scale on the Kenia Peninsula (Figure 6-3).

*Elevation.–*As elevation increased across the landscape on the Kenai Peninsula, the probability of use by black bears decreased. Few black bears were expected to occur above tree line at 500 m (i.e., 20 percent probability of use; Figure 6-4). Black bears were also rarely detected near the tree line in the Rocky Mountains in Alberta and British Columbia, possible due to competitive exclusion by brown bears (Mowat et al. 2005). Goldstein et al. (2010) reported that after brown bears leave foraging areas in the fall on the Kenai Peninsula, they often selected den sites that were associated with habitat high in elevation. This movement pattern may have precluded black bears from areas above tree line resulting in our findings.

Use-area

The variables that entered into our models describing probability of use by black bears within use areas consistently described security for black bears rather than productivity of food resources or other aspects of their natural history. The multi-model RSF developed at this scale for black bears indicated that they selected habitats within use areas based on distance to cover, densities of recreation sites, densities of human developments, densities of recreation trails, and densities of salmon streams with low salmon potential (Table 6-12). Quality of habitat, as described by the RSF, was primarily based on security. Female black bears consistently selected use areas with higher RSF values than did male black bears, indicating that security was more of a concern for female than males. This would enhance the contention that when balancing the risks and rewards of access to food, food resources may be higher priority for males whereas security may be more of a concern for females.

Distance to Cover.–As in the RSF developed for habitat selection at the landscape scale, distance to cover again entered into the RSF at the use-area scale. Based on the cumulative model weights of the multi-model, distance to cover had the highest importance of all variables in the RSF. There was a level of magnitude difference in the effect of this variable at the use-area scale compared to the landscape scale. Relative probability of use dropped below 20 percent at >13 meters from cover within the use area vs. >540 m at the landscape scale indicating that access to security cover was essential to black bears on a day-to-day basis.

Recreation Sites/Human Development.–Although black bears have often been characterized as nuisances seeking anthropogenic foods at recreation sites (e.g., campgrounds) and at residences (e.g., Beckmann and Berger 2003, Merkle et al. 2013), the work of Johnson et al. (2015) suggested that black bears perceive a cost associated with that behavior and limit selection for human development to poor natural food years when alternatives were not available. These areas may provide abundant, high quality forage for black bears, but usually also present a risk of lethal conflict with humans (DeStefano and DeGraaf 2003). Animals generally respond to this trade-off by avoiding human-dominated landscapes (the apparent reaction by our study animals), adjusting their foraging behavior spatially or temporally to avoid conflicts, or by simply ignoring the risk and foraging in a normal manner (Knight and Cole 1991, Whittaker and Knight 1998).

Our work showed that black bears on the Kenai Peninsula established use areas where densities of recreation sites and human development were very low. In effect, avoiding such sites and the potential food resources associated with them. Schwartz and Franzmann (1991) indicated that during the timeframe that the data on black bear locations that we used were collected, high quality food in the form of moose calves was available to this population of black bears in addition to generally good production of American devilsclub and lowbush cranberry fruits. As a result, these black bears were not induced to seek out anthropogenic foods at recreation sites and at residences.

Recreation Trails.–Kasworm and Thier (1994) reported that black bears that survived hunting mortality during their study in northwest Montana had movement patterns that kept them farther from trails than black bears that did not survive. Additionally in Montana, Kasworm and Manley (1990) found that black bears used habitat in proximity to trails less than expected throughout the non-denning season. Studies elsewhere did not show an avoidance of recreation trails by black bears (e.g., Tennessee: Quigley 1982, Maryland: Fecske et al. 2002, Colorado: Baldwin and Bender 2008). Our results showed an avoidance of trails by black bears during establishment of use areas. Density of recreation trails within use areas was very low (i.e., <20 percent relative probability of use when trail density exceeded 200 m/square km).

Salmon streams.–Black bears selected use areas with low densities of salmon streams that had low potential for spawning salmon and then avoided parts of the use areas with greater densities of salmon streams. Relative probability of use of black bears within use areas decreased rapidly as density of salmon streams increased (i.e., <20 percent relative probability of use as density of streams increased >145 m/square km) despite the potential for access to high-quality food (Figure 6-9). Again, we expect this pattern of habitat use resulted from attempts to avoid any contact with brown bears.

Management Implications

Maintaining large tracts of forested habitat for security cover with minimal human disturbance appears essential to maintaining populations of black bears on the Kenai Peninsula. Development of roads, subdivisions, recreation sites, and recreation trails without consideration of their potential effect on black bears can influence them in several ways: disturbance, displacement, social disruption, and human-induced mortality (McLellan 1990). As the stresses of expanding development reduce habitats available to black bears, the availability of high-quality food and security cover become more critical in remaining habitats (Pelton 1982). If black bears are forced to forage on low-quality food resources in sites where they have less protection, the associated increased mortality will result in declining populations.

Similar to Gaines et al. (2005), our results highlight 2 features of road access that land and wildlife managers on the Kenai Peninsula may wish to include while considering potential impacts of development on black bears. Open road densities seem to have significant influence on where black bears establish their use areas on the Kenai Peninsula and elsewhere (Young and Beecham 1986, Brody and Pelton 1989). Traffic volumes also appear to influence the relative probability of use by black bear of the landscape. Both of these variables can be managed through limitations on road construction and by road closures; manipulating timing and location of road access may be useful tools in the management of black bears.

Additionally, movement corridors between seasonal feeding areas (e.g., Schwartz and Franzmann 1991) and for population dispersal should be maintained with continuous security cover (Beecham 1983). Maintenance of such corridors, including road overpasses or underpasses at critical locations is an important aspect of management strategies for black bears (Jonkel 1978, Pelton 2000).

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Appendix – Black Bear

Table A6-1. Selection of land cover classes by male black bears across the landscape during spring on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 15)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.003	-0.047	$-0.034 \leq p \leq 0.139$
Forb	0.090	0.051	-0.068	$-0.100 \leq p \leq 0.286$
Shrub	0.138	0.094	-0.072	$-0.106 \leq p \leq 0.374$
Conifer forest	0.515	0.544	0.028	$0.203 \leq p \leq 0.857$
Deciduous forest	0.058	0.114	0.095	$-0.104 \leq p \leq 0.218$
Mixed forest	0.172	0.195	0.033	$-0.076 \leq p \leq 0.431$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-2. Selection of land cover classes by male black bears across the landscape during summer on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 7)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.003	-0.046	$-0.055 \leq p \leq 0.191$
Forb	0.090	0.045	-0.079	$-0.163 \leq p \leq 0.376$
Shrub	0.138	0.154	0.025	$-0.208 \leq p \leq 0.483$
Conifer forest	0.515	0.406	-0.114	$-0.087 \leq p \leq 1.016$
Deciduous forest	0.058	0.144	0.143	$-0.208 \leq p \leq 0.292$
Mixed forest	0.172	0.249	0.108	$-0.185 \leq p \leq 0.551$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-3. Selection of land cover classes by male black bears across the landscape during all seasons on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 21)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.003	-0.046	$-0.030 \leq p \leq 0.122$
Forb	0.090	0.063	-0.047	$-0.078 \leq p \leq 0.255$
Shrub	0.138	0.170	0.050	$-0.047 \leq p \leq 0.337$
Conifer forest	0.515	0.429	-0.089	$0.142 \leq p \leq 0.804$
Deciduous forest	0.058	0.132	0.125	$-0.064 \leq p \leq 0.193$
Mixed forest	0.172	0.202	0.044	$-0.030 \leq p \leq 0.391$

[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-4. Selection of land cover classes by female black bears across the landscape during spring on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 34)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.003	-0.048	$-0.021 \leq p \leq 0.101$
Forb	0.090	0.094	0.007	$-0.039 \leq p \leq 0.220$
Shrub	0.138	0.160	0.034	$-0.007 \leq p \leq 0.295$
Conifer forest	0.515	0.378	-0.144	$0.158 \leq p \leq 0.742$
Deciduous forest	0.058	0.148	0.149	$-0.014 \leq p \leq 0.164$
Mixed forest	0.172	0.217	0.065	$0.030 \leq p \leq 0.344$

[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-5. Selection of land cover classes by female black bears across the landscape during summer on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 23)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.004	-0.046	$-0.030 \leq p \leq 0.117$
Forb	0.090	0.089	-0.002	$-0.069 \leq p \leq 0.248$
Shrub	0.138	0.171	0.051	$-0.037 \leq p \leq 0.328$
Conifer forest	0.515	0.330	-0.201	$0.070 \leq p \leq 0.791$
Deciduous forest	0.058	0.139	0.136	$-0.052 \leq p \leq 0.187$
Mixed forest	0.172	0.267	0.132	$0.022 \leq p \leq 0.381$

[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-6. Selection of land cover classes by female black bears across the landscape during all seasons on the Kenai Peninsula Alaska, USA**.**

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 42)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.003	-0.047	$-0.020 \leq p \leq 0.094$
Forb	0.090	0.082	-0.013	$-0.030 \leq p \leq 0.207$
Shrub	0.138	0.178	0.061	$0.022 \leq p \leq 0.279$
Conifer forest	0.515	0.359	-0.166	$0.163 \leq p \leq 0.719$
Deciduous forest	0.058	0.147	0.148	$0.002 \leq p \leq 0.153$
Mixed forest	0.172	0.230	0.082	$0.058 \leq p \leq 0.327$

[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-7. Selection of land cover classes by all black bears across the landscape during spring on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 49)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.002	-0.050	$-0.014 \leq p \leq 0.089$
Forb	0.090	0.080	-0.017	$-0.023 \leq p \leq 0.198$
Shrub	0.138	0.139	0.002	$0.008 \leq p \leq 0.268$
Conifer forest	0.515	0.427	-0.091	$0.240 \leq p \leq 0.704$
Deciduous forest	0.058	0.140	0.138	$0.009 \leq p \leq 0.146$
Mixed forest	0.172	0.212	0.057	$0.057 \leq p \leq 0.315$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-8. Selection of land cover classes by all black bears across the landscape during summer on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 30)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.003	-0.047	$-0.023 \leq p \leq 0.106$
Forb	0.090	0.077	-0.022	$-0.052 \leq p \leq 0.228$
Shrub	0.138	0.168	0.046	$-0.013 \leq p \leq 0.305$
Conifer forest	0.515	0.344	-0.184	$0.114 \leq p \leq 0.757$
Deciduous forest	0.058	0.143	0.142	$-0.026 \leq p \leq 0.171$
Mixed forest	0.172	0.265	0.129	$0.052 \leq p \leq 0.355$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-9. Selection of land cover classes by all black bears across the landscape during all seasons on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available across the landscape[2]	Mean proportion (p) used across the landscape (n = 63)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in the landscape (p)
Barren	0.027	0.003	-0.047	$-0.015 \leq p \leq 0.082$
Forb	0.090	0.075	-0.025	$-0.013 \leq p \leq 0.185$
Shrub	0.138	0.176	0.058	$0.049 \leq p \leq 0.253$
Conifer forest	0.515	0.381	-0.141	$0.219 \leq p \leq 0.682$
Deciduous forest	0.058	0.143	0.142	$0.026 \leq p \leq 0.136$
Mixed forest	0.172	0.221	0.070	$0.082 \leq p \leq 0.298$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 3,041 random points across the landscape

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-10. Selection of land cover classes by male black bears within use areas during spring on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (p) used within use areas (n = 13)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (p) (95% family confidence coefficient)
Barren	0.004	0.002	-0.005	$-0.029 \leq p \leq 0.053$
Forb	0.067	0.044	-0.041	$-0.107 \leq p \leq 0.251$
Shrub	0.118	0.096	-0.036	$-0.121 \leq p \leq 0.356$
Conifer forest	0.562	0.536	-0.025	$0.169 \leq p \leq 0.927$
Deciduous forest	0.082	0.116	0.056	$-0.120 \leq p \leq 0.285$
Mixed forest	0.166	0.205	0.057	$-0.092 \leq p \leq 0.440$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-11. Selection of land cover classes by male black bears within use areas during summer on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (*p*) used within use areas (n = 7)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (*p*) (95% family confidence coefficient)
Barren	0.005	0.000	-0.010	$0.000 \leq p \leq 0.076$
Forb	0.057	0.042	-0.028	$-0.159 \leq p \leq 0.290$
Shrub	0.091	0.158	0.107	$-0.208 \leq p \leq 0.379$
Conifer forest	0.549	0.395	-0.158	$-0.095 \leq p \leq 1.048$
Deciduous forest	0.095	0.148	0.086	$-0.208 \leq p \leq 0.388$
Mixed forest	0.203	0.257	0.073	$-0.181 \leq p \leq 0.607$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-12. Selection of land cover classes by male black bears within use areas during all seasons on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (*p*) used within use areas (n = 18)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (*p*) (95% family confidence coefficient)
Barren	0.009	0.003	-0.011	$-0.032 \leq p \leq 0.067$
Forb	0.085	0.054	-0.054	$-0.087 \leq p \leq 0.259$
Shrub	0.140	0.157	0.025	$-0.070 \leq p \leq 0.358$
Conifer forest	0.508	0.456	-0.052	$0.145 \leq p \leq 0.820$
Deciduous forest	0.090	0.116	0.043	$-0.084 \leq p \leq 0.269$
Mixed forest	0.168	0.213	0.065	$-0.043 \leq p \leq 0.402$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-13. Selection of land cover classes by female black bears within use areas during spring on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (p) used within use areas (n = 33)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (p) (95% family confidence coefficient)
Barren	0.003	0.002	-0.001	$-0.019 \leq p \leq 0.027$
Forb	0.096	0.092	-0.006	$-0.041 \leq p \leq 0.231$
Shrub	0.169	0.157	-0.018	$-0.011 \leq p \leq 0.342$
Conifer forest	0.431	0.376	-0.060	$0.153 \leq p \leq 0.659$
Deciduous forest	0.117	0.151	0.053	$-0.014 \leq p \leq 0.266$
Mixed forest	0.185	0.222	0.052	$0.030 \leq p \leq 0.364$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-14. Selection of land cover classes by female black bears within use areas during summer on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (p) used within use areas (n = 14)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (p) (95% family confidence coefficient)
Barren	0.003	0.001	-0.004	$-0.025 \leq p \leq 0.043$
Forb	0.113	0.094	-0.032	$-0.113 \leq p \leq 0.338$
Shrub	0.163	0.180	0.026	$-0.092 \leq p \leq 0.424$
Conifer forest	0.406	0.335	-0.081	$0.001 \leq p \leq 0.754$
Deciduous forest	0.124	0.135	0.019	$-0.107 \leq p \leq 0.357$
Mixed forest	0.191	0.254	0.087	$-0.055 \leq p \leq 0.470$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-15. Selection of land cover classes by female black bears within use areas during all seasons on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (p) used within use areas (n = 38)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (p) (95% family confidence coefficient)
Barren	0.003	0.001	-0.003	$-0.015 \leq p \leq 0.025$
Forb	0.102	0.088	-0.024	$-0.034 \leq p \leq 0.233$
Shrub	0.182	0.181	-0.001	$0.016 \leq p \leq 0.348$
Conifer forest	0.412	0.363	-0.055	$0.156 \leq p \leq 0.624$
Deciduous forest	0.120	0.138	0.030	$-0.010 \leq p \leq 0.259$
Mixed forest	0.181	0.227	0.066	$0.047 \leq p \leq 0.346$

[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-16. Selection of land cover classes by all black bears within use areas during spring on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (p) used within use areas (n = 46)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (p) (95% family confidence coefficient)
Barren	0.003	0.002	-0.002	$-0.015 \leq p \leq 0.025$
Forb	0.088	0.079	-0.015	$-0.027 \leq p \leq 0.198$
Shrub	0.155	0.140	-0.022	$0.004 \leq p \leq 0.296$
Conifer forest	0.468	0.422	-0.049	$0.228 \leq p \leq 0.663$
Deciduous forest	0.107	0.141	0.054	$0.005 \leq p \leq 0.228$
Mixed forest	0.179	0.217	0.054	$0.056 \leq p \leq 0.329$

[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-17. Selection of land cover classes by all black bears within use areas during summer on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (p) used within use areas (n = 46)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (p) (95% family confidence coefficient)
Barren	0.001	0.004	-0.006	$-0.017 \leq p \leq 0.040$
Forb	0.077	0.095	-0.031	$-0.077 \leq p \leq 0.264$
Shrub	0.173	0.139	0.052	$-0.046 \leq p \leq 0.339$
Conifer forest	0.355	0.454	-0.109	$0.078 \leq p \leq 0.742$
Deciduous forest	0.140	0.114	0.041	$-0.061 \leq p \leq 0.298$
Mixed forest	0.255	0.195	0.082	$0.003 \leq p \leq 0.425$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Table A6-18. Selection of land cover classes by all black bears within use areas during all seasons on the Kenai Peninsula Alaska, USA.

Land cover class[1]	Proportion available within use areas[2]	Mean proportion (p) used within use areas (n = 56)	Modified Ivlev's selectivity index[3]	Confidence interval on proportion in use areas (p) (95% family confidence coefficient)
Barren	0.005	0.002	-0.005	$-0.014 \leq p \leq 0.029$
Forb	0.097	0.077	-0.033	$-0.017 \leq p \leq 0.201$
Shrub	0.169	0.174	0.007	$0.039 \leq p \leq 0.301$
Conifer forest	0.443	0.393	-0.054	$0.220 \leq p \leq 0.619$
Deciduous forest	0.110	0.131	0.034	$0.012 \leq p \leq 0.221$
Mixed forest	0.177	0.223	0.066	$0.075 \leq p \leq 0.312$

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[1] See Begley et al. (2017) for a description of land cover classes

[2] Calculated from 434–497 random points within each use area

[3] Ivlev's selectivity index as modified by Reynolds-Hogland and Mitchell (2007)

Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 7 – Movement patterns and potential corridors for black bears on the Kenai Peninsula, Alaska, USA

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Introduction

The population of black bears on the Kenai Peninsula was recently estimated to be ≥4,000 (Herreman 2014). Although black bears are long-lived, mature slowly, and have low reproductive rates (Bunnell and Tait 1981) this population has a sport harvest that exceeds all other big game species on the Kenai Peninsula (mean annual harvest of 576 black bears) (Herreman 2014). The black bear population on the Kenai Peninsula is believed to be stable; however, expanding human activity in the area is projected to increase stress on bear populations (Schwartz and Franzmann 1992, Herreman 2014). Recruitment in this population is slow, and recovery from population reductions may require many years (Miller 1989). Dispersal of young females from natal areas is more limited than dispersal of young males (Schwartz and Franzmann 1992) so opportunities for dispersal and population maintenance need to be maintained. Black bears on the Kenai Peninsula also move seasonally to seek high quality foods (Schwartz and Franzmann 1991). Black bears with access to high quality foods, especially in the fall, tend to have superior reproductive performance (Rogers 1987, Elowe and Dodge 1989).

Adult female survival has been shown to be closely linked to population persistence in black bears leading to the recommendation that highway mortality of this segment of the population should be minimized (Hebblewhite et al. 2003). Although black bears have been reported to alter their patterns of movements and space use in relation to highways, they consistently continue to cross highways (Brody and Pelton 1989, Lewis et al. 2011). However, as traffic volume increases, black bears increasingly tend to change highway-crossing patterns or avoid crossing highways (McCoy 2005). Black bears have been reported to consistently cross the Sterling Highway; a large proportion of wildlife-vehicle collisions (WVCs) on this highway result in deaths of black bears (Ernst et al. 2009). WVCs have been identified as an important cause of reduction in population abundance for black bears (Nicholson 2009).

Black bears on the Kenai Peninsula have been described as genetically divergent from those on the mainland (Robinson et al. 2007a). Currently, population connectivity throughout the Kenai Peninsula is high. However, a spatial analysis indicated that the genetic group on the Kenai Peninsula was not completely intermixed, but exhibited a patchy genetic pattern (Robinson et al. 2007b). Genetic patches were distributed in different ecological regions of the Kenai Peninsula and were separated by anthropogenic features such as major highways. This spatial structuring and relation to roads (or landforms that are correlated with roads) indicates the potential for black bear populations to become increasingly subdivided if barriers become more severe.

When black bear populations experience habitat fragmentation and reductions in abundance, maintaining connectivity among subpopulations may be crucial to ensuring that ecologic, social, and economic benefits provided by the population continue. This may be accomplished by providing opportunities for exchange of demographic migrants among its subpopulations or colonization of extirpated areas (Noss et al. 1996), particularly for females. Because dispersal distances of female black bears are generally small (Schwartz and Franzmann 1992), bridging larger distances between subpopulations or habitat areas will require true habitat linkages. Such habitat linkages should be of sufficient size and quality so that female black bears can gradually move through the linkages over time with a low risk of mortality, particularly in areas with a high density of development (Nicholson 2009). Providing safe passage across highways is an integral component of designing functional habitat linkages among black bear populations (van Mannen et al. 2012).

Our specific objective in this work was to identify potential movement corridors for black bear on the Kenai Peninsula so that resource managers could include that information in planning for habitat management, resource development, and infrastructure development (including transportation). Specifically we wanted to identify potential movement patterns within milepost (MP) 45–60 on the Sterling Highway that may be suitable areas for practices to mitigate the effects of highway development on black bears. We focused on this objective by incorporating resource selection functions (RSFs; Manly et al. 2002) developed using telemetry data (Chapter 6; Suring et al. 2017) to predict areas of high quality habitat across the Kenai Peninsula, and to predict probable movement corridors throughout the Peninsula. We combined RSF modeling with least-cost modeling (e.g., Chetkiewicz and Boyce 2009), and circuit theory (McRae et al. 2008), to identify and map linkage areas within our study area.

Methods

Resource Selection Function

Development of a RSF describing landscape use by black bears on the Kenai Peninsula was reported on by Suring et al. (2017) (Chapter 6). This analysis were based on locations of 72 adult female radio-collared black bears 62 adult male black bears, and 77 subadult black bears from 1978-1985, from which 5,258 telemetry point locations were obtained (Schwartz and Franzmann 1991). In brief, landscape use by black bears was modeled by logistic regression with multiple explanatory variables. Variables were included in the RSF models when significant differences occurred between used and available locations. Through this process, variables were eliminated so the models included those most specifically affecting habitat selections by black bears. Landscape characteristics associated with telemetry locations from black bears not included in the RSF analysis were used to evaluate the resulting model (Chapter 6; Suring et al. 2017).

Resistance Surface

We generally followed the process outlined by Beier et al. (2007) to move from the range of estimated relative probability of use derived from the RSF calculations for black bear to the development of resistance surfaces.

We used the inverse of the mean relative probability of use to generate resistance values across the landscape on the Kenai Peninsula. Through this subjective translation (Beier et al. 2007), we assumed that pixels with higher habitat values afforded lower costs to movement than those with low habitat values. Resistance reflects the ecological cost of black bears traveling through a pixel. In general, resistance increases with the energetic cost of travel through the pixel. Resistance decreases as the quality of habitat increases in a pixel; it is not necessarily related to the speed of travel through the pixel.

Core Areas

We followed a convention similar to that established by WHCWG (2010) and used the term core area to describe high-quality habitats between which we evaluated movement patterns for focal species. Core areas were generated using the Core Mapper tool from the Gnarly Landscape Utilities ArcGIS toolbox applied to the results of RSF models with probability of use scaled from 0-100 (Shirk and McRae 2013). Core habitat areas for black bears were defined as significant habitat areas that are expected or known to be important based on habitat association modeling (WHCWG 2010).

To meet that criterion we described potential core habitat as areas having a habitat value >80 (on a 0 – 100 scale). We then calculated the proportion of habitat within a circular moving window with a radius of 1,000 m (i.e., the probable distance black bears move on a daily basis [Amstrup and Beecham 1976, Young and Ruff 1982, Powell et al. 1997]). This step generated a surface representing where the largest concentrations of good habitat existed. We removed cells from the initial maps of core areas if the average habitat value of the window centered on a particular cell was <85 (on a 0 – 100 scale). This prevented habitat cores from being identified in areas where high-quality habitat was not sufficiently concentrated.

Potential Movement Corridors

Connectivity among habitat patches for animals within a landscape depends on characteristics of the landscape (structural connectivity) and on aspects of the mobility of the animal (functional connectivity) (Adriaensen et al. 2003). Least-cost modeling has been used to incorporate detailed information about the landscape as well as behavioral aspects of the animal to describe connectivity. Cost-weighted distance approaches to estimate movement corridors of animals represent the least accumulative cost required to move between a specified source and a specified destination (Beier et al. 2007). This method provides a flexible tool that provides insights into the relationship between dispersal and landscape characteristics. This method also identifies a set of near-optimal corridors for the landscape linkage network, with emphasis on corridors with the least cumulative cost-weighted distances (Chetkiewicz et al. 2006, Beier et al. 2008).

While these least-cost models implicitly assume animals have perfect knowledge of the landscape, current flow models assume they do not have knowledge of potential movements more than 1 step ahead (Newman 2005). Real-world movement behavior of animals like black bear may fall somewhere between these extremes (McRae et al. 2008, Richard and Armstrong 2010). While shortest-path methods have been used to develop empirical multivariate models of habitat connectivity (Schwartz et al. 2009, Richard and Armstrong 2010), predictions from current flow-based models are highly correlated with observed genetic distance in several plant and animal populations and may better reflect actual movement corridors (McRae et al. 2008, Lee-Yaw et al. 2009, Shirk et al. 2010).

Circuit theory has been applied to connectivity analyses in other fields (McRae et al. 2008), and has been used to model gene flow in heterogeneous landscapes (McRae 2006, McRae and Beier 2007). Because connectivity increases with multiple pathways in circuit networks, distance metrics based on electrical connectivity are applicable to processes that respond positively to increasing connections and redundancy (McRae et al. 2008). Circuit theory is based in Markovian random walk theory and describes every movement as a random choice with movement in every direction equally probable. The landscape then acts as an electrical-resistance surface or, inversely, as a conductance surface, as the current travels outward to surrounding cells from the source patch of core habitat. The areas of least resistance or greatest conductance across the landscape are the most probable areas for movement. This theory can be applied to predict movement patterns of random walkers moving across complex landscapes, to generate measures of connectivity or isolation of habitat patches, and to identify important connective elements (e.g., corridors) for conservation planning.

The resistance distance concept of circuit theory incorporates multiple pathways connecting nodes, with resistance distances measured between core area pairs decreasing as more connections are added (McRae et al. 2008). Therefore, the resistance distance does not reflect the distance traveled or movement cost accrued by an individual animal. Rather, it incorporates both the minimum movement distance or cost and the availability of alternative pathways. As additional linkages are added, individuals do not necessarily travel shorter distances, but have more pathways available to them. Current density can be used to identify landscape corridors or ''pinch points,'' (i.e., features through which moving animals have a high likelihood – or necessity – of passing). High current through these pinch points indicates that stopping the flow through these points, or maintaining it, will have a high impact on connectivity.

To identify potential movement corridors, we used a combination of least-cost modeling and circuit theory (McRae et al. 2008) using the Linkage Mapper Toolkit (McRae and Kavanagh 2011) in ArcGIS 10.3. These analyses were performed by applying the final map of core habitat to identify start and end locations for building the corridor network from the resistance layers. We used the one-to-many criterion, whereby 1 source was connected to all end nodes in an iterative fashion. Circuit theory supplemented least-cost analyses to identify important areas for prioritization of conservation connectivity associated with the Sterling Highway (McRae et al. 2008).

The Pinchpoint Mapper module (McRae 2012) of Linkage Mapper was used to apply circuit theory through the program Circuitscape (McRae and Shah 2009) to identify and map "pinch points" (i.e., constrictions) within the resulting corridors. Circuitscape calculates the resistance of the landscape to movement between each pair of core areas (analogous to electrical resistance in a circuit diagram), allowing for multiple pathways between core areas. The pinch points we identified represented locations where loss of a small area could disproportionately compromise connectivity of the broader landscape. Using this hybrid approach, we merged least-cost corridors with pinch points to identify and display the most efficient movement corridors and the critical areas within them that contributed the most to habitat connectivity (McRae and Kavanagh 2011).

Results

Resource Selection Function

The most parsimonious model within the suite of models evaluated consisted of covariates for low-use and high-use roads, low-potential and high-potential salmon streams, distance to cover, and elevation (Chapter 6; Suring et al. 2017). There was evidence that black bears avoided areas with greater densities of roads, avoided areas with greater densities of salmon streams, avoided areas further from cover, and avoided areas with higher elevation.

Probability of Use and Resistance to Movement

Probability of use (and the inverse, resistance to movement) varied across the Kenai Peninsula landscape for black bears and ranged from none (0%; water, ice fields) to very high (92–100%) (Figure 7-1). Black bears likely structured their use of habitats according to the productivity of food resources and to the security they provided (Chapter 6; Suring et al. 2017).

Core Areas

Patterns of habitat quality for black bears on the Kenai Peninsula were closely associated with low-elevation areas in proximity to cover (Figure 7-2). Consequently, core areas were concentrated on the west side of the Kenai Peninsula (Figure 7-2). One-hundred-ninety-two core areas for black bear were modeled and mapped across the Kenai Peninsula. Core areas varied in size from 1.0–730.4 km^2 ($\bar{x}$ = 21.4 km^2) with a mean habitat quality index value of 91.7 (on a 0–100 scale).

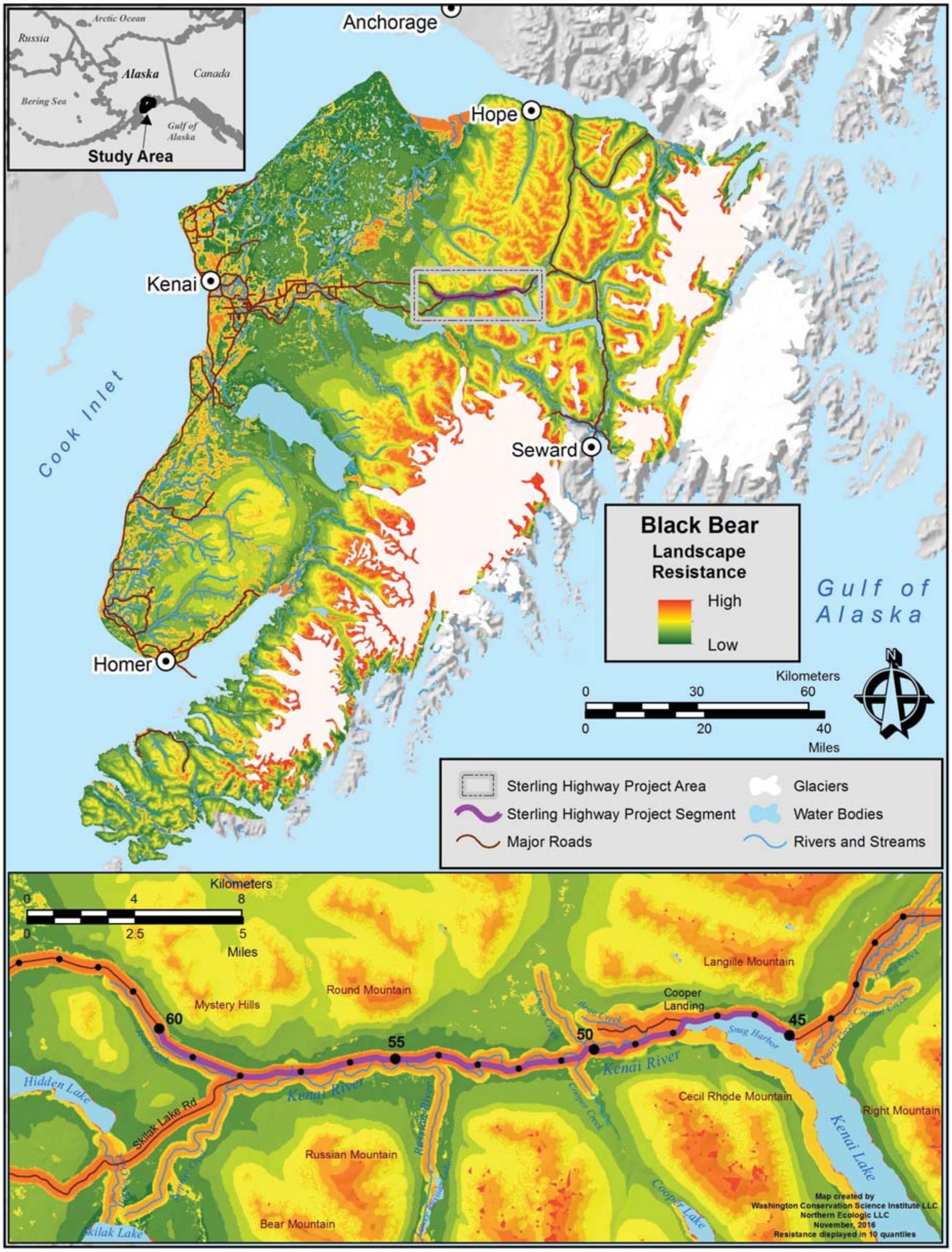
Potential Movement Corridors

Analysis of least-cost corridors showed multiple potential corridors across the Sterling Highway for black bears from milepost (MP) 45–60 in the vicinity of Cooper Landing (Figure 7-3). This analysis revealed potential crossing points in the vicinity of MP 48, 50–51, 54–56, 57, and 59. We used circuit theory to estimate the effective resistance of the landscape within these corridors between all pairs of core areas (all-to-one mode in the Circuitscape software; McRae and Shah 2011). This analysis prioritized potential crossing points at MP 51, 53, 56, and 58 (Figure 7-4).

Based on these analyses, potential north-south movements of black bears across the Sterling Highway in the vicinity of Cooper Landing revealed 2 primary pinch points where animals were most likely to concentrate their crossings (MP 50–51 in the vicinity of Juneau and Cooper creeks and MP 53 where the Sterling Highway currently crosses the Kenai River).

Discussion

The most efficient and effective means of mitigating the barrier effects of roadways on black bears is to identify important crossing areas and focus management activities within those areas (Glista et al. 2009). We have demonstrated through modeling that the movement patterns of black bears on the Kenai Peninsula are likely to be impeded by the Sterling Highway. Individual black bears have been able to negotiate this potential obstacle, although mortality from WVCs can be high (Ernst et al. 2009). Additionally, the long-term persistence of the black bear population on the Kenai Peninsula may depend upon being able to successfully cross the Sterling Highway. Our work provided information about how characteristics of the landscape can be used to predict and identify likely road crossing areas. The high-probability crossing areas we identified and validated warrants management by landscape planners to promote continued wildlife use of these road crossing areas and to reduce WVCs.



Map created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016
Resistance displayed in 10 quantiles

Figure 7-1. Resistance surface used to model habitat connectivity for black bear on the Kenai Peninsula, Alaska, USA.

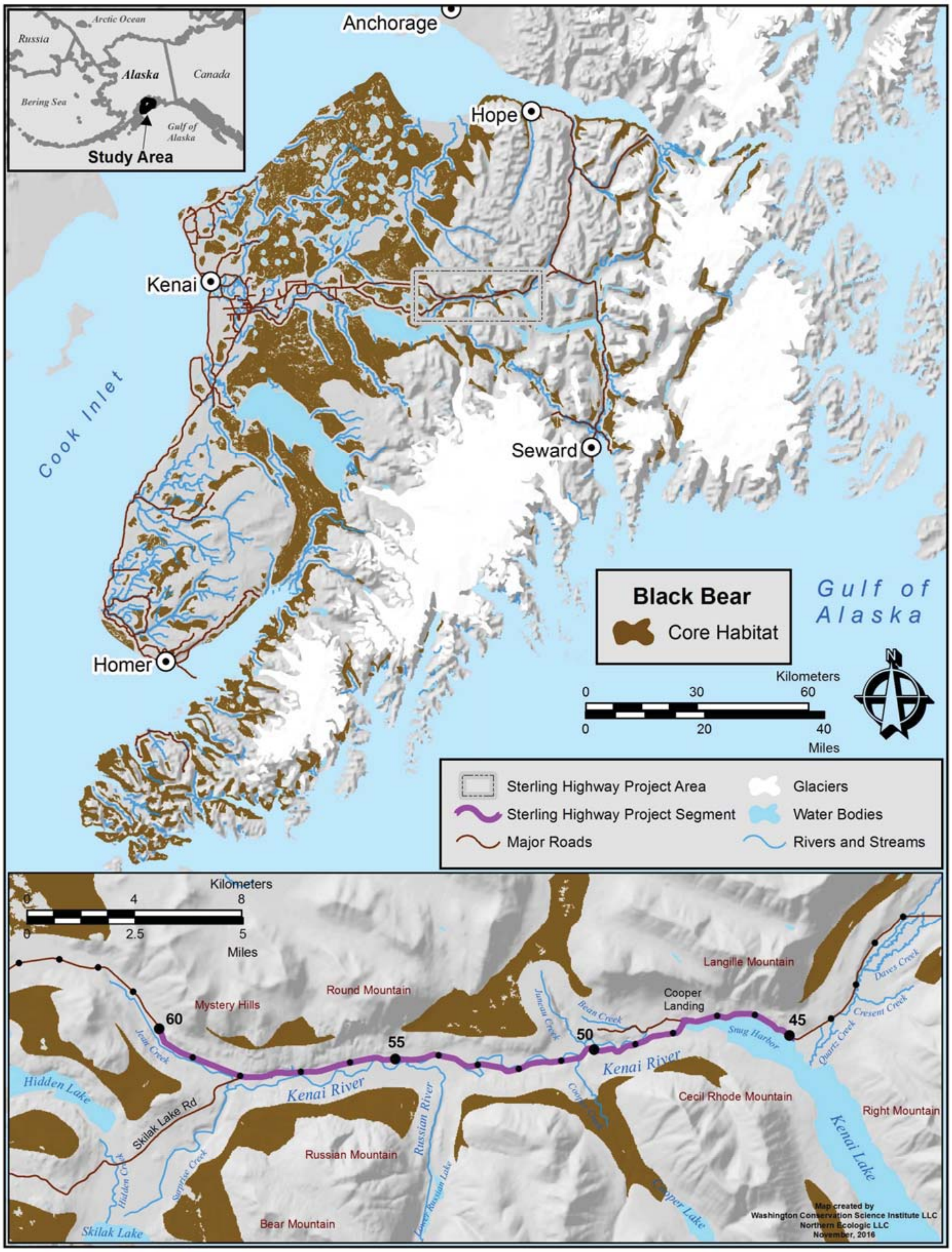
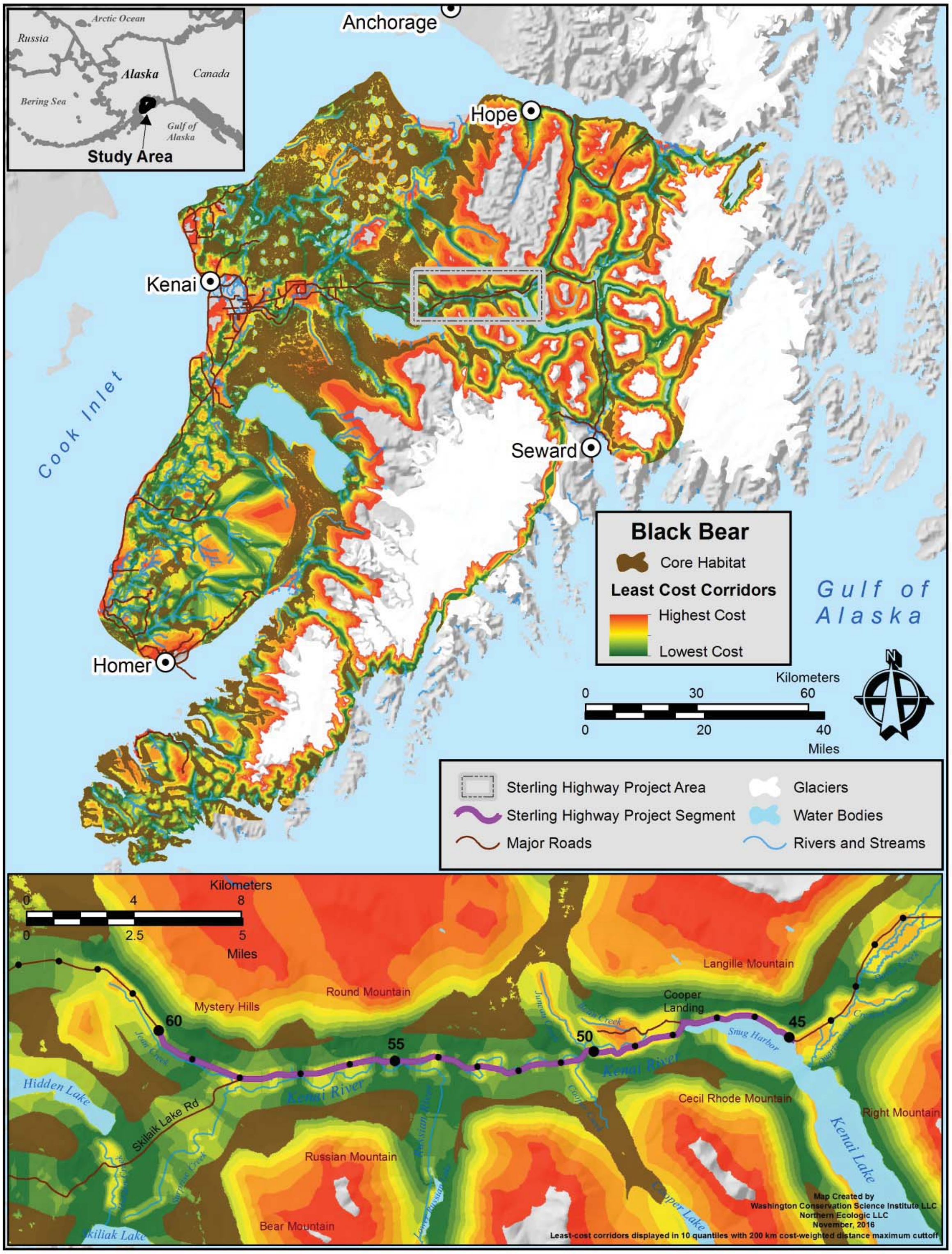


Figure 7-2. Core areas used to model habitat connectivity for black bear on the Kenai Peninsula, Alaska, USA.



Map Created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016

Least-cost corridors displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 7-3. Core areas for black bear and potential least-cost corridors for their movement across the Sterling Highway in the vicinity of Cooper Landing, Kenai Peninsula, Alaska, USA.

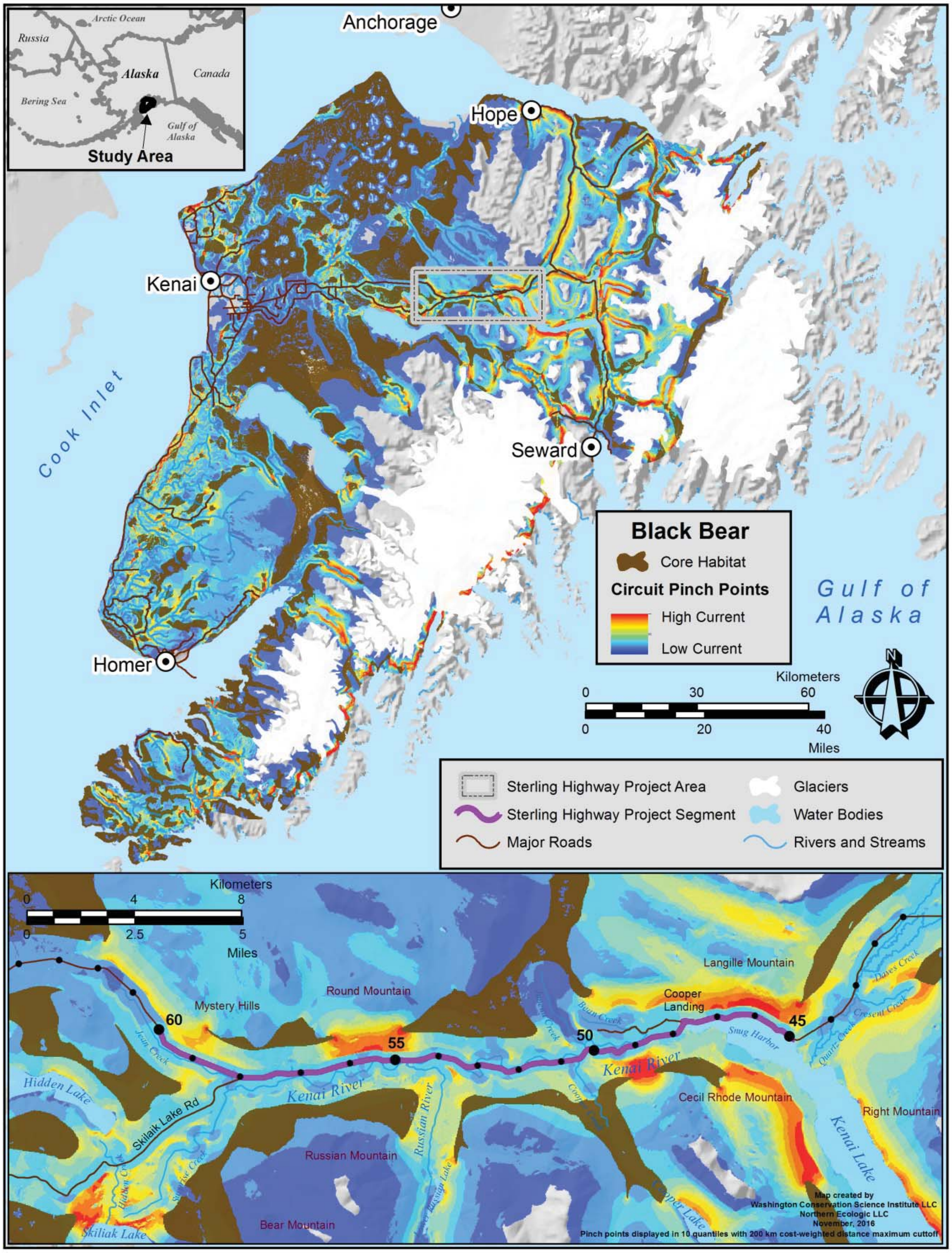


Figure 7-4. Core areas for black bear and the potential primary pinch points for their movement across the Sterling Highway in the vicinity of Cooper Landing, Kenai Peninsula, Alaska, USA.

Black bears on the Kenai Peninsula are likely crossing the Sterling Highway in response to life history demands and ecological influences (Gibeau et al. 2002, Chruszcz et al. 2003). An understanding of why black bears cross this highway would lead to knowledge of how these road crossings are related to the distribution of potential mates, social interactions, distribution of high quality forage, and other important life history considerations (Lewis et al. 2011). Additional research is necessary to evaluate if successful crossings of the Sterling Highway by black bears positively leads to gene flow in this population.

The objective of this study was to identify potential movement corridors for black bears on the Kenai Peninsula so that resource managers could include that information in planning for habitat management, resource development, and infrastructure development (including transportation). Identifying likely road-crossing areas for black bears allows landscape and transportation planners to focus management activities in key areas to promote black bear movement across roadways, maintain connectivity within and among populations on the Kenai Peninsula, and reduce the potential for WVCs.

Management Implications

Areas providing cover without associated human development (i.e., roads) were components of habitat preferred by black bears on the Kenai Peninsula. These conditions were incorporated into models which identified potential highway crossings by black bears. This information may be used to identify locations and attributes where mitigation practices may be implemented, such as crossing structures, including overpasses and underpasses, to facilitate black bear movement across the Sterling Highway, thereby reducing human injury and mortality, vehicle damage, and black bear mortality from WVCs. Since landscape characteristics influence highway-crossing behavior by black bears, planners should consider road crossing locations and potential migration measures in the context of multiple spatial scales, including roadside and landscape extents, when developing approaches to highway construction or reconstruction.

Clevenger and Waltho (2005) found that black bears prefer constricted crossing structures with low heights and narrow widths. Black bears occasionally used underpasses 29–47 m wide by 3 m high (95–154 ft by 10 ft) in North Carolina (McCollister and van Mannen 2010). However, Donaldson (2006) reported that black bears did not use underpasses 18 m wide by 3 m high (59 ft by 10 ft). The presence of herbaceous vegetation at structure entrances was found to be important in underpass use by black bears (Smith 2003), and distance to nearest drainage was found to be positively correlated with black bear use (Clevenger and Waltho 2005). Clevenger and Barrueto (2014) speculated that the longer, more constricted crossing structures black bears tend to use most for safe passage might be explained by this species' requirements for cover and avoidance of exposed, sparsely wooded habitats (Kansas and Raine 1990, Lyons et al. 2003). Also, brown bears showed far more willingness to cross roads and far less tolerance to humans than black bears (Sawaya et al. 2014).

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Appendix – Black Bear

Table 7A-1. Parameter values assigned in the core mapper software to identify core habitats for black bears on the Kenai Peninsula, Alaska, USA.

Analysis strata	Moving window radius (m)[a]	Minimum average probability of use[b]	Minimum probability of use per pixel[c]	Expand cores by this cost weighted distance (m)	Minimum size of core areas (ha)[d]
All black bears	1000	80	85	--	100

[a] Smaller values result in larger numbers of more-detailed core areas.

[b] Average probability of use in the moving window around a pixel must be greater than this for the pixel to be considered 'core'.

[c] Pixel value must be greater than this to be 'core'.

[d] Core areas smaller than this will be eliminated at end of the run.

Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 8 – Habitat Use Patterns of Canada Lynx on the Kenai Peninsula, Alaska, USA

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Introduction

Canada lynx are cyclically abundant in forested areas of the Kenai Peninsula with larger populations in mixed deciduous-spruce forests than in pure spruce forests (McDonough 2010). A population estimate of 15.09±4.34 Canada lynx was calculated for a 285-km^2 study area in north-central Kenai Peninsula in 1987 (i.e., 53±15/1,000 km^2) (Becker 1991). Lynx are managed as a game species on the Kenai Peninsula and harvest regulations and harvest success depend on lynx population numbers. Trapping seasons were closed on the Peninsula (but hunting seasons remained open) during local Canada lynx population declines (Brand and Keith 1979). Annual harvest on the Kenai Peninsula averaged 9.25 (range 8–12) animals during 2004–2008 while the trapping season was closed. Following an open trapping season in 2008–2009, harvest increased to 97 animals while the population cycle was at or near its peak (McDonough 2010).

Recruitment into Canada lynx populations has been reported to be extremely low or lacking for ≥3-4 years after a snowshoe hare population crash because of reduced productivity and high kitten mortality (Parker et al. 1983). Trapping mortality in Canada lynx also appears additive to natural mortality, making the population on the Kenai Peninsula sensitive to any human-caused mortality (Brand and Keith 1979, Bailey et al. 1986). As a result, maintaining distribution of Canada lynx across the Kenai Peninsula is often dependent on immigration from local refugia (Slough and Mowat 1996).

Lynx typically inhabit gentle, rolling topography (Maletzke et al. 2008, Squires et al. 2013). Across the range of lynx, dense horizontal cover, persistent snow, and moderate to high snowshoe hare densities (>0.5 hares/ha) are common attributes of their habitat (Hoving et al. 2005, ILBT 2013). Spruce-fir forests are the primary vegetation type that characterizes lynx habitat (Apps 2000, Aubry et al. 2000, McKelvey et al. 2000a, Koehler et al. 2008, Moen et al. 2008, Vashon et al. 2008, Squires et al. 2010). Landscapes containing a mix of forest age classes are more likely to provide lynx habitat components (e.g., foraging habitat, denning habitat, travel habitat) throughout the year (Poole et al. 1996, Griffin and Mills 2004, Squires et al. 2010).

Lynx distribution and habitat use reflect seasonal changes in prey abundance. In winter, lynx do not appear to hunt in openings, where lack of cover limits habitat for snowshoe hares (Mowat et al. 2000, Maletzke et al. 2008, Squires et al. 2010). Areas with recent disturbances (fires or timber harvest) can contribute herbaceous summer foods for snowshoe hares, and woody winter browse (Fox 1978, Paragi et al. 1997, ILBT 2013). Multi-story forests provide a greater availability of browse as snow depths vary throughout the winter and may also include habitat components important for denning (ILBT 2013). Common components of natal and maternal den sites appear to be large woody debris and dense horizontal cover (Koehler et al. 1990, Mowat et al. 2000, Squires and Laurion 2000, Moen et al. 2008, Organ et al. 2008, Squires et al. 2008).

Lynx home ranges are comprised of a variety of habitats (foraging, denning and travel) and can vary annually in response to changes in snowshoe hare populations in previous years. Lynx home ranges may also vary seasonally depending on sex and reproductive status. Males generally have larger home ranges than females, and females with kittens will stay close to the den in early spring and expand their range as the kittens grow (Mowat et al. 2000).

As specialized predators of snowshoe hares, Canada lynx exhibit little flexibility in foraging behavior, and virtually every aspect of their demographic, spatial, and behavioral ecology is tied to snowshoe hare abundance (Koehler and Aubry 1994). Due to the narrow range of habitat conditions with which they are associated, Canada lynx may be distributed as several small subpopulations on the Kenai Peninsula. Canada lynx persistence in suitable habitats throughout the Kenai Peninsula may depend on continual interchange among subpopulations. Considering their specialized habitat and prey adaptations, low productivity, and the importance of Peninsula-wide movements to population persistence, the resilience of Canada lynx on the Kenai Peninsula may be low. This is reinforced by the fact that the population of Canada lynx on the Kenai Peninsula has less genetic variation than other populations (i.e., fewer mean numbers of alleles per population and lower than expected heterozygosity) (Schwartz et al. 2003). This is true even though Canada lynx have the capacity to move long distances (Squires and Oakleaf 2005). The genetic pattern on the Kenai Peninsula can be explained by the fact that peripheral populations often have smaller population sizes, limited opportunities for genetic exchange, and may be disproportionately affected by the species' natural population cycles (Schwartz et al. 2003).

The influence that roads and trails can have on lynx resource selection varies by study area and by the behavior being evaluated. In Montana and Washington, forest roads with low vehicular or snowmobile traffic had little effect on lynx seasonal resource selection patterns (McKelvey et al. 2000b, Squires et al. 2010). However, in Maine, Fuller et al. (2007) found that roads and their associated edges were selected against within home ranges. Squires et al. (2008) reported that lynx denned further away from roads when compared to random expectation. They attributed the observed avoidance of roads as a function of the correlation of roads and landscape patterns; fewer roads were located in denning habitat and higher road densities occurred where there were managed forest stands, which lynx generally avoided (Squires et al. 2010).

To examine Canada lynx habitat selection on the Kenai Peninsula, we reviewed the literature to identify a set of map-based variables that could be used to assess an ecologically plausible set of resource selection models. Based on our review of the literature, we developed the following hypotheses about Canada lynx resource selection to test with our statistical analyses:

- H1: Lynx will generally select for gentle topography.
- H2: Lynx resource selection will not be greatly influenced by human activities.
- H3: Lynx resource selection will be positively influenced by the distribution of boreal forests and mixed boreal-hardwood forests.
- H4: Lynx resource selection will be positively influenced by the presence of snow cover.

Methods

We used VHF telemetry data provided by the Kenai National Wildlife Refuge collected during 1982-2001 that included males and females, and adults, subadults, and kittens. We filtered the data so that we only used data from adult lynx with $\geq$20 relocations per season. We used 2 seasons: winter (1 November to 30 April) and summer (1 May to 31 October). We used SNOTEL data from Kenai Moose Research Center (i.e., Kenai Moose Pens) and Cooper Lake weather stations to get average dates of persistent snow on the ground to define the dates for each season. For subsequent habitat selection analyses we used data from 29 males and 27 females during the winter season, and 24 males and 29 females during the summer season.

We defined the analysis area for each season by pooling data from all lynx for the season and then calculating a 100% minimum convex polygon. We then buffered the resulting seasonal analysis area by the average radius of male lynx home ranges calculated from our dataset. This resulted in a 7.5 km buffer and an analysis area of 587,617 ha for the winter season, and a 5.9 km buffer and an analysis area of 874,183 ha for the summer season.

Resource Selection Functions

We developed Resource Selection Functions (RSFs) to estimate habitat selection by Canada lynx at multiple spatial and temporal scales, generally following methods described in Squires et al. (2013). We used logistic regression to estimate the probability of use by season at 1st and 2nd orders of habitat selection (Johnson 1980). To provide a general description of lynx habitat selection we developed 1st order habitat selection models where the radio-telemetry locations (used points) were assessed relative to 6,000 random points (availability) distributed across each seasonal analysis area. We pooled males and females by season, and also conducted separate analyses using only data from the males by seasons and then only data from females by seasons. To assess 2nd order habitat selection we used 500 random points from within individual lynx seasonal and annual home ranges (used points) compared to the 6,000 points from the seasonal analysis areas (availability). We calculated home ranges using a 100% minimum convex polygon (Mohr 1947), which provided an estimate of the total amount of area potentially used by each individual. This allowed us to maximize our sample size for subsequent resource selection functions. Home ranges were calculated with the Adehabitat HR package (Calenge 2015) in R (R Version 3.1.2, 2014).

Based on our review of the literature, we identified a suite of variables with available spatial data that included topography (slope, elevation, aspect), human use (roads, trails, recreation sites), and environment (vegetation, canopy closure, snow) factors that we deemed biologically meaningful to Canada lynx habitat selection and of interest to managers (Table 8-1; Squires et al. 2010, 2013; Baigas et al. 2017). We used Pearson's Correlation to evaluate collinearity, and if covariates were highly correlated ($r>0.7$) we did not retain them in the same model. We ran a suite of 22 models determined *a priori* using different combinations of topography, human use, and environment variables (Table 8-2). We used Akaike's Information Criterion (AIC, Burnham and Anderson 2002) to select the model that best fit the structure of our data. To avoid the potential bias associated with pooling data from multiple individuals in the 1st order RSF, we estimated the standard error and confidence intervals with a robust cluster estimator where individuals denoted the cluster (Proctor et al. 2015, White 1980).

Because we were interested in generalizing 2nd order habitat selection within a home range, we averaged the most parsimonious model over the lynx population. We used the variable coefficients (sign and magnitude) and significance levels to assess how influential variables were on Canada lynx resource selection at each level evaluated.

We used the model variables from 1st order resource selection analyses to construct sex-specific population level seasonal RSFs that we extrapolated to the entire Kenai Peninsula. We applied those RSFs using Peninsula-wide, GIS-based maps of the variables included in the functions to create maps of habitat quality by sex and season (Figures 8-1–8-4).

Model Evaluation

We used telemetry locations from individuals that did not meet the $\geq$20 relocation/season threshold to develop a dataset we could use to evaluate our resource selection maps (similar to Sawyer et al. 2007). To address a strong positive skew we used a logarithmic function to transform the RSF results and develop spatial maps for each resource selection Level (1st and 2nd Order), season, and sex. We then categorized the maps into low-use, mod-low use, mod-high

Table 8-1. Descriptions of variables used in candidate models to assess resource selection by Canada lynx on the Kenai Peninsula, Alaska, USA.

Variable	Description
Topography	
Slope	Continuous variable. Slope in degrees based on digital elevation model and spatial analyst. SLOPE.
Elevation	Continuous variable. Based on digital elevation model. ELEVATION.
Aspect	Categorical variable based on 90 degree intervals. Used "flat" as reference category. ASPECT-NE (1-90), ASPECT-SE (91-180), ASPECT-SW (181-270), ASPECT-NW (271-360).
Human use	
Distance to road	Continuous variable (m). DISTRD.
Distance to trail	Continuous variable (m). DISTTRAIL.
Distance to recreation site	Continuous variable (m). DISTREC
Environmental	
Landcover	Categorical variable based on NLCD 2001 Land Cover (Version 1.0). NLCD 2001 was reclassified into the following classes: EVERGREEN FOREST, DECIDUOUS FOREST, MIXED FOREST, SHRUB/SCRUBLAND, WETLANDS
Canopy	NLCD 2001 Percent Tree Canopy. Discrete variable dataset representing the percentage of tree canopy cover (0-100%)
Snow	
Snow	Discrete variable dataset expressed as snow days (20-85 days). Snow days represent the average annual number of days observed with snow.

Table 8-2. Candidate models used to develop Resource Selection Functions for Canada lynx on the Kenai Peninsula. Different model versions are denoted by the number preceding the model description.

Model name	Model descriptions
Topography variations	1/SLOPE; 2/ASPECT; 3/SLOPE+ASPECT
Human use variations	4/DISTRD; 5/DISTRRAIL; 6/DISTREC; 7/DISTRD+DISTTRAIL; 8/DISTRD+DISTREC; 9/DISTTRAIL+DISTREC; 10/DISTRD+DISTTRAIL+DISTREC
Global – Topography/ Human use/Environment	18/SLOPE+ASPECT+DISTRD+DISTTRAIL+DISTREC+LANDCOVER+CANOPY+SNOW
Topography/Human use Model B	19/SLOPE+ASPECT+DISTRD+DISTTRAIL+DISTREC
Topography/Environment Model C	20/SLOPE+ASPECT+LANDCOVER+SNOW
Topography/Human use Model D	21/Best topography + best human use (based on AIC scores)
Topography/Environment Model E	22/Best topography + best environment (based on AIC scores)

use, and high use bins of approximately equal area proportions. We overlayed the model evaluation dataset onto these maps to determine the proportion of the telemetry points that intersected with each resource-use category.

Results

The number of telemetry locations available to evaluate 1st Order resource selection ranged from 20-123 locations per individual for a total of 1,007 points in the summer and 1,219 points in the winter (Table 8-3). We found a high level of correlation between SLOPE and ELEVATION (r=0.76). ELEVATION also displayed a strong non-normal distribution with a preponderance of low elevation across the study area so we removed ELEVATION from all subsequent models.

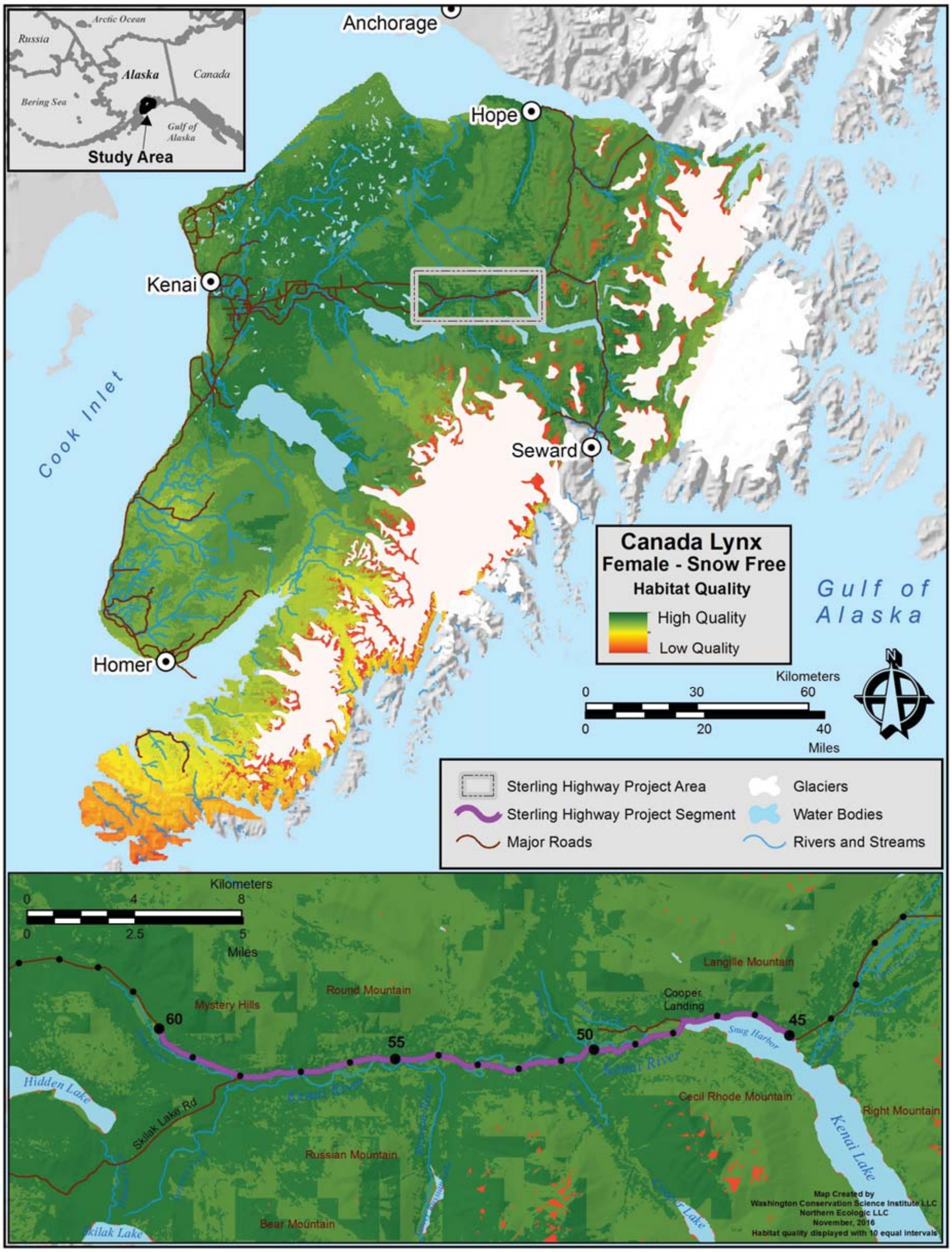


Figure 8-1. Habitat quality for female Canada lynx during the snow-free season on the Kenai Peninsula, Alaska, USA.

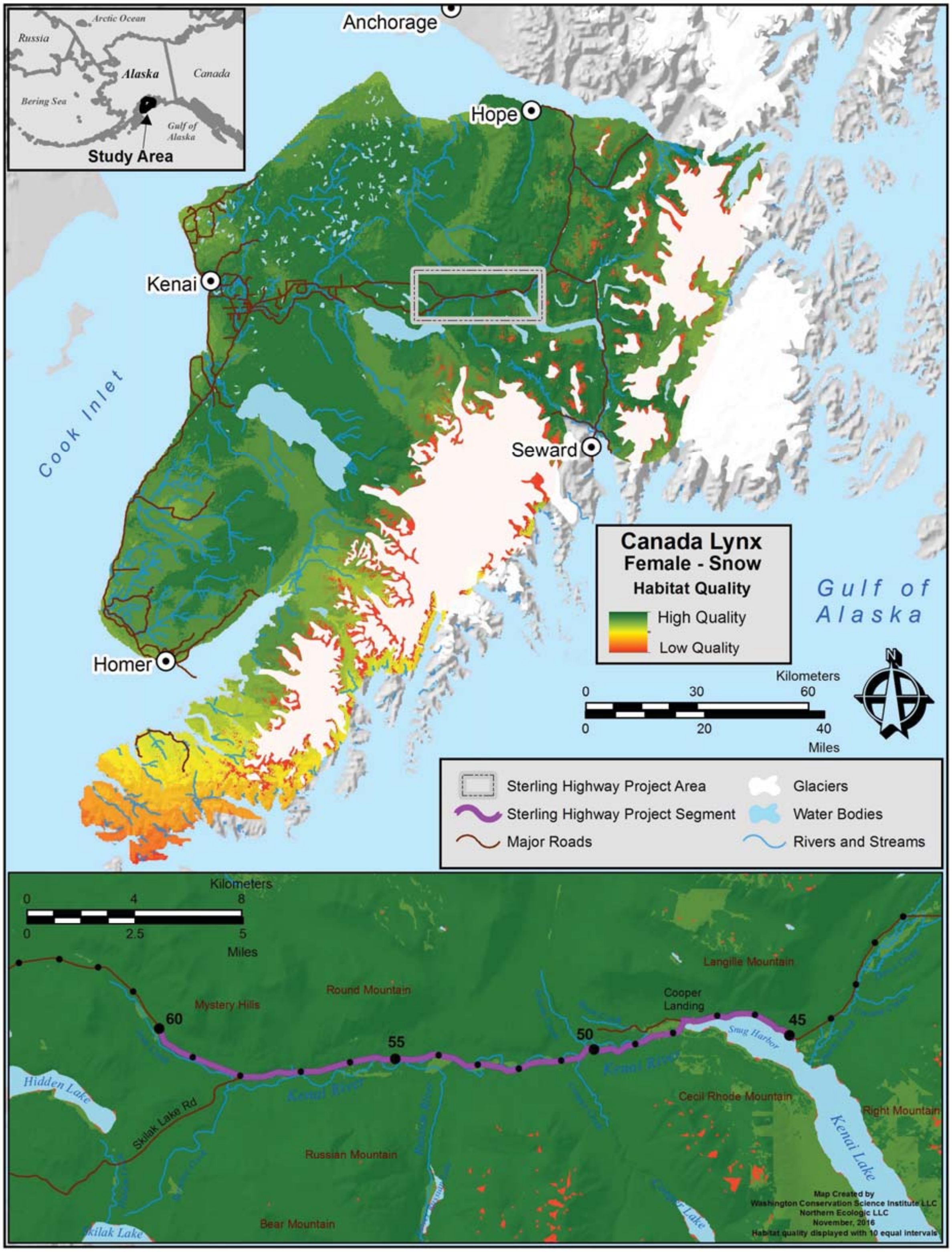
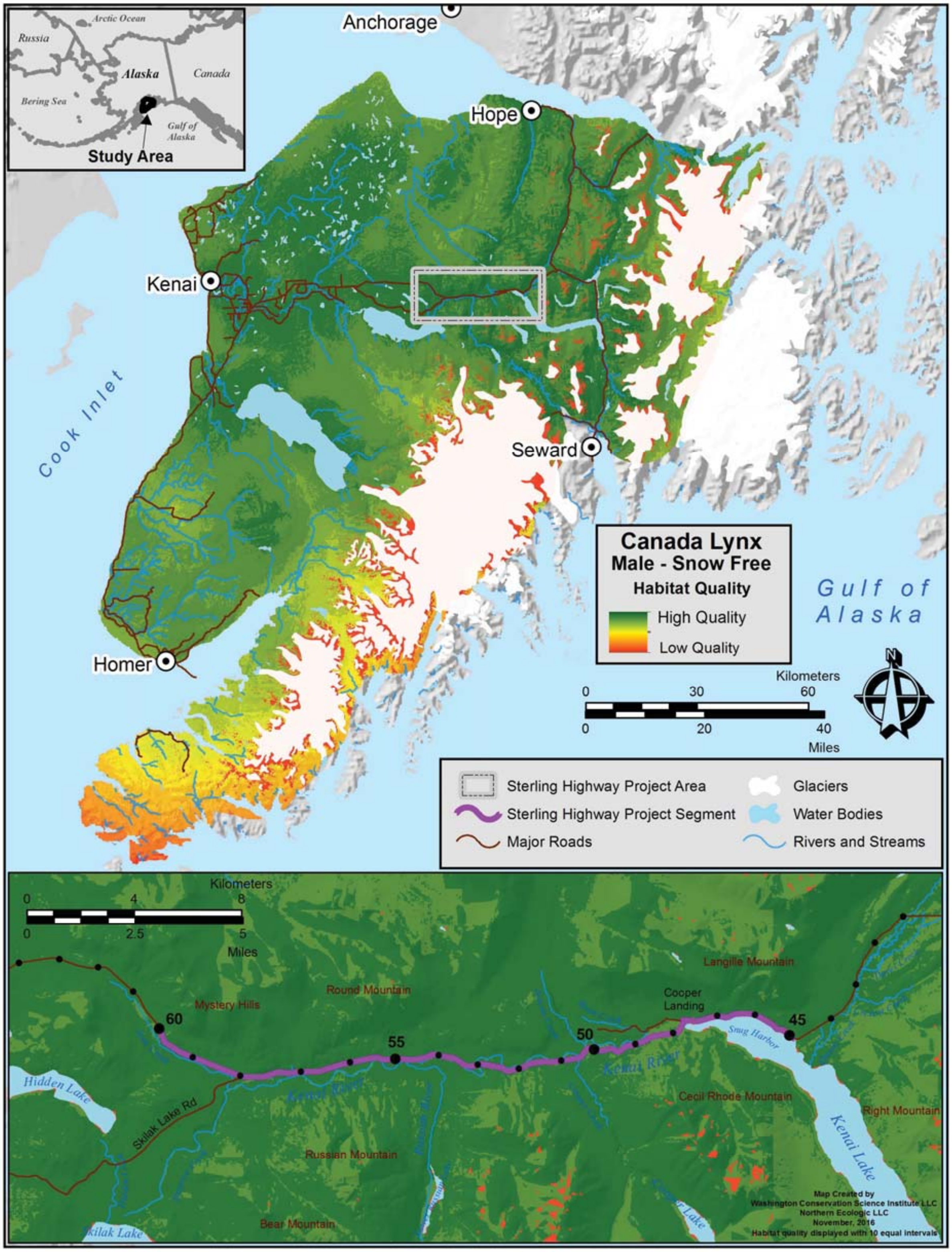


Figure 8-2. Habitat quality for female Canada lynx during the snow season on the Kenai Peninsula, Alaska, USA.



Map Created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016
Habitat quality displayed with 10 equal intervals

Figure 8-3. Habitat quality for male Canada lynx during the snow-free season on the Kenai Peninsula, Alaska, USA.

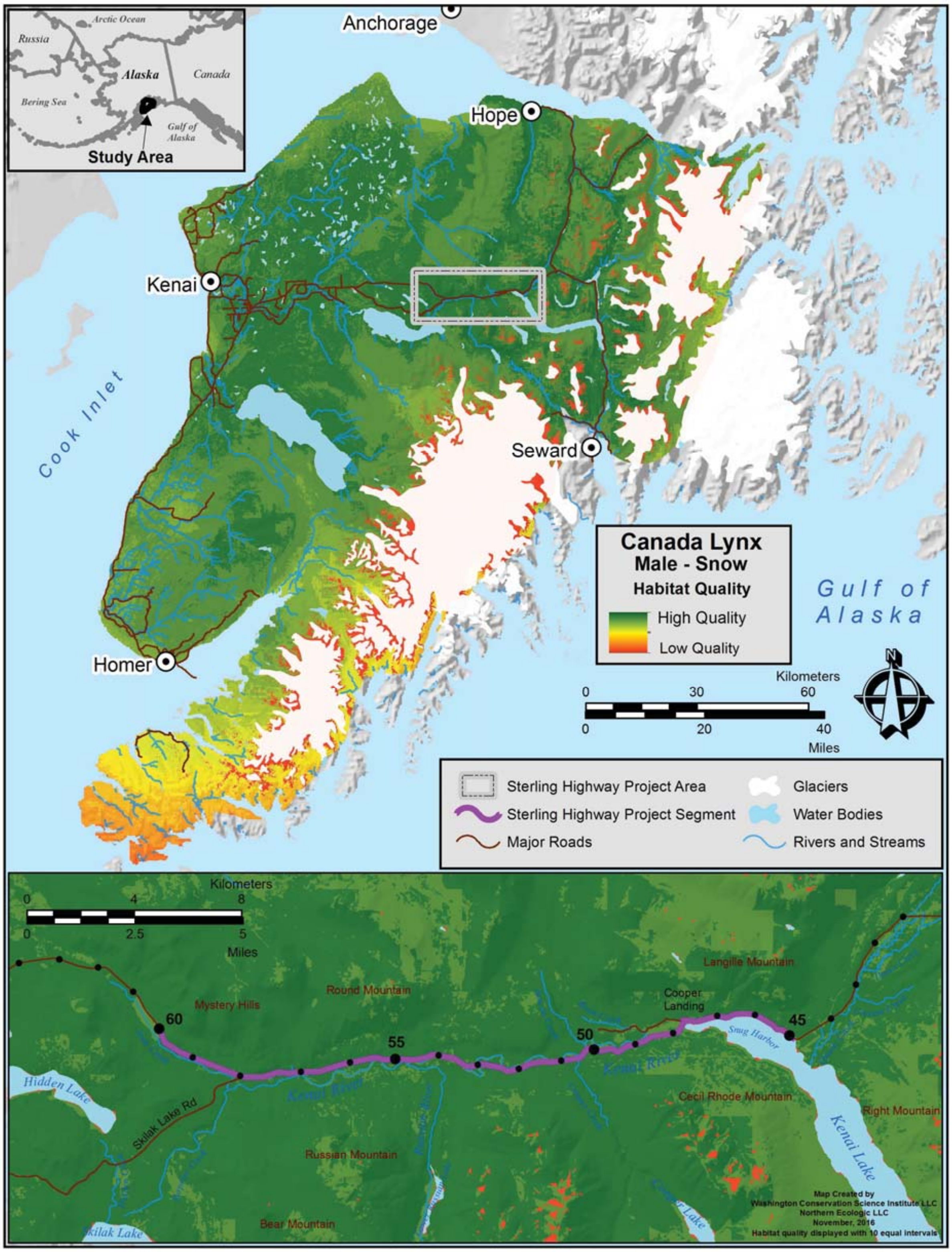


Figure 8-4. Habitat quality for male Canada lynx during the snow season on the Kenai Peninsula, Alaska, USA.

Table 8-3. Summary of telemetry data used to build RSF models to describe lynx habitat use on the Kenai Peninsula.

Sex	Season	Range in number of telemetry relocations	Mean number of relocations per animal	Standard error	Sample size
Males	Winter	21-95	40.4	6.1	17
	Summer	20-67	28.7	4.0	14
Females	Winter	20-123	33.3	6.8	16
	Summer	20-85	27.9	3.7	20

1st Order Resource Selection

The results of resource selection modeling for 1st order selection showed the Global Model, which included topography, human use, and environment variables (Table 8-4) provided the best fit to the structure of our dataset for males and all lynx combined across both seasons and females in summer. The best fitting model for Females in the winter was similar with the exception of canopy cover. Empirical support for remaining models was considerably less than that for the Global model.

The topographical variable that had the greatest impact on lynx resource selection at the 1st order was ASPECT, across both seasons and sexes (Table 8-4). All aspect categories showed significant positive influences compared to flat areas. At this scale of resource selection, slope was not a very influential factor.

Human use variables were significant but the magnitude of the coefficients were low, meaning that resource selection was only somewhat influenced (Table 8-4). As the DISTANCE TO ROAD increased, the probability of use by lynx also increased. This was generally consistent across seasons and sexes. Conversely, as the distance to trail or recreation site increased, the probability of use decreased somewhat across all seasons and for both sexes.

The environment variables showed the greatest influence on resource selection by lynx at resource selection level 1, both in terms of the magnitude of the coefficient values and their significance levels (Table 8-4). In particular, EVERGREEN FOREST, DECIDUOUS FOREST, AND MIXED FOREST were the most influential for both sexes and seasons. SNOW also had positive and significant influence on resource selection, though the magnitude was much less than that of vegetative landcover.

Table 8-4. Resource selection function coefficients from the "best" models for 1st order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA by season and gender.

Strata Variable	Coefficient	Probability	95% confidence interval Lower	 Upper
Male lynx in winter				
SLOPE	0.0040	0.3210	-0.0040	0.0120
ASPECT-NE	0.7000	0.0020	0.2610	1.1390
ASPECT-SE	0.8960	<0.0001	0.4170	1.3740
ASPECT-SW	0.6350	0.0080	0.1480	1.1220
ASPECT-NW	0.4360	0.0250	0.0620	0.8100
DISTRD	<0.0001	0.6040	<-0.0001	0.0001
DISTTRAIL	-0.0003	<0.0001	-0.0005	-0.0001
DISTREC	-0.0001	0.0090	-0.0002	<-0.0001
EVERGREEN FOREST	1.5450	<0.0001	0.7800	2.3100
DECIDUOUS FOREST	2.1410	<0.0001	1.3000	2.9820
MIXED FOREST	1.7120	<0.0001	0.9410	2.4840
SHRUB/SCRUBLAND	0.9220	0.0350	0.0060	1.8380
WETLANDS	0.6570	0.0320	-0.0170	1.3310
CANOPY COVER	0.0040	0.1920	-0.0030	0.0110
SNOW	0.1380	<0.0001	0.0580	0.2170
Constant	-12.2680	<0.0001	-18.5180	-6.0170

Table 8-4. Resource selection function coefficients from the “best” models for 1st order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA by season and gender.

Strata Variable	Coefficient	Probability	95% confidence interval Lower	 Upper
Male lynx in summer				
SLOPE	<0.0001	0.9700	-0.0100	0.0090
ASPECT-NE	0.7530	0.0310	-0.0040	1.5100
ASPECT-SE	0.8680	0.0190	0.0320	1.7040
ASPECT-SW	0.4970	0.1310	-0.1770	1.1710
ASPECT-NW	0.7560	0.0310	0.0210	1.4920
DISTRD	-0.0001	0.7330	-0.0001	<0.0001
DISTTRAIL	-0.0003	0.0010	-0.0004	-0.0001
DISTREC	-0.0002	<0.0001	-0.0003	-0.0001
EVERGREEN FOREST	1.0830	0.0010	0.4060	1.7610
DECIDUOUS FOREST	1.9740	<0.0001	1.0820	2.8660
MIXED FOREST	1.4260	<0.0001	0.6920	2.1610
SHRUB/SCRUBLAND	0.9530	0.0170	0.0750	1.8310
WETLANDS	0.9140	0.0070	0.1490	1.6790
CANOPY COVER	0.0060	0.0570	<0.0001	0.0130
SNOW	0.1110	<0.0001	0.0540	0.1690
Constant	-10.0880	<0.0001	-14.241	-5.9350

Table 8-4. Resource selection function coefficients from the “best” models for 1st order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA by season and gender.

Strata Variable	Coefficient	Probability	95% confidence interval Lower	 Upper
Female lynx in winter				
SLOPE	0.0030	0.6560	-0.0140	0.0190
ASPECT-NE	2.8010	<0.0001	-18.1120	23.7140
ASPECT-SE	2.7420	<0.0001	-18.4400	23.9240
ASPECT-SW	3.0170	<0.0001	-19.6600	25.6950
ASPECT-NW	2.5640	0.0010	-17.6890	22.8180
DISTRD	0.0001	0.0960	<-0.0001	0.0001
DISTTRAIL	-0.0010	<0.0001	-0.0010	-0.0002
DISTREC	-0.0001	0.0220	-0.0003	<0.0001
EVERGREEN FOREST	1.3360	<0.0001	0.5370	2.1340
DECIDUOUS FOREST	1.9790	<0.0001	1.1090	2.8490
MIXED FOREST	1.4910	<0.0001	0.6380	2.3450
SHRUB/SCRUBLAND	0.8840	0.0800	-0.5960	2.3650
WETLANDS	0.2570	0.5390	-0.5770	1.0910
SNOW	0.1340	<0.0001	0.0570	0.2110
Constant	-13.8250	<0.0001	-26.4710	-1.1800

Table 8-4. Resource selection function coefficients from the “best” models for 1st order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA by season and gender.

Strata			95% confidence interval	
Variable	Coefficient	Probability	Lower	Upper
Female lynx in summer				
SLOPE	0.0040	0.3640	-0.0050	0.0120
ASPECT-NE	1.1960	0.0410	-0.3470	2.7380
ASPECT-SE	1.3570	0.0160	-0.0640	2.7770
ASPECT-SW	1.4650	0.0150	-0.0880	3.0190
ASPECT-NW	1.1470	0.0540	-0.4630	2.7570
DISTRD	<0.0001	0.1830	<-0.0001	0.0001
DISTTRAIL	-0.0002	0.0010	-0.0004	-0.0001
DISTREC	-0.0002	<0.0001	-0.0003	-0.0001
EVERGREEN FOREST	0.9420	0.0970	-0.4130	2.2960
DECIDUOUS FOREST	2.0310	<0.0001	0.7670	3.2940
MIXED FOREST	1.3610	0.0150	0.0390	2.6840
SHRUB/SCRUBLAND	0.3030	0.5900	-1.1260	1.7330
WETLANDS	-0.1770	0.7490	-1.5540	1.1990
CANOPY COVER	0.0030	0.3860	-0.0040	0.0090
SNOW	0.1580	<0.0001	0.0910	0.2260
Constant	-13.7480	<0.0001	-18.9670	-8.5290

Table 8-4. Resource selection function coefficients from the “best” models for 1st order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA by season and gender.

Strata Variable	Coefficient	Probability	95% confidence interval Lower	 Upper
All lynx in winter				
SLOPE	0.0040	0.2550	-0.0040	0.0130
ASPECT-NE	1.1430	<0.0001	0.6370	1.6480
ASPECT-SE	1.2600	<0.0001	0.7730	1.7470
ASPECT-SW	1.2540	<0.0001	0.7370	1.7700
ASPECT-NW	0.9120	<0.0001	0.4430	1.3820
DISTRD	<0.0001	0.1740	<-0.0001	<0.0001
DISTTRAIL	-0.0004	<0.0001	-0.0005	-0.0002
DISTREC	-0.0001	0.0010	-0.0002	-0.00005
EVERGREEN FOREST	1.5210	<0.0001	0.9780	2.0640
DECIDUOUS FOREST	2.0900	<0.0001	1.5070	2.6720
MIXED FOREST	1.6650	<0.0001	1.1080	2.2220
SHRUB/SCRUBLAND	0.9710	0.0030	0.3260	1.6170
WETLANDS	0.5360	0.0370	0.0550	1.0180
CANOPY COVER	0.0020	0.2740	-0.0020	0.0060
SNOW	0.1410	<0.0001	0.0830	0.2000
Constant	-12.2500	<0.0001	-16.4480	-8.0510

Table 8-4. Resource selection function coefficients from the "best" models for 1st order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA by season and gender.

Strata Variable	Coefficient	Probability	95% confidence interval Lower	Upper
All lynx in summer				
SLOPE	0.0022	0.4151	-0.0035	0.0079
ASPECT=2	0.9936	0.0024	0.2799	1.7073
ASPECT=3	1.1596	0.0005	0.4617	1.8575
ASPECT=4	1.0947	0.0019	0.3565	1.8330
ASPECT=5	0.9888	0.0035	0.2929	1.6846
DISTRD	<0.0001	0.4797	<-0.0001	0.0001
DISTTRAIL	-0.0002	<0.0001	-0.0003	-0.0001
DISTREC	-0.0002	<0.0001	-0.0003	-0.0001
LANDCOVER=1	0.9637	0.0071	0.1733	1.7542
LANDCOVER=2	1.9875	<0.0001	1.2673	2.7077
LANDCOVER=3	1.3599	0.0002	0.5866	2.1332
LANDCOVER=4	0.5970	0.1088	-0.2657	1.4597
LANDCOVER=6	0.3463	0.3430	-0.4365	1.1291
CANOPY COVER	0.0044	0.0464	-0.0003	0.0092
SNOW	0.1426	<0.0001	0.0948	0.1904
Intercept	-11.7707	<0.0001	15.2087	-8.3327

2nd Order Resource Selection

The results of resource selection modeling for 2nd order selection showed the Global Model, which included topography, human use, and environment variables (Table 8-5) provided the best fit to the structure of our dataset across seasons, and for males and females. Empirical support for remaining models was considerably less than that for the Global model.

ASPECT influenced lynx resource selection as male and female lynx selected for east facing slopes more than west. Additionally, across both seasons and sexes, the probability of use

Table 8-5. Resource selection function coefficients from the “best” model for 2nd order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA.

	Males				Females			
Season Variable	Mean	Standard Error	Confidence Level (95%)	Probability	Mean	Standard Error	Confidence Level (95%)	Probability
Winter								
SLOPE	-0.0140	0.0030	0.0060	<0.01	-0.0103	0.0050	0.0100	0.02
ASPECT-NE	0.6550	0.2300	0.4840	0.04	2.6700	1.0230	2.1490	0.02
ASPECT-SE	0.6950	0.2080	0.4370	0.04	2.3590	0.9930	2.0860	0.03
ASPECT-SW	0.5410	0.1670	0.3500	0.04	2.6630	1.0700	2.2480	0.02
ASPECT-NW	0.4310	0.1920	0.4030	0.08	2.3570	0.9830	2.0650	0.03
DISTRD	-0.0001	0.0001	0.0002	0.33	-0.0001	0.0001	0.0002	0.47
DISTTRAIL	-0.0007	0.0001	0.0002	<0.01	-0.0006	0.0001	0.0002	<0.01
DISTREC	-0.0001	0.0001	0.0002	0.12	-0.0002	0.0001	0.0003	0.25
EVERGREEN FOREST	0.1220	0.2130	0.4470	0.14	0.7320	0.2970	0.6240	0.02
DECIDUOUS FOREST	0.6710	0.1810	0.3810	0.03	0.6620	0.2750	0.5770	0.03
MIXED FOREST	0.2200	0.1930	0.4050	0.09	0.6150	0.2280	0.4780	0.02
SHRUB/SCRUBLAND	-0.5260	0.3020	0.6340	0.40	-0.0490	0.3010	0.6330	0.87
WETLANDS	0.0500	0.2020	0.4240	0.17	-0.0220	0.2150	0.4510	0.92
CANOPY	0.0020	0.0020	0.0030	0.39	-0.0010	0.0020	0.0040	0.57
SNOW	0.2710	0.0480	0.1000	<0.01	0.2210	0.0670	0.1410	0.01
Constant	-20.4730	3.4960	7.3440		-19.8510	4.4000	9.2440	
Summer								
SLOPE	-0.0120	0.0050	0.0100	<0.01	-0.0110	0.0050	0.0100	<0.01
ASPECT-NE	0.4780	0.2310	0.4860	0.02	1.5400	0.8200	1.7230	0.01
ASPECT-SE	0.3630	0.2320	0.4870	0.08	1.4250	0.8140	1.7100	0.02
ASPECT-SW	0.3860	0.2250	0.4720	0.04	1.6180	0.8860	1.8610	0.03
ASPECT-NW	0.3000	0.2230	0.4680	0.07	1.3100	0.8400	1.7650	0.05

Table 8-5. Resource selection function coefficients from the “best” model for 2^{nd} order habitat selection analysis for Canada lynx on the Kenai Peninsula, Alaska, USA.

	Males				Females			
Season Variable	Mean	Standard Error	Confidence Level (95%)	Probability	Mean	Standard Error	Confidence Level (95%)	Probability
DISTRD	-0.0002	0.0001	0.0001	0.02	<-0.0001	0.0001	0.0001	0.92
DISTTRAIL	-0.0007	0.0001	0.0002	<0.01	-0.0005	0.0001	0.0003	<0.01
DISTREC	-0.0003	0.0001	0.0002	<0.01	-0.0002	0.0001	0.0002	<0.01
EVERGREEN FOREST	0.1610	0.2740	0.5760	0.18	0.9520	0.3720	0.7830	0.03
DECIDUOUS FOREST	0.9710	0.2250	0.4730	<0.01	1.1650	0.2780	0.5850	<0.01
MIXED FOREST	0.5650	0.1790	0.3760	<0.01	0.9640	0.2600	0.5460	<0.01
SHRUB/SCRUBLAND	-0.9010	0.3310	0.6950	0.07	-0.1930	0.4140	0.8700	0.22
WETLANDS	0.0550	0.2360	0.4960	0.22	0.3300	0.2660	0.5580	0.71
CANOPY	0.0030	0.0020	0.0040	0.23	-0.0030	0.0020	0.0040	0.15
SNOW	0.2440	0.0620	0.1300	<0.01	0.3210	0.0600	0.1260	<0.01
Constant	-17.7090	4.57600	9.6140		-25.5170	4.4260	9.2980	

was negatively associated with increasing slope (steepness) (Table 8-5). Human use variables were all negatively associated with lynx probability of use across both seasons and sexes (Table 8-5). However the magnitude of the influence varied, with DISTANCE TO TRAIL being the most significant across all seasons and sexes. DISTANCE TO ROAD and DISTANCE TO RECREATION SITE was also particularly influential for male resource selection during the summer season. DISTANCE TO RECREATION SITE also had a strong negative association with lynx probability of use for females during the summer season.

Similar to the results from the 1st order resource selection, EVERGREEN FOREST, DECIDUOUS FOREST, AND MIXED FOREST consistently showed significant positive influences on lynx resource selection at the 2nd order (Table 8-5). EVERGREEN FOREST, DECIDUOUS FOREST, AND MIXED FOREST were most influential for females during both seasons, while DECIDUOUS FOREST influenced male selection in the winter and in summer along with MIXED FOREST. SNOW showed a positive and significant influence on lynx resource selection, with a stronger influence at the 2nd level compared to the 1st level of resource selection.

Model Evaluation

Our evaluation of the seasonal resource selection functions using an independent (i.e., not used in model development) set of telemetry data points (validation data points) showed a high degree of overlap between extrapolated RSF values and telemetry locations (Table 8-6). The validation dataset consisted of 1892 points and the proportion of validation data points that fell in the High Use category ranged from 81% for females during the winter season to 90% for males during the winter season. Based on these results, we assumed that we had a robust set of seasonal RSF models describing the relative probability of use by Canada lynx across the landscape of the Kenai Peninsula.

Table 8-6. The proportion of model evaluation data points that intersected each habitat-use category based on 1st order resource selection functions for Canada lynx the Kenai Peninsula.

Sex	Season	Habitat use category			
		High	Moderate-high	Moderate-low	Low
Male	Summer	0.87	0.12	0.01	0.00
	Winter	0.90	0.09	0.01	0.00
Female	Summer	0.86	0.14	0.00	0.00
	Winter	0.81	0.17	0.02	0.00

Discussion

In general, the results of our resource selection analyses for Canada lynx on the Kenai Peninsula showed support for the hypotheses we derived from previous research conducted in a variety of study areas and conditions. Our results showed that slope was not a strong factor that influenced resource selection by lynx on the Kenai Peninsula at RSL1; however at RSL2 lynx resource selection was negatively influenced by increasing slope steepness. This provided support for our hypothesis that lynx would generally select areas of gentle topography, as found in other studies (Maletzke et al. 2008, Squires et al. 2013).

We hypothesized that lynx resource selection would not be strongly influenced by human activities. The human use variables (distance to road, trail, or recreation site) we used to model resource selection by lynx on the Kenai Peninsula were included in the "best" model but generally did not have a considerable influence (based on model coefficients) on the model results at RSL1. This is similar to the results of several other studies that have shown that lynx are not particularly sensitive to the human activities (McKelvey et al. 2000b, Squires et al. 2008, Squires et al. 2010). However, at RSL2, we found that lynx resource selection was influenced by human activities, especially during the summer season. Other studies have found some influence of human activities during denning (Squires et al. 2008) or when the activity is associated with a major highway (Apps et al. 2007, Devineau et al. 2010). Thus, we have mixed support for our hypothesis about the influence of human activities, finding that the influence varied dependent upon the scale of our analyses.

Several studies have documented a strong association between boreal forests and resource selection by Canada lynx (McKelvey et al. 2000b, Hoving et al. 2005, Fuller et al. 2007, Vashon et al. 2008). Similarly, we found that the vegetation variables associated with evergreen and deciduous forest cover were either the most influential or among the most influential variables that determined lynx resource selection, at both RSL1 and 2, on the Kenai Peninsula. We found strong and consistent support for our hypothesis that the distribution of boreal and mixed-boreal forests would positively influence lynx resource selection. While our vegetation data did not allow analyses of forest successional stages, research has shown that landscapes that contain a mix of forest age classes are more likely to provide lynx foraging habitat throughout the year (Poole et al. 1996, Griffin and Mills 2004, Squires et al. 2010). Both timber harvest and natural disturbances can create foraging habitat for lynx when the resulting stem densities and stand structure provide habitat for snowshoe hares (Wolff 1980, Parker et al. 1983, Litvaitis et al. 1985, Bailey et al. 1986, Monthey 1986, Koehler and Brittell 1990). In winter, lynx do not appear to hunt in openings, where a lack of cover limits habitat for snowshoe hares (Mowat et al. 2000, Maletzke et al. 2008, Squires et al. 2010).

Canada lynx and snowshoe hare are specially adapted to cold-dry snow conditions that persist in northern boreal forests (Buskirk et al. 2000, ILBT 2013). Thus, we hypothesized the snow cover would have an important and positive influence on lynx resource selection. We found consistent support for our hypothesis at both RSL1 and 2 as snow cover was positively associated with lynx resource selection.

Lynx typically inhabit gentle, rolling topography (Maletzke et al. 2008, Squires et al. 2013), such as is found on much of the Kenai Peninsula. The distribution of the highest quality lynx habitat during the summer season generally occurred in the north-central and north-western portions of the Peninsula and was similar between males and females (Figures 8-1, 8-3). In addition, there was a high degree of overlap in the distribution of high quality habitat across the summer and winter seasons (Figures 8-1–8-4). The eastern edge of the Peninsula, along the entire length, was consistently identified as low quality habitat for both sexes and across seasons.

Management Implications

Understanding what factors influence resource selection by animals is fundamental to the management of their habitats and populations (Morrison et al. 1992, Garshelis 2000). Buskirk et al. (2000) cautioned against the extrapolation of research results on Canada lynx habitat use from the relatively few areas in North America where lynx have been studied. They encouraged habitat studies to occur in more locations within the distribution of lynx to account for unique regional attributes and site conditions (Buskirk et al. 2000). Our research presents unique results on the resource selection by Canada lynx on the Kenai Peninsula and has many applications for lynx habitat management.

The resilience of Canada lynx on the Kenai Peninsula may be low due to their specialized habitat and prey adaptations, low productivity, and the importance of Peninsula-wide movements to population persistence. This is supported by the fact that the population of Canada lynx on the Kenai Peninsula is considered to be peripheral and has less genetic variation when compared to mainland or core populations (Schwartz et al. 2003). In addition, peninsulas have been implicated as places where genetic variability is reduced, presumably because of smaller population sizes and isolation (Gaines et al. 1997). Thus, factors that influence habitat quality and mortality are important to understand and manage in order to maintain lynx populations on the Kenai Peninsula.

One factor that has been identified as a mortality factor for Canada lynx in recent studies is mortality associated with lynx-vehicle collisions. For example, vehicle collisions accounted for nearly half of the mortalities of reintroduced lynx in the Adirondack Mountains in New York (McKelvey et al. 2000), 20% of the mortalities in Colorado (Divineau et al. 2010), and 45% of the mortalities for Eurasian lynx (*Lynx lynx*) in Germany (Kramer-Schadt et al. 2005). Recent studies have combined resource selection and habitat connectivity analyses to inform highway planning to reduce the potential impacts of vehicle collisions on highways to Canada lynx populations (Squires et al. 2013, Baigas et al. 2017). Because the population of Canada lynx on the Kenai Peninsula may be susceptible to human caused mortality, reducing the potential for mortality associated with highways is an important management consideration.

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Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 9 – Movement Patterns and Potential Corridors for Canada Lynx on the Kenai Peninsula, Alaska, USA

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Introduction

Mortality by wildlife-vehicle collisions (WVC) has been found to be significant for Canada lynx in other parts of their range (Brocke et al. 1990, 1991; Aubry et al. 2000; McKelvey et al. 2000a; Kramer-Schadt et al. 2005; Devineau et al. 2010). Roads and highways are sometimes found to be a barrier to lynx movements (Apps 2000), and some researchers have found that Canada lynx avoid roadways (Apps 2000, Squires et al. 2013). However, other investigations suggest that Canada lynx may have a neutral relationship with roads, meaning that they are neither avoiding nor attracted to roadways (McKelvey et al. 2000b, Carroll et al. 2001). Further, a study suggested that road density in a given area did not have a detectable effect on Canada lynx land use (Hoving et al. 2005). However, modeling exercises have shown that populations of the closely related Eurasian lynx (*Lynx lynx*) are sensitive to potential road mortality (Kramer-Schadt 2004).

For many wildlife species, the locations that they select to cross highways are often influenced by habitat or road characteristics (Malo et al. 2004, Ramp et al. 2005, Neumann et al. 2012). Baigas et al. (2017) studied radio-collared lynx crossing highways in Colorado. They found that lynx mitigated the risk of increased highway exposure by crossing roads at greater frequency during dusk and at night, when traffic volume was lower (Baigas et al. 2017). They used resource selection models to predict the probability of lynx crossing given fine- and landscape-scale environmental characteristics. At both spatial scales, lynx were more likely to cross highways in areas with greater vegetative cover, while at the landscape scale, lynx also preferred north-facing slopes and areas with topographical concavity, such as river drainage (Baigas et al. 2017).

The resilience of Canada lynx on the Kenai Peninsula may be low due to their specialized habitat and prey adaptations, low productivity, and the importance of Peninsula-wide movements to population persistence. This is supported by the fact that the population of Canada lynx on the Kenai Peninsula is considered to be peripheral and has less genetic variation when compared to mainland or core populations (Schwartz et al. 2003). In addition, peninsulas have been implicated as places where genetic variability is reduced, presumably because of smaller population sizes and isolation (Gaines et al. 1997). Thus, factors that influence habitat quality and mortality are important to understand and manage in order to maintain lynx populations on the Kenai Peninsula.

Our specific objective was to identify paths of potential movement for Canada lynx on the Kenai Peninsula to inform planning for habitat management, resource development, and infrastructure development, such as transportation planning. Specifically, we identified potential movement paths for lynx between MP 45 to 60 on the Sterling Highway that may be important for consideration in transportation planning and mitigation design.

Methods

Habitat Connectivity Modeling

We used existing tools to develop models of habitat connectivity. This approach involved the following steps: 1) development of resistance surfaces, 2) identification of core areas of high quality habitat, and 3) identification of potential habitat linkages between core areas across the Sterling Highway. We completed steps 1 and 2 using the resource selection functions developed from the 1st order resource selection level analyses (Chapter 8; Gaines et al. 2017) as an inverse of resistance and to index habitat quality for male and female lynx across summer and winter. Winter was defined as the period 1 November to 30 April and summer was defined as 1 May to 31 October.

Resistance Surfaces

We used CoreMapper (Shirk and McRae 2013) and the results of the RSF modeling (Chapter 8; Gaines et al. 2017) to develop resistance surfaces for each of the seasons and by sex. In general, we followed Beier et al. (2007) to develop resistance surfaces from the seasonal RSFs. The following considerations were used to develop resistance surfaces:

- Variable combinations that resulted in high relative probability of use by Canada lynx were assigned low resistance values.
- Conversely, variable combinations that resulted in low relative probability of use by lynx were assigned higher resistance values.
- Human features on the landscape (e.g., highways, housing development) that resulted in negative correlations with high quality for lynx were assigned the highest resistance values.

Core Areas

We mapped core areas to identify relatively large patches of high quality habitat and to identify areas between which we evaluated patterns of habitat connectivity. Core areas are significant habitat areas that are expected or known to be important for lynx based on the seasonal RSF models. We used CoreMapper (Shirk and McRae 2013) and the RSF models to identify core areas for each season using a 1,000 meter moving window radius. The minimum average habitat value (based on all pixels within the moving window) within the window for a pixel to be assigned as core area ranged from 92 – 95.5 depending on season. The minimum habitat value for any pixel to be assigned as core area ranged from 90 – 95.5 depending on the season. We used a minimum core area size of 1 km^2. This resulted in a map of concentrations of high quality habitat, or core areas, which were distributed across the Peninsula and within the Sterling Highway study area.

Potential Habitat Linkages

We identified potential habitat linkages for movement paths for lynx using the resistance surfaces and core areas as described above. Cost-weighted distance approaches to estimate movement paths of animals represent the least accumulative cost required to move between specific source and a specified destination (Beier et al. 2007). The cost accumulated by moving through each intermediate cell is equal to the cell's resistance value multiplied by the cell size (30-m in this study). The central concept in these analyses is that the cost distance from a source to a cell increases as the resistance of the intervening landscape (measured along the most efficient path from source to target cell) increases. While the shortest-path, or least-cost, methods have used to develop empirical models of habitat connectivity (Schwartz et al. 2009, Richard and Armstrong 2010), predictions from current flow-based models (e.g., circuit theory) have been highly correlated with observed genetic distance in several plant and animal populations and may better reflect actual movement ecology (McRae et al. 2008, Lee-Yaw et al. 2009, Shirk et al. 2010).

Circuit theory assumes a random walk dispersal behavior (least-cost assumes an animal has perfect knowledge of landscape resistance), simultaneously integrates the contribution of all possible pathways to gene flow, and attributes greater resistance to narrow corridors than wide corridors (McRae 2006). This may explain why landscape distances derived from circuit theory have been more strongly correlated with genetic distance in both simulated and real landscapes than least-cost (McRae 2006, McRae and Beier 2007).

We used LinkageMapper (McRae and Kavanagh 2011) to identify potential linkages or movement paths between core areas. We then applied circuit theory through the program CircuitScape (McRae and Shah 2009) using the Pinchpoint Mapper module (McRae 2012). Once potential linkages were mapped using LinkageMapper, Pinchpoint Mapper runs Circuitscape within the resulting corridors. This produces current maps that identify and map pinch points (constrictions, bottlenecks, choke points) in the linkage network. It also provides effective resistance values for each linkage, a measure of connectivity that complements least-cost distances.

Results

Core Areas

The number of core areas we identified ranged from 22 for females during the summer season to 49 for males during the winter season (Figures 9-1 – 9-4, Table 9-1). The amount of area identified as core area on the Kenai Peninsula ranged from a low of 1,017 km^2 for males in the summer season to a high of 1,751km^2 for females in the summer season (Table 9-1). The lowest mean core area size was 21.1 km^2 (range 1.1-218.1) for males in the summer and the highest mean core area size was 79.6 km^2 (range 1.1-1,391.1) for females in the summer (Table 9-1).

Table 9-1. Summary of Canada lynx core areas by sex and season used in the habitat connectivity assessment for the Kenai Peninsula, Alaska, USA.

Sex	Season	Number of core areas	Total area in core habitat (km^2)	Mean core area size (km^2)	Range of core area size (km^2)
Male	Winter	49	1,321.2	27.0	1.0 – 607.5
	Summer	48	1,017.0	21.2	1.1 – 218.1
Female	Winter	35	1,177.4	33.6	1.0 – 419.0
	Summer	22	1,750.8	79.6	1.1 – 1,391.1

Potential Habitat Linkages

We used least-cost corridor techniques to identify potential habitat linkages across the Sterling Highway and circuit theory to estimate the effective resistances of the landscape between all pairs of core areas. Based on these analyses, we identified three primary north-south habitat linkages across the Sterling Highway between milepost (MP) 45–60 (Figures 9-5 – 9-8). Some of the linkages were identified across both seasons and for both sexes, however the degree that the linkages were constrained varied by season (Figures 9-9 – 9-12).

Linkage at MP 51

This linkage was near MP 51, west of where Cooper Creek and Juneau Creek join the Kenai River (Figures 9-7, 9-8). The linkage runs north-south, generally following the valleys associated with Juneau and Cooper Creeks. This linkage is identified for male lynx during both seasons, and is the primary linkage identified for them in the study area. For females, this linkage was identified in the pinch point analysis using circuit theory during the snow season (Figure 9-10).

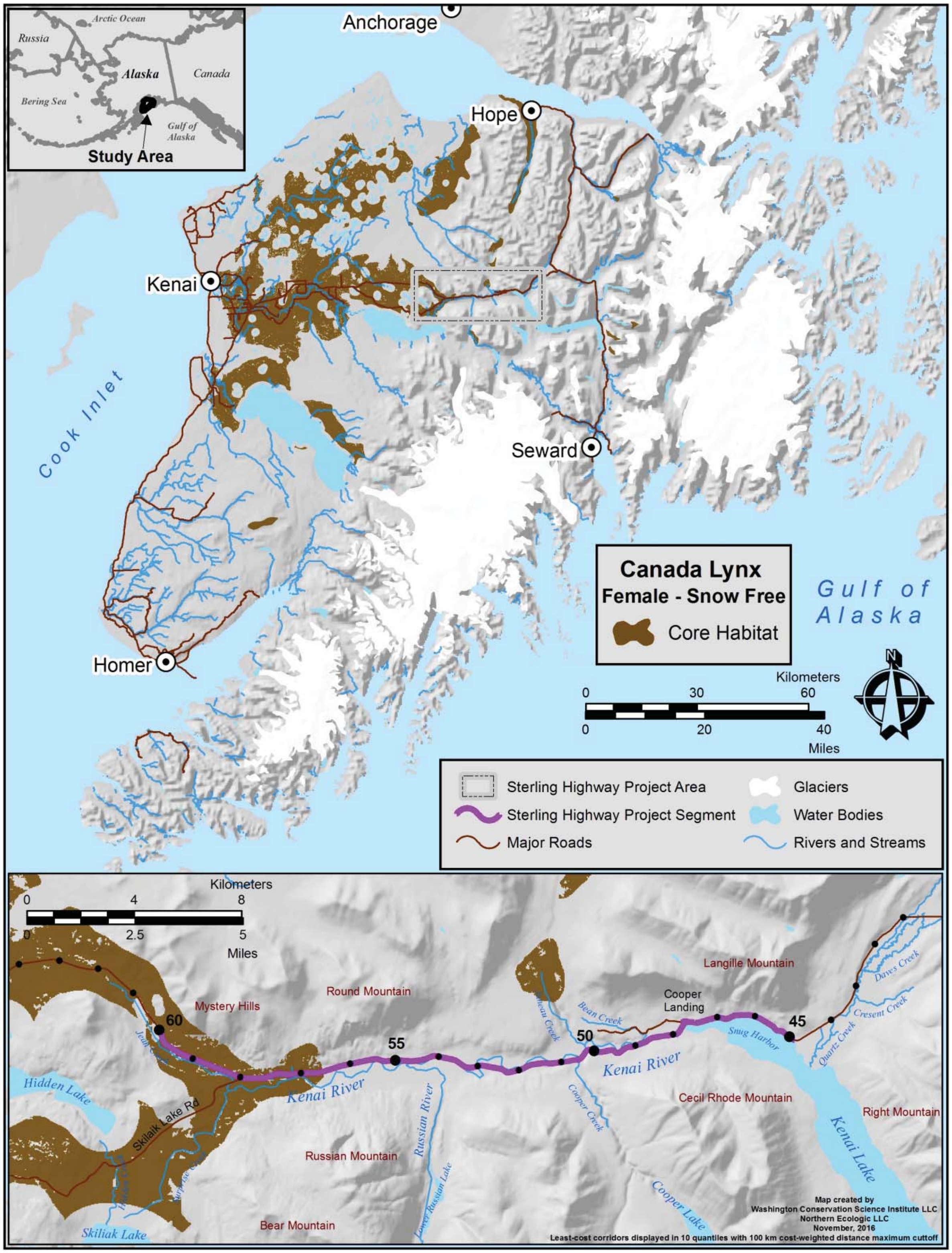


Figure 9-1. Core areas for female Canada lynx during the snow-free season on the Kenai Peninsula, Alaska, USA

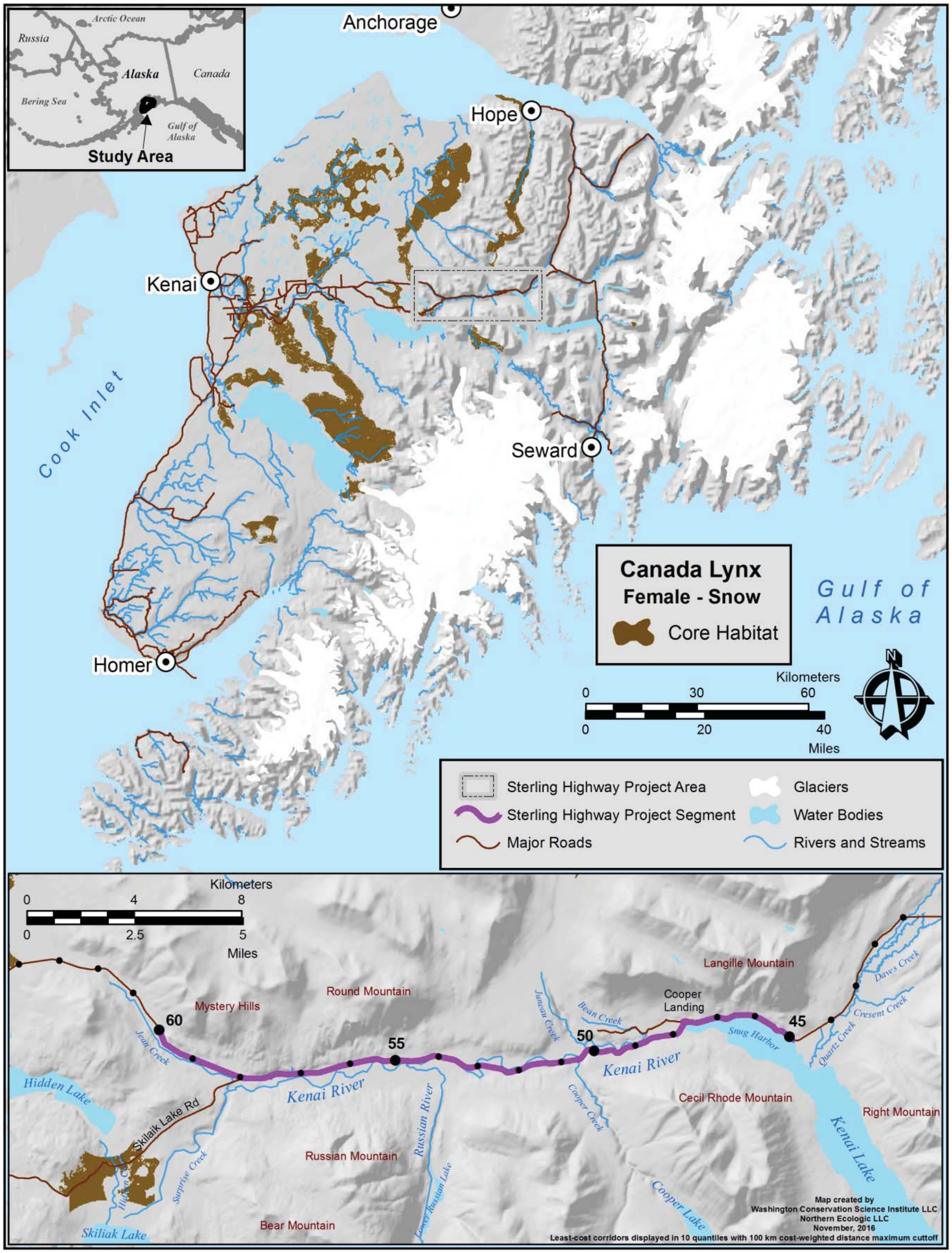


Figure 9-2. Core areas for female Canada lynx during the snow season on the Kenai Peninsula, Alaska, USA

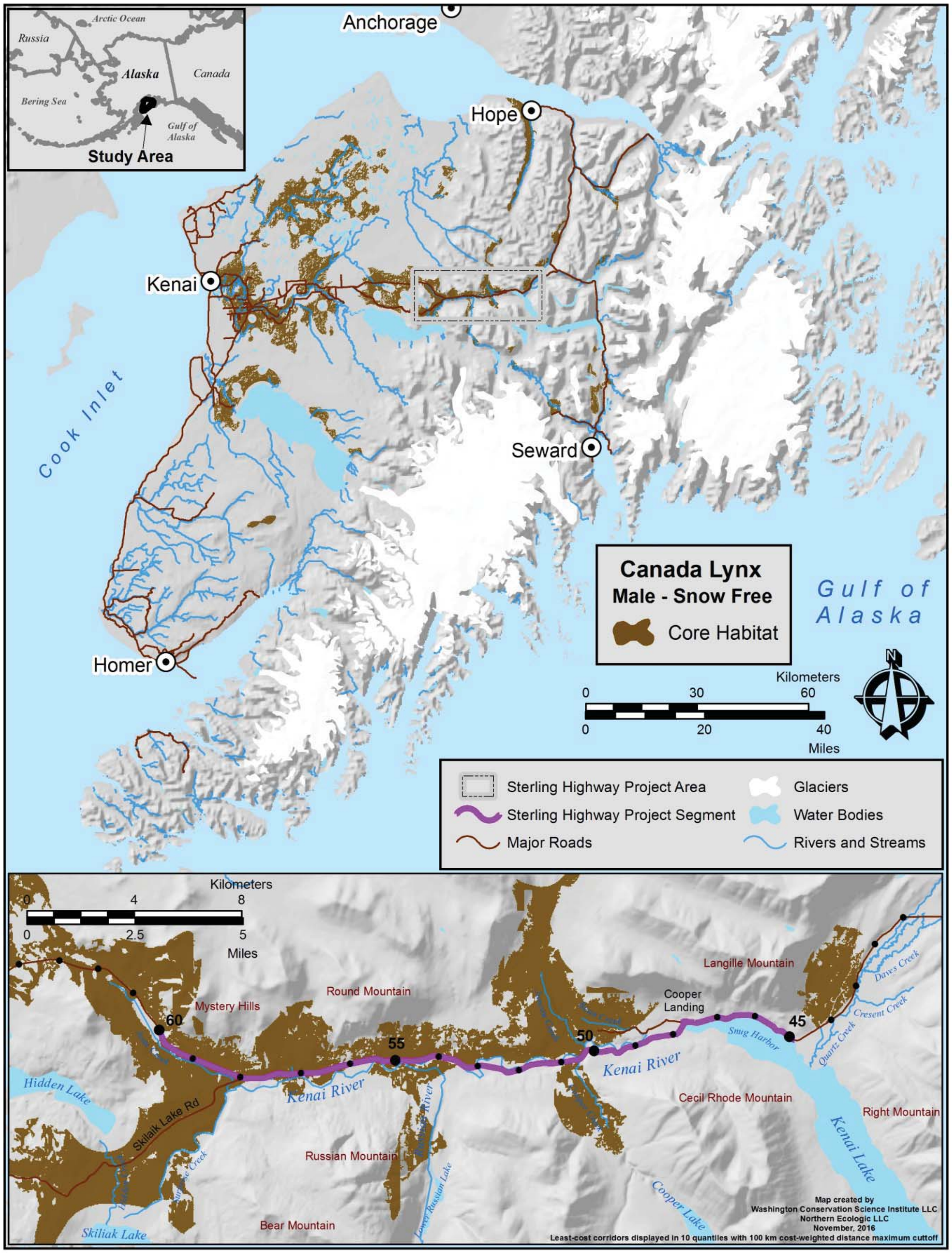
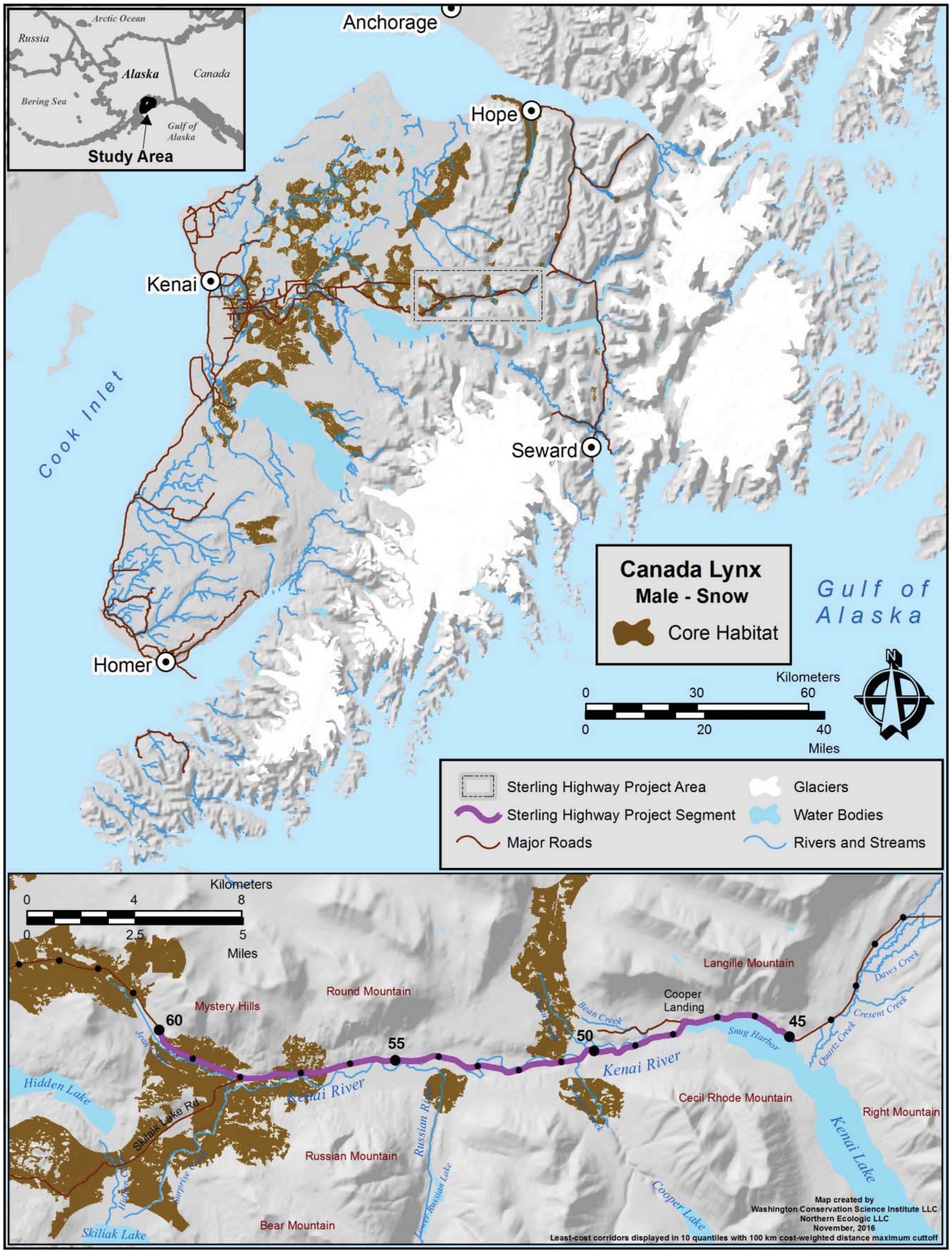


Figure 9-3. Core areas for male Canada lynx during the snow-free season on the Kenai Peninsula, Alaska, USA



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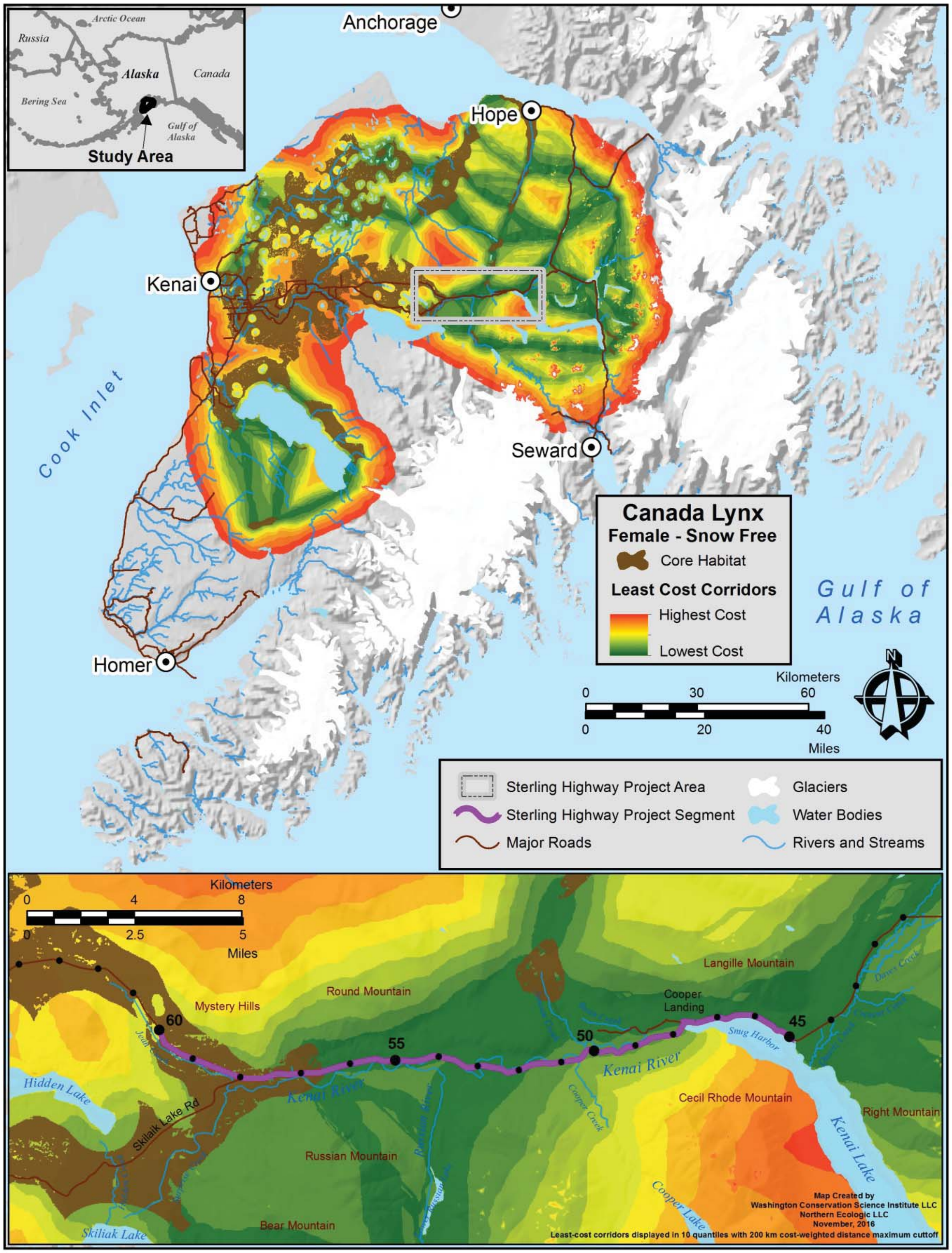
November, 2016

Least-cost corridors displayed in 10 quantiles with 100 km cost-weighted distance maximum cuttoff

Figure 9-4. Core areas for male Canada lynx during the snow season on the Kenai Peninsula, Alaska, USA



Map Created by
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November, 2016

Least-cost corridors displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 9-5. Least-cost corridors for movement of female Canada lynx in the snow-free season on the Kenai Peninsula, Alaska, USA.

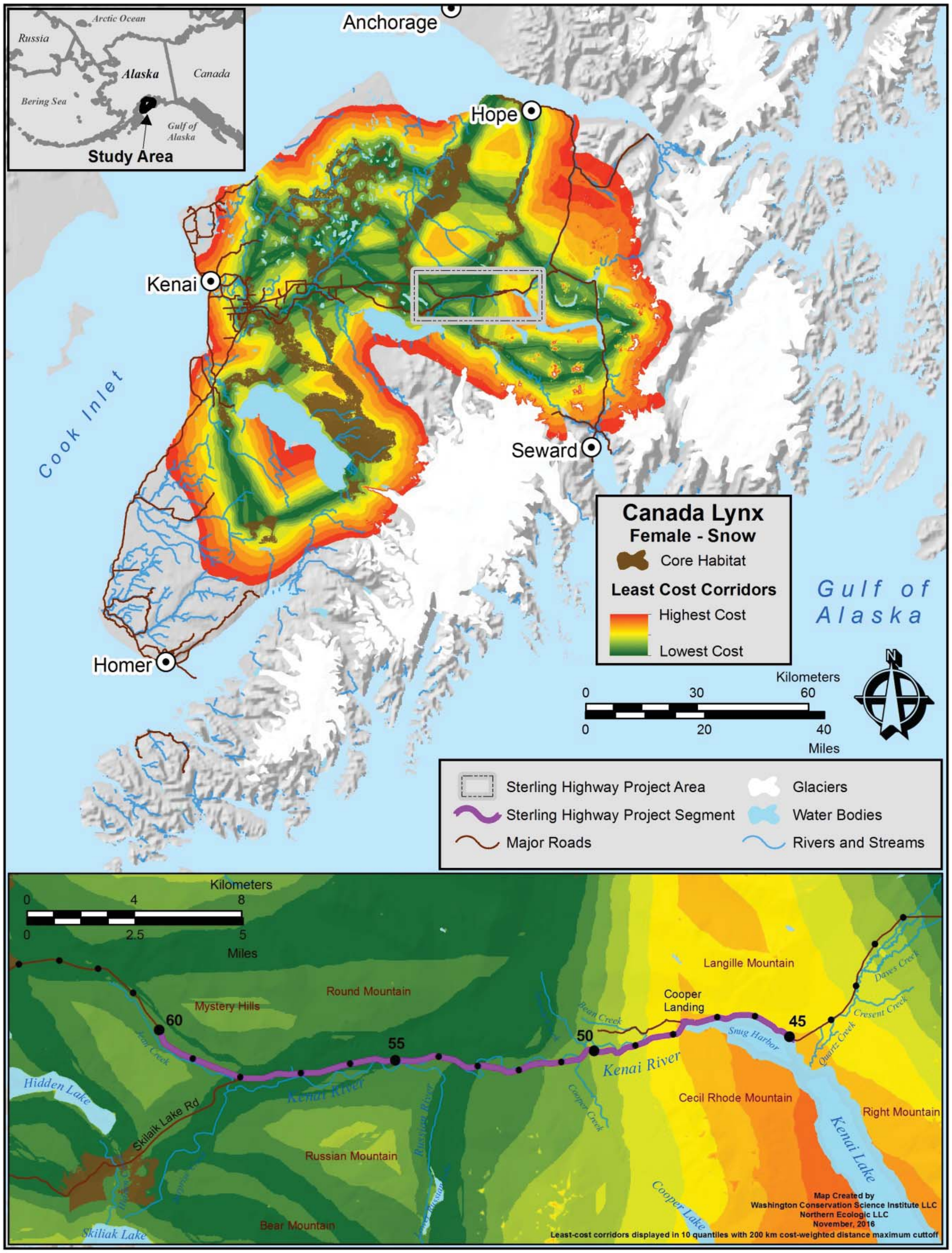


Figure 9-6. Least-cost corridors for movement of female Canada lynx in the snow season on the Kenai Peninsula, Alaska, USA.

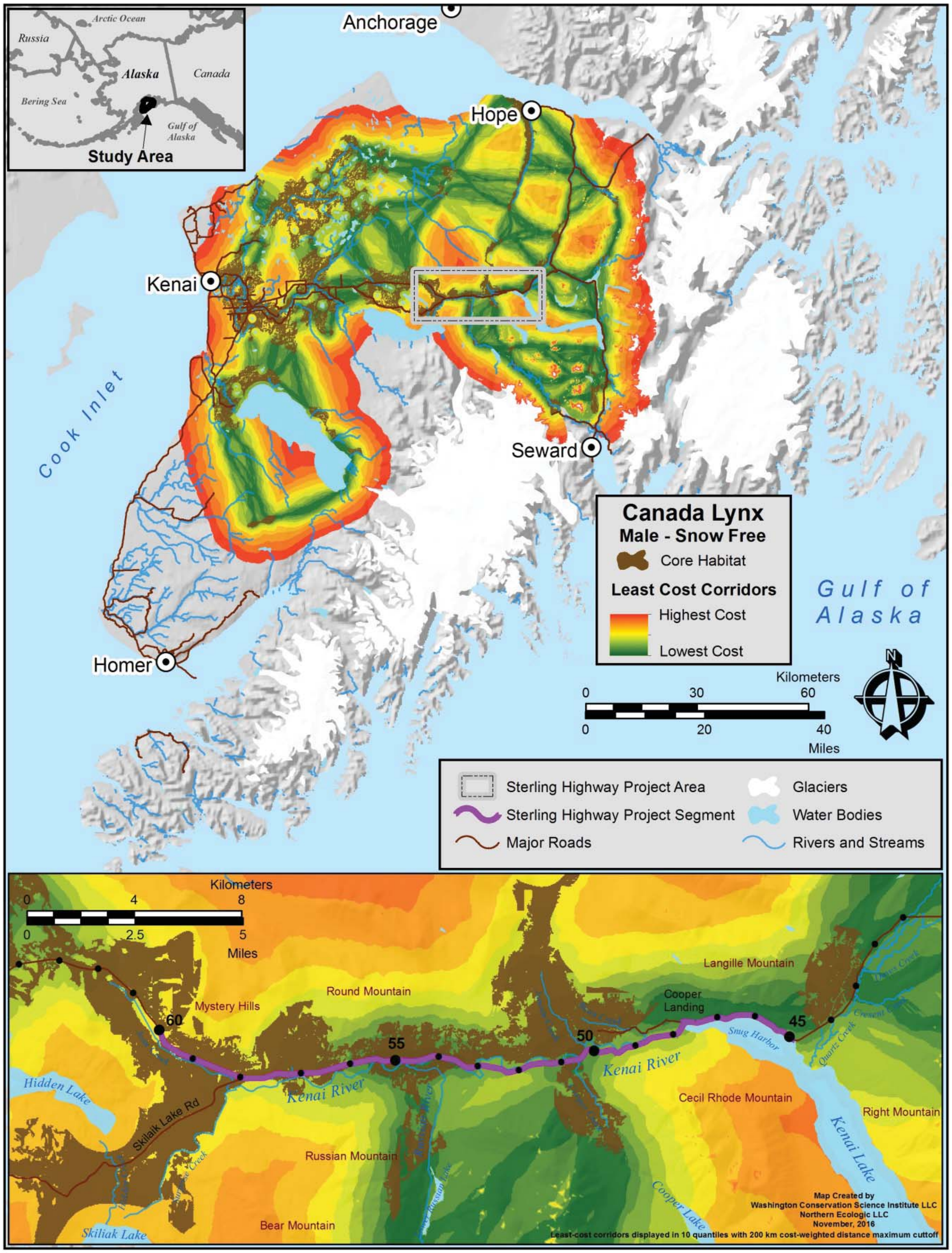


Figure 9-7. Least-cost corridors for movement of male Canada lynx in the snow-free season on the Kenai Peninsula, Alaska, USA.

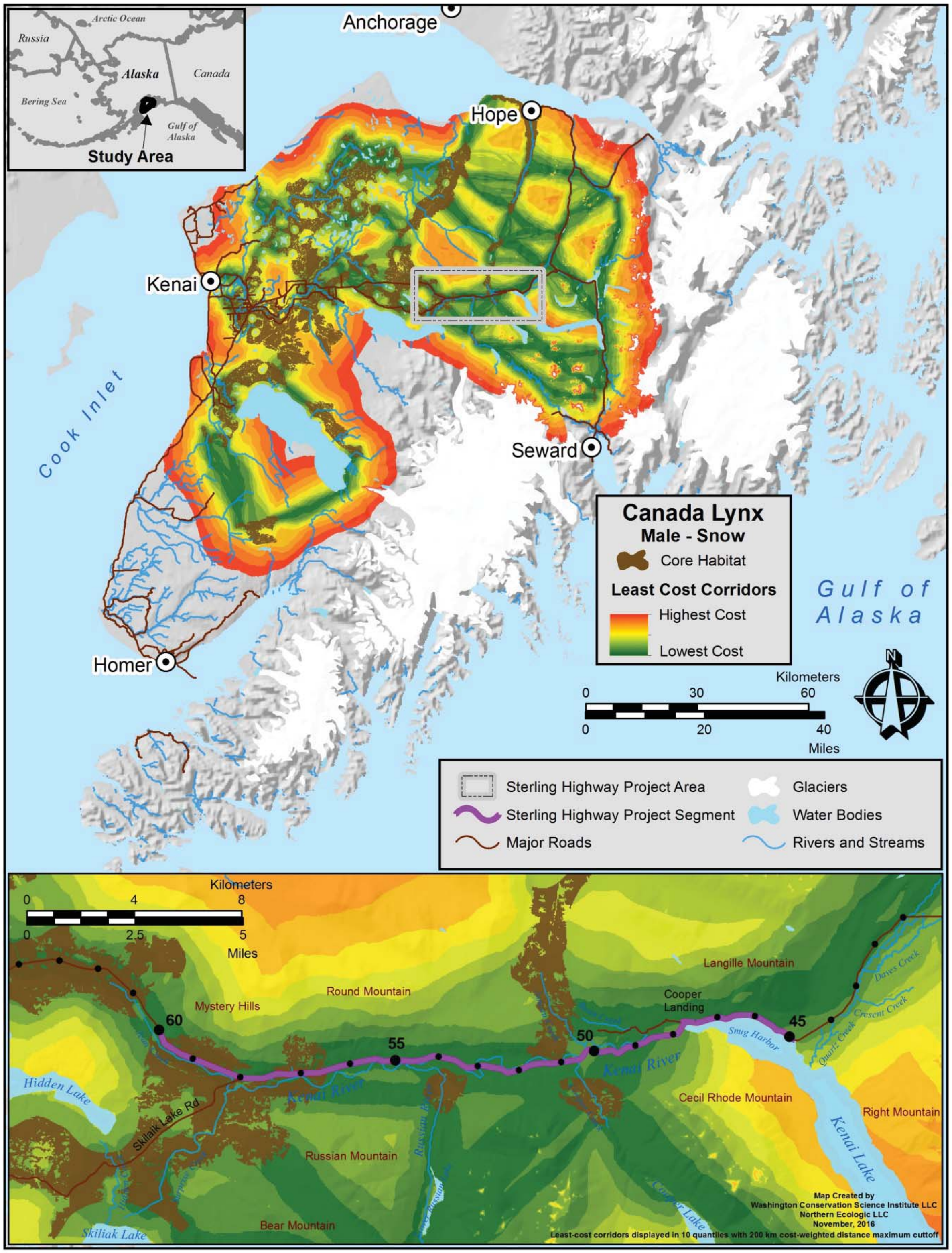


Figure 9-8. Least-cost corridors for movement of male Canada lynx in the snow season on the Kenai Peninsula, Alaska, USA.

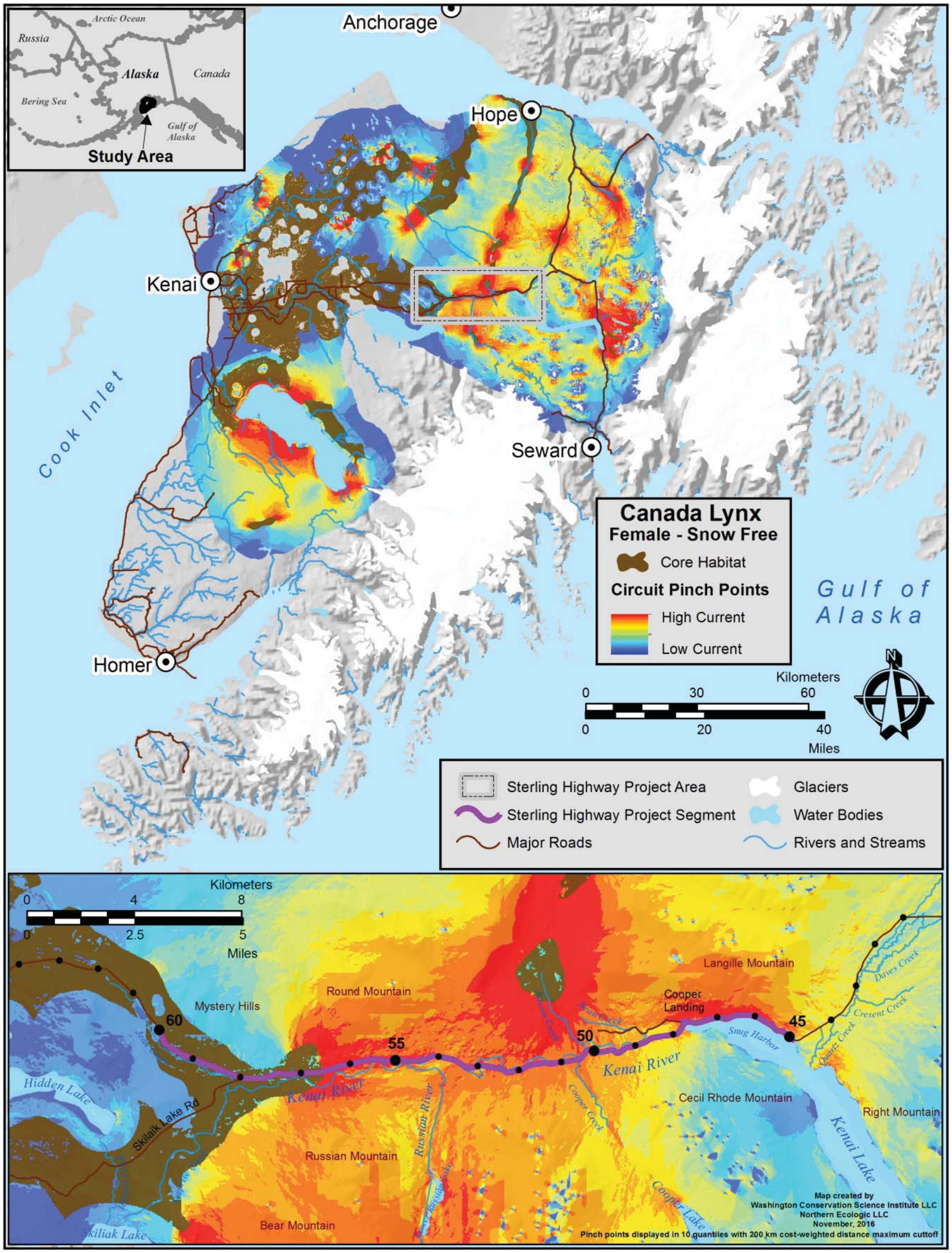


Figure 9-9. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female Canada lynx during the snow-free season.

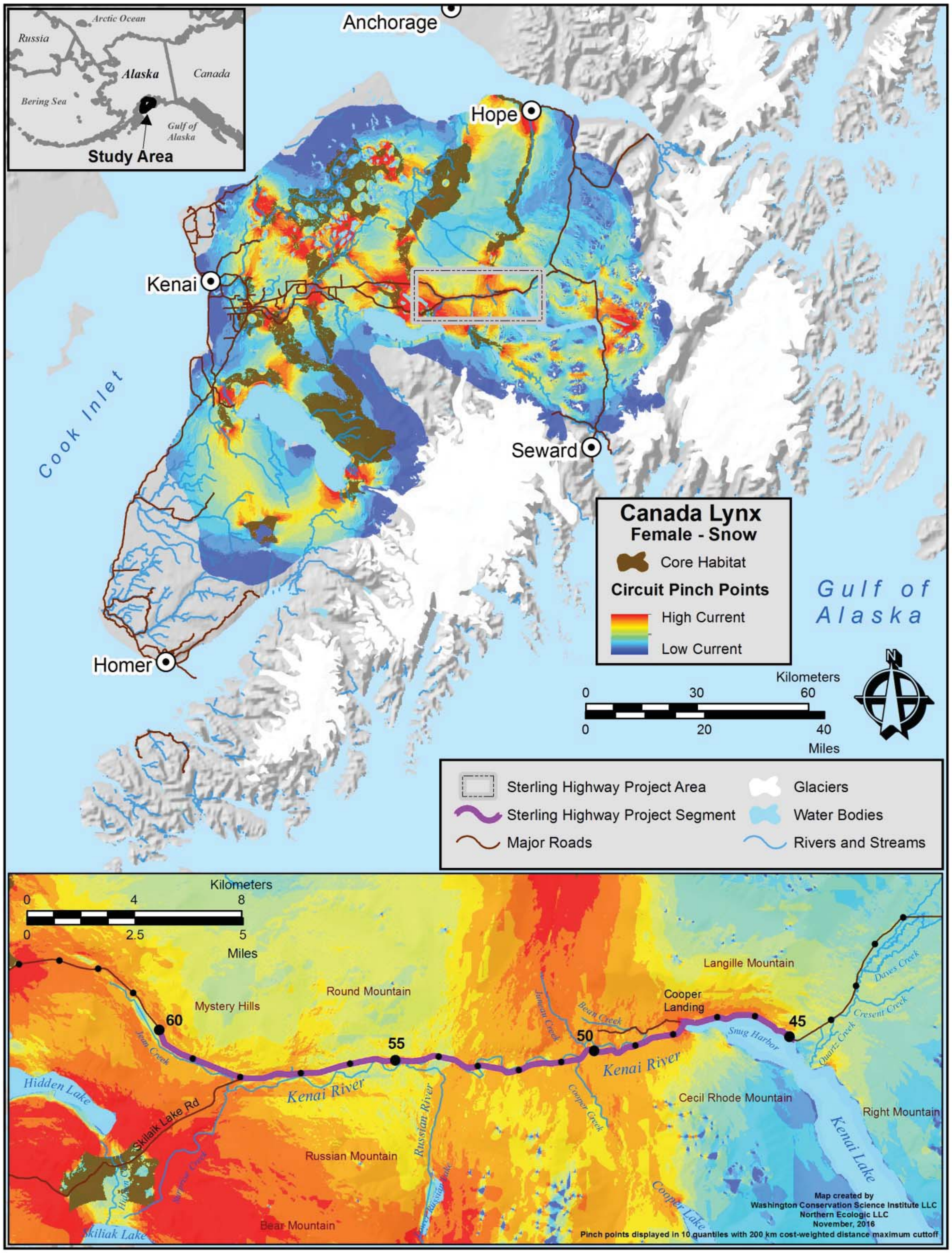


Figure 9-10. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for female Canada lynx during the snow season.

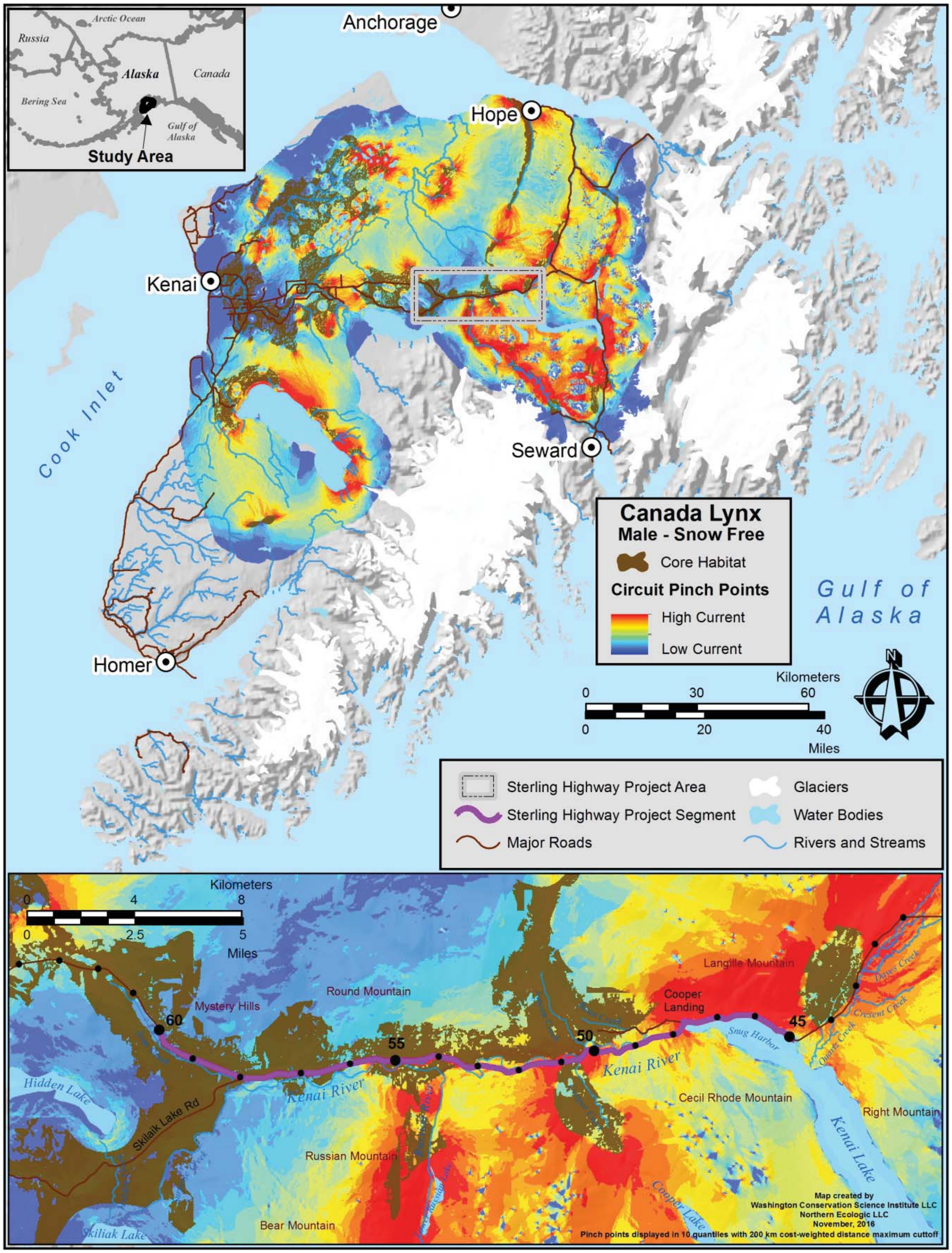
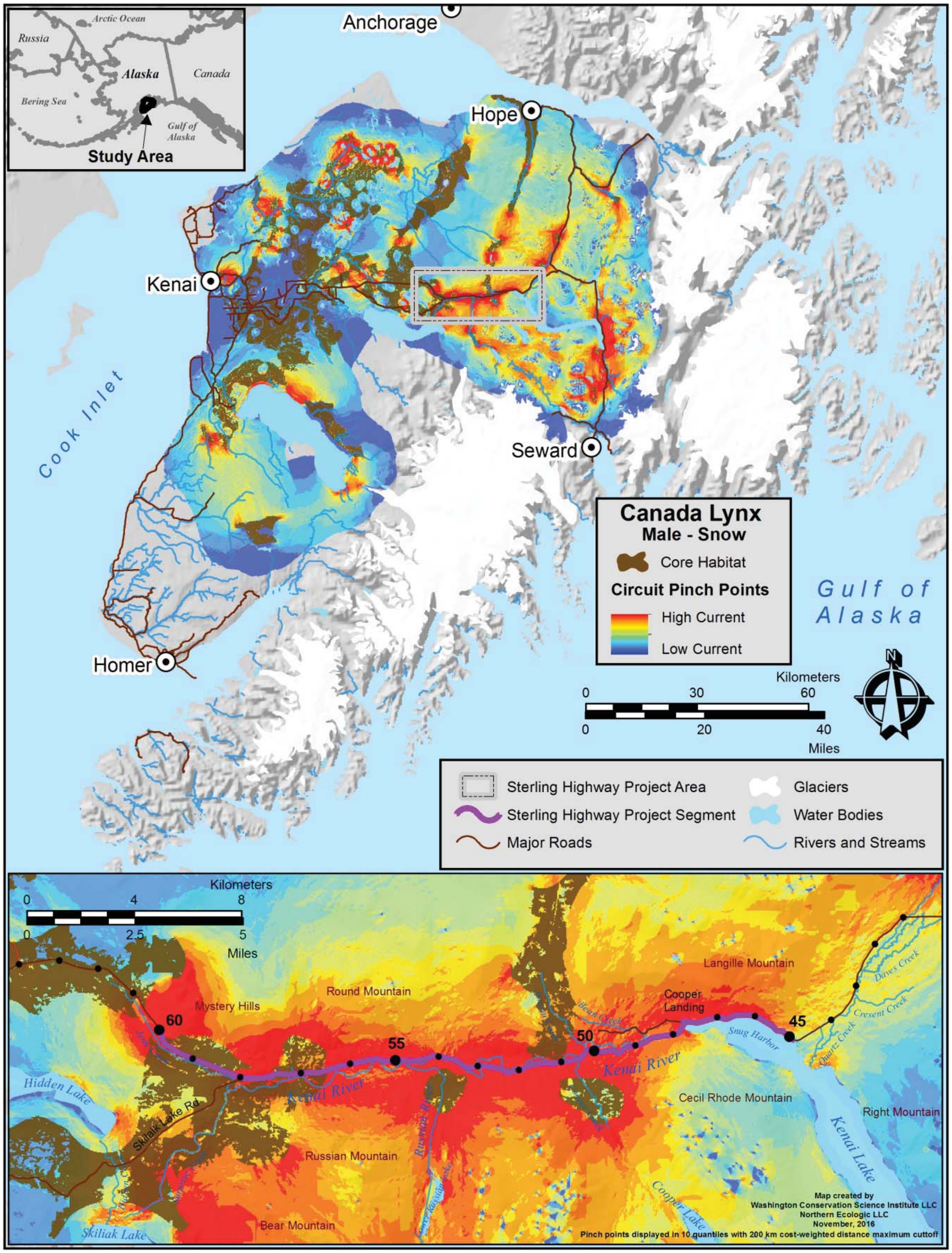


Figure 9-11. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for male Canada lynx during the snow-free season.



Map created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016

Pinch points displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 9-12. Potential primary crossing points across the Sterling Highway, Kenai Peninsula, Alaska, USA for male Canada lynx during the snow season.

Linkage at MP 53-54

This linkage occurs near the confluence of the Russian and Kenai Rivers near MP 53-54 (Figures 9-5, 9-6). It runs north-south, generally following the Russian River valley south of the highway, then extending to the northeast up the Juneau Creek valley. This linkage was identified in the least-cost corridor analyses for female lynx during the snow-free and snow seasons.

Linkage at MP 57

This linkage extends east-west across the Sterling highway near MP 57 (Figures 9-5, 9-6). It extends from where the Kenai River bends south near MP 58, crossing the Sterling highway at MP 57 then extending northeast up the Juneau Creek valley. This linkage was identified in the least-cost corridor analysis for female lynx during the snow-free and snow seasons.

Discussion

Carnivores, such as Canada lynx, are particularly susceptible to reduced population connectivity caused by roads given their large home ranges, long-distance movements, and low recruitment rates (Noss et al. 1996, Woodroffe and Ginsberg 2000, Baigas et al. 2017). This is even more of a concern for Canada lynx on the Kenai Peninsula because of their low genetic variability (Schwartz et al. 2003), likely due to the fact that lynx on the Kenai are a peripheral population, with smaller population size and limited opportunities for genetic exchange (Schwartz et al. 2003).

Management actions that promote highway permeability for carnivores require an empirical basis so that mitigation is most effective (Baigas et al. 2017). Carnivores can be particularly sensitive to the design and location of crossing structures (Ruediger and DiGiorgio 2007, Crooks et al. 2008, Baigas et al. 2017) making it particularly important that species-specific information be used to identify environmental conditions that facilitate their movements across highways (Squires et al. 2013, Baigas et al. 2017). Similar to the efforts of others, we used RSF modeling combined with recently developed habitat linkage assessment techniques to identify potential crossing locations for Canada lynx (Squires et al. 2013, Baigas et al. 2017).

Previous research to identify movement corridors for lynx found that greater vegetative cover, north-facing slopes, and areas with topographical concavity, such as river drainages were most likely to facilitate highway crossings (Squires et al. 2013, Baigas et al. 2017). Similarly, we found potential movement corridors identified for lynx along the Sterling Highway were generally associated with river and stream drainages.

Management Implications

Due to the potential low resiliency of the lynx population on the Kenai Peninsula, managers will need to carefully consider how to reduce or manage human caused mortalities. Reducing the potential for lynx to be killed in vehicle collisions is 1 way to accomplish this. Our analyses, based on recent approaches that combine resource selection and habitat connectivity modeling (Squires et al. 2013, Baigas et al. 2017), identify opportunities to integrate lynx movement ecology with highway design and engineering.

Physical crossing structures, such as over- or under-passes and fencing can effectively facilitate safe wildlife crossings of major highways (Foster and Humphrey 1995, Yanes et al. 1995, Ng et al. 2004). However, the extent to which these improvements benefit lynx may depend on the size of the highway and related traffic volume, as well as the landscape around the passage structures (Baigas et al. 2017). Scarce data exist on what type of crossing structures lynx will use. Monitoring of wildlife crossings on the Trans-Canada Highway in Banff National Park and adjacent provincial lands detected lynx using a range of structure types on the Trans-Canada Highway including a 50-m (164-ft) wide overpass and an open span bridge underpass (12 m wide by 4 m high) (39 ft wide by 13 ft high). Crooks et al. (2008) failed to detect lynx using any of 7 underpasses that were constructed specifically to reduce lynx highway mortalities in Colorado (i.e., 2 corrugated steel pipes 1.8–2.7 m [5.8–8.8 ft] wide by 1.2–1.8 m [3.9–5.9 ft] high; 5 concrete boxes 1.2–3.5 m [3.9–11.5 ft] wide by 1.2–3.0 m [3.9–9.8 ft] high). Clevenger and Huijser (2011) recommended that wildlife crossing structures for rare, mid-sized carnivores such as lynx, be also designed for larger animals to increase probability of them being used. They recommended landscape bridges from 70–>100 m (230–>328 ft) wide, wildlife overpasses 40–70 m (131–230 ft) wide, and viaducts or flyovers (Clevenger and Huijser 2011).

Acknowledgements

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Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 10 – Movement Patterns and Potential Corridors for Wolverines on the Kenai Peninsula, Alaska, USA

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Introduction

Wolverines exhibit very low demographic potential (Weaver et al. 1996), with average kit production <0.5 per year and most females not breeding until at least their 3rd year. Considering wolverine's low reproductive potential (Persson et al. 2006) and low survivorship (Krebs et al. 2004) compared with most other furbearers or large carnivores, it is important to closely monitor mortality, however it occurs (Golden et al. 2007b). This is particularly true if, as suggested by Krebs et al. (2004), human-caused mortality may be mostly additive to natural mortality. Most wolverine mortality is attributed to human causes and populations can be expected to decline in the absence of immigration from protected refugia (Krebs et al. 2004).

On the Kenai Peninsula, primary wolverine habitat is currently characterized as being located in the Kenai Mountains (including southern and eastern coastal areas), Caribou Hills, and the Deep Creek and Anchor River drainages (McDonough 2010). The estimated density within these areas was 3.0 (±0.4) wolverines/1,000 km^2 (Golden et al. 2007a). Harvest density reported for the Kenai Peninsula during 1984–2003 ranged within 0.3–1.5 wolverines/1,000 km^2 (Golden et al. 2007b). The reported wolverine trapping harvest in this area from 2004–2009 averaged 22 animals annually (range 18–26) with a mean of 34% females (McDonough 2010). The Kenai Peninsula also had higher and more consistent levels in percentage of area without wolverine harvest than other areas in south-central Alaska, indicating substantial potential refugia for wolverines despite high levels of human activity (Golden et al. 2007b).

Krebs and Lewis (2000) found that capture success and landscape use by wolverines in British Columbia was at least partially related to remoteness from human disturbance and protection from trapping. Wolverine reproductive success may be related to the quality and availability of denning sites, and may be partially influenced by the constancy of deep snow throughout the winter denning period (Magoun and Copeland 1998, May et al. 2012). Natal and maternal dens are often at high elevations, in cirque basins, with woody debris and large talus (Magoun and Copeland 1998, May et al. 2012). Wolverine home ranges are extensive, averaging 311–405 km^2 for females and 1,005–1,582 km^2 for males, and with subadults (particularly males) covering greater areas (Copeland 1996, Krebs and Lewis 2000, Inman et al. 2012). Juvenile dispersals of 185–378 km have also been reported (Copeland 1996, Krebs and Lewis 2000, Inman et al. 2012).

Food sources for wolverines are abundant on the Kenai Peninsula in the form of large ungulate carrion, smaller mammals, and birds (Golden et al. 2007a). Wolverines are primarily scavengers of ungulates killed by other predators, starvation, disease, or accidents, but they are also opportunistic predators, and their summer diet includes prey such as hoary marmots, ground squirrels, and smaller species (Lofroth et al. 2007). The health and viability of wolverine populations may be directly linked to the abundance and diversity of ungulates in a region (Lofroth and Krebs 2007, Lofroth et al. 2007, Koskela et al. 2013a). Habitat use patterns reflect the availability of carrion in ungulate wintering areas, fossorial rodents in alpine habitats during summer, energetic requirements, and/or human avoidance (summarized in Krebs et al. 2007).

Our specific objective in this work was to use information available in the literature to identify paths of potential movement for wolverines on the Kenai Peninsula. This is important for resource managers so that they may include that information in planning for habitat management, resource development, and infrastructure development (including transportation) to ensure maintenance of a healthy population of wolverines in this area. Specifically we wanted to identify movement paths within milepost (MP) 45–60 on the Sterling Highway that may be suitable areas for practices to mitigate the effects of highway development on wolverines.

Methods

Habitat Quality Model

We expressed the relationships among wolverines, characteristics of land cover classes, and other landscape characteristics and described the resulting habitat quality through Bayesian Networks (BN) using the Netica® shell (Norsys Software Corporation, Vancouver, British Columbia, Canada). BNs provided a structured tool for integrating information on habitat associations to assist in describing habitat quality upon which to base development of potential movement corridors. BNs depict probabilistic relations among causal variables and use Bayesian statistics to calculate probabilities of population presence in response to a given set of habitat conditions (Marcot 2006). The habitat relationships expressed in the BNs throughout this analysis were developed from application of findings reported in the scientific literature (i.e., field data were not used).

Applying the Model

BNs used in habitat-related analyses are typically applied to the values of variables within spatially registered polygons. To create a series of polygons, we placed approximately 144,000 hexagons, each 13.9 ha in size, across the study area. This size was selected to provide a degree of precision across the landscape within a database that was small enough to facilitate efficient processing. The mean of continuous variables and the values of categorical variables with the largest area within each hexagon were assigned to each hexagon. The BN was then applied to each hexagon and a value depicting quality of habitat within each hexagon was calculated.

Effect of Variables

Sensitivity analysis was performed in Netica® to determine how much the values of a selected node were influenced by a single finding at each of the other nodes. Sensitivity analysis in BNs evaluates the degree to which variation in the outcome variable (i.e., Habitat Quality Index) is explained by other variables (Marcot 2012). Sensitivity analyses can help identify the relative influence of each variable on the model outcome and can be conducted on any dependent node (Marcot et al. 2001, Marcot 2006). Variance reduction was calculated as the reduction in the variation of the value of the Habitat Quality Index by each of the input variables using a routine in the Netica® shell. The results of these analyses were used to quantitatively compare and rank the effect of input variables on the outcome of the model. Sensitivity analyses are useful for determining which habitat attributes might be prioritized for management for greatest effectiveness in conservation or restoration planning.

Resistance Surfaces by Variable

Connectivity analyses require data that quantify estimates of the resistance presented by different landscape features to movement of animals (Singleton et al. 2002, Adriaensen et al. 2003, Beier et al. 2008). We developed a resistance layer for wolverine using species-specific effects on dispersal by each of the landscape variables included in the BN following the process developed by WHCWG (2010).

Conceptually, we defined the resistance contributed by each landscape variable as the number of additional grid cells of ideal habitat wolverine would move through to avoid 1 grid cell of the variable being considered. For each landscape variable, we estimated the additional resistance to movement imposed by the variable relative to “ideal” habitat, ranging from 0 for ideal habitat to infinity for complete barriers. The final resistance data layer for wolverine was then derived by summing the resistances from each variable and adding 1 (to account for Euclidean distance). Each cell in the resulting resistance layer for wolverine had a resistance value summing the individual resistances from the 9 variables included in the BN: land cover, persistence of spring snow, winter habitat for moose, elevation, landform, terrain complexity, building density, and road density (see Chapter 2; Begley et al. 2017 and Chapter 4; Gaines et al. 2017a} for information on how data were developed for each variable).

The resistance associated with individual variables was estimated using the relationships established in the BN to synthesize how factors would limit movement through behavioral responses (e.g., avoidance of roads) and through mortality (e.g., vehicle collisions). The parameters used to build the resistance model were developed based on literature review and expert judgment. Resistance reflects the ecological cost of wolverines traveling through a pixel. In general, resistance increases with the energetic cost of travel through the pixel. Resistance decreases as the quality of habitat increases in a pixel; it is not necessarily related to the speed of travel through the pixel.

Core Areas

We followed a terminology convention similar to that established by WHCWG (2010) and thus used the term core area to describe high-quality habitats between which we evaluated movement patterns for wolverine. Core areas were generated using the Core Mapper tool from the Gnarly Landscape Utilities ArcGIS toolbox applied to the results of habitat quality models with habitat quality index scaled from 0-100 (Shirk and McRae 2013). Core areas for wolverine were defined as significant habitat areas that are expected or known to be important based on habitat association modeling (WHCWG 2010). To meet that criterion we described potential core habitat as areas having a habitat value >75 (on a 0 – 100 scale). We then calculated the proportion of habitat within a circular moving window with a radius of 200 m. This step generated a surface representing where the largest concentrations of habitat existed. We removed cells from the initial maps of core areas if the average habitat value of the window centered on a particular cell was <86 (on a 0 – 100 scale). This prevented habitat cores from being identified in areas where high-quality habitat was not sufficiently concentrated.

Potential Movement Corridors

Connectivity among habitat patches for animals within a landscape depends on characteristics of the landscape (structural connectivity) and on aspects of the mobility of the animal (functional connectivity) (Adriaensen et al. 2003). Least-cost modeling, which originated from graph theory, has been used to incorporate detailed information about the landscape as well as behavioral aspects of the animal to describe connectivity. Cost-weighted distance approaches to estimate movement corridors of animals represent the least accumulative cost required to move between a specified source and a specified destination (Beier et al. 2007). This method provides a flexible tool that provides insights into the relationship between dispersal and landscape characteristics. This method identifies a set of near-optimal corridors for the landscape linkage network, with emphasis on corridors with the least cumulative cost-weighted distances (Chetkiewicz et al. 2006, Beier et al. 2008).

While these least-cost models implicitly assume animals have perfect knowledge of the landscape, current flow models assume they do not have knowledge of potential movements more than 1 step ahead (Newman 2005). Real-world movement behavior of animals like wolverines may fall somewhere between these extremes (McRae et al. 2008, Richard and

Armstrong 2010). While shortest-path methods have been used to develop empirical multivariate models of habitat connectivity (Schwartz et al. 2009, Richard and Armstrong 2010), predictions from current flow-based models are highly correlated with observed genetic distance in several plant and animal populations and may better reflect actual movement corridors (McRae et al. 2008, Lee-Yaw et al. 2009, Shirk et al. 2010).

Circuit theory has been applied to connectivity analyses in other fields (McRae et al. 2008), and has been used to model gene flow in heterogeneous landscapes (McRae 2006, McRae and Beier 2007). Because connectivity increases with multiple pathways in circuit networks, distance metrics based on electrical connectivity are applicable to processes that respond positively to increasing connections and redundancy (McRae et al. 2008). Circuit theory is based in Markovian random walk theory and describes every movement as a random choice with movement in every direction equally probable. The landscape then acts as an electrical-resistance surface or, inversely, as a conductance surface, as the current travels outward to surrounding cells from the source patch of core habitat. The areas of least resistance or greatest conductance across the landscape are the most probable areas for movement. This theory can be applied to predict movement patterns of random walkers moving across complex landscapes, to generate measures of connectivity or isolation of habitat patches, and to identify important connective elements (e.g., corridors) for conservation planning.

The resistance distance concept of circuit theory incorporates multiple pathways connecting nodes, with resistance distances measured between core area pairs decreasing as more connections are added (McRae et al. 2008). Therefore, the resistance distance does not reflect the distance traveled or movement cost accrued by an individual animal. Rather, it incorporates both the minimum movement distance or cost and the availability of alternative pathways. As additional linkages are added, individuals do not necessarily travel shorter distances, but have more pathways available to them. Current density can be used to identify landscape corridors or ''pinch points,'' (i.e., features through which moving animals have a high likelihood – or necessity – of passing). High current through these pinch points indicates that stopping the flow through these points, or maintaining it, will have a high impact on connectivity.

To identify potential movement corridors, we used a combination of least-cost modeling and circuit theory (McRae et al. 2008) using the Linkage Mapper Toolkit (McRae and Kavanagh 2011) in ArcGIS 10.3. These analyses were performed by applying the final map of core habitat to identify start and end locations for building the corridor network from the resistance layer developed for wolverine. We used the one-to-many criterion, whereby 1 source was connected to all end nodes in an iterative fashion. Circuit theory supplemented least-cost analyses to identify important areas for prioritization of conservation connectivity associated with the Sterling Highway (McRae et al. 2008).

The Pinchpoint Mapper module (McRae 2012) of Linkage Mapper was used to apply circuit theory through the program Circuitscape (McRae and Shah 2009) to identify and map "pinch points" (i.e., constrictions) within the resulting corridors. Circuitscape calculates the resistance of the landscape to movement between each pair of core areas (analogous to electrical resistance in a circuit diagram), allowing for multiple pathways between core areas. The pinch points we identified represented where loss of a small area could disproportionately compromise connectivity of the broader landscape. Using this hybrid approach, we merged least-cost corridors with pinch points to identify and display the most efficient movement corridors and the critical areas within them that contributed the most to habitat connectivity (McRae and Kavanagh 2011).

Results

Habitat Quality Model

Wolverines are highly mobile, with home range sizes that may be >950 km^2, reported dispersal distances up to 378 km, and daily movements that may be >42 km (Hornocker and Hash 1981; Gardner et al. 1986; Copeland 1996; Inman et al. 2007, 2009). As a result, landscape characteristics that influence movements in wolverines have not been well studied (Ruggiero et al. 2007). However, wolverine habitat in western North America has been described as being primarily at high elevation and isolated from human activity (Hash 1987, Hatler 1989, Carroll et al. 2001, Rowland et al. 2003). The habitat quality model included features that likely reflect wolverine life requisites including available seasonal food sources, habitat suitable for reproduction, and their apparent avoidance of human activity (Weaver et al. 1996).

The habitat quality model was based on research that indicated that wolverines generally occupy rugged, high-elevation areas that usually follow the alpine timberline (Hornocker and Hash 1981, Copeland 1996, Edelmann and Copeland 1999, Squires et al. 2006, Aubry et al. 2007, Brock et al. 2007, Copeland et al. 2007). These areas include conifer forest land cover and the edge between conifer forest and non-forest land covers (Brock et al. 2007) where deep spring snowpack is maintained for denning (Magoun and Copeland 1998, Aubry et al. 2007). The model also reflected that, conversely, wolverines avoid areas with high densities of roads and buildings (Copeland 1996, Carroll et al. 2001, Rowland et al. 2003). The combination of variables in the habitat quality model was supported by the work of Balkenhol (2009) who reported that wolverine movements and gene flow was influenced by a combination of climatic, anthropogenic, and topographic landscape characteristics, and that these factors are much more important for successful wolverine dispersal than distance alone.

Habitat relationships

Spring Snow Cover.–Wolverines are morphologically adapted to survive and forage in snow (Haglund 1966, Tefler and Kelsall 1984, Aubry et al. 2007) (e.g., wolverines have a stocky build with heat-retentive pelage and low-foot loading). Snowpack may be important for wolverine foraging and movement efficiency over the course of the winter (Lofroth et al. 2007) and may be particularly critical in early spring when the animals den and nurse neonates (Magoun and Copeland 1998; Lofroth et al. 2007). All historical wolverine records in the western United States, and most in the eastern United States, were located in areas with a measurable probability of snow cover persisting through the wolverine denning period during the last 40 years (Aubry et al. 2007). Wolverine population growth rate was positively related to temporal trends in winter snowpack (Brodie and Post 2010). They reported that in areas where winter snowpack levels were declining the fastest, wolverine populations tended to be declining most rapidly. They also found that spring snowpack appeared to influence wolverine population dynamics (Brodie and Post 2010).

Schwartz et al. (2009) used a landscape genetic approach to show that persistent spring snow cover influenced movement, and subsequently gene flow in wolverines, with areas lacking consistent snow cover having a resistance to movement approximately 20 times higher than those with sufficient spring snow cover. Balkenhol (2009) also reported that snow is 1 of the major factors influencing successful wolverine dispersal even though he used snow depth rather than a representation of persistent spring snow cover. Snow depth may be more important than snow cover for wolverines because snow depth can influence predation rates, dispersal, and availability and access to den sites (Balkenhol 2009).

If reduced snowpack limits dispersal (Schwartz et al. 2009), individuals could potentially be precluded from successfully establishing new home ranges (Brodie and Post 2010). Lower snowpack may also reduce reproductive success (Magoun and Copeland 1998). Female wolverines often select natal den sites with snow cover late into spring (Copeland 1996). Copeland et al. (2010) reported what they considered an obligatory relationship between wolverine den sites and spring snow coverage. These sites allow wolverines to construct snow tunnels that provide thermoregulatory benefits for kits, are secure from excavation by predators, and are located in habitat that is used by few other carnivores (Magoun and Copeland 1998, Carroll et al. 2001). Lower snowpack may also decrease the availability of food in winter and early spring (Persson 2005, Lofroth et al. 2007) by reducing the density of ungulate carcasses through increased ungulate survival (Wilmers and Post 2006), and lower hunting success of wolves (Mech et al. 2001). Landa et al. (1997) also suggested that wolverine reproductive success may depend on small-mammal abundance, which may, in turn, be affected by snowpack via positive relationships between snowpack depth and small-mammal overwinter survival (Korslund and Steen 2006).

Thus, as McKelvey et al. (2011) concluded, the areas with spring snow cover that supported reproduction (Magoun and Copeland 1998) could also be used to predict year-round habitat use, dispersal pathways, and both historical (Aubry et al. 2007) and current ranges (Copeland et al. 2010).

Elevation.–Carroll et al. (2001) reported that wolverine use occurred more frequently at higher elevations than random sites throughout the Rocky Mountains. Copeland et al. (2007) reported that elevation was the key variable for distinguishing wolverine presence in central Idaho. It was the strongest and most consistent variable across all logistic regression models. Wolverines preferred higher elevations in almost all models in which it was present. Use of high elevation was most notable during summer when all elevations >2,400 m were used more than expected and elevations <2,200 m used less than expected (Figure 10-1).

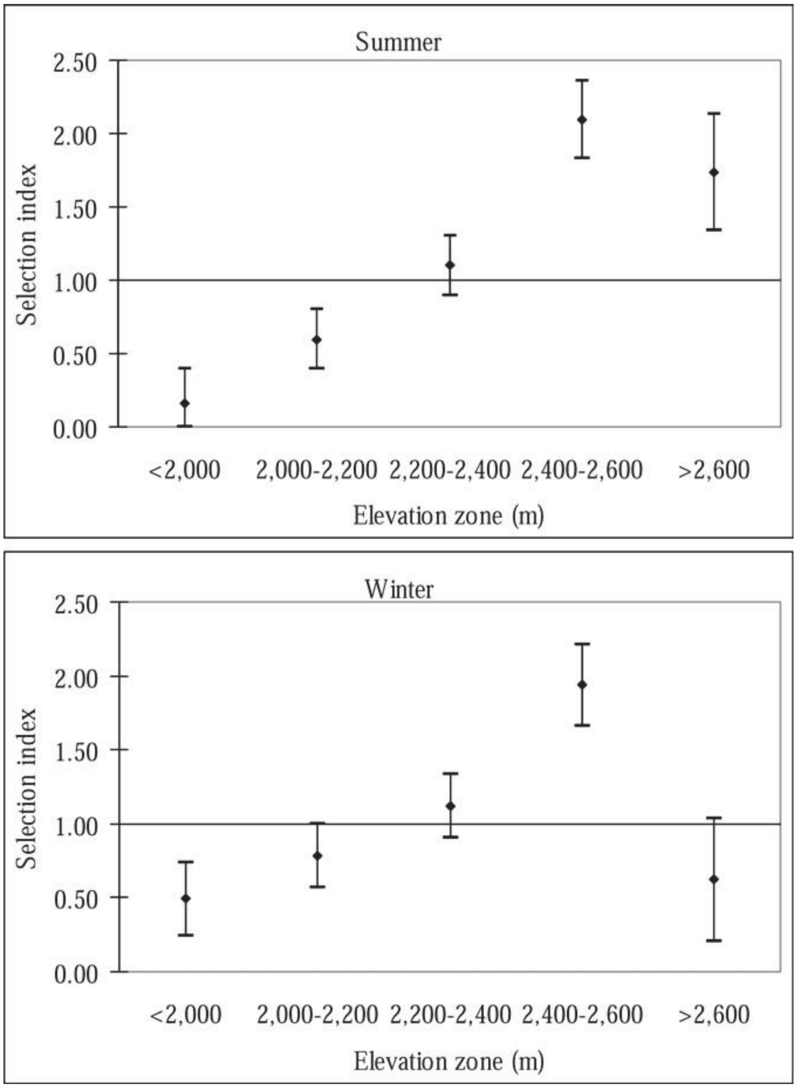


Figure 10-1. Selection indices (95% CI) for seasonal wolverine use points versus random points for elevational zones in central Idaho, USA, 1992–1996 (from Copeland et al. 2007). Intervals occurring >1.00 or <1.00 indicate use or nonuse, respectively. Intervals that include 1.00 indicate no selection.

Wolverines tendency for active marking behavior, defecation, resting, and hunting at high elevations indicated their concentration in these areas in southeast Norway (van Dijk et al. 2008). This finding was confirmed by May et al. (2008) who reported that wolverines in southeast Norway selected open, rugged terrain at higher elevations. Additionally, at the home-range and landscape scales, den sites were found in rugged terrain around the tree-line at 1,100 m (May et al. 2012). Dens in Sweden were located at elevations between 486 and 1,316 meters above sea level (mean = 799; 95% C.I. = ±42, n = 81) (Mattsing 2008). Additionally, dens were located more often than expected at elevations between 700–800 m and 900–1,000 m.

Land type.–Carroll et al. (2001) reported that the locations of cirques were a crude approximation of known natal den sites indicating that they may be an important limiting factor.

Topographic ruggedness.–Balkenhol (2009) reported that terrain ruggedness strongly influenced movements and population genetic structure in wolverines and Carroll et al. (2001) also reported a positive relationship with occurrence of wolverines. Steep slopes were a strong indicator of wolverine presence in summer in central Idaho, most notably in adults (Copeland et al. 2007). Female wolverines in British Columbia were positively associated with rugged terrain where security habitat is presumably more abundant (Krebs et al. 2007). Wolverines in southeast Norway selected open, rugged terrain at higher elevations (May et al. 2008) and at the home-range and landscape scales, den sites were found in rugged terrain (May et al. 2012). Rauset et al. (2013) also found that wolverines in northern Sweden selected for steep and rugged terrain.

However, wolverines are also reported to show high levels of genetic connectivity in areas without much topographic variation (i.e., taiga and tundra [Wilson et al. 2000; Kyle and Strobeck 2001, 2002]). So while rugged terrain may be preferred habitat where it occurs, it is unlikely that wolverine dispersal is actually limited across non-rugged areas. High topographic ruggedness may indicate areas with little human influences. These areas often not only show low levels of human population and housing densities, but probably also experience relatively low levels of recreational activity, and may simply be in a more pristine, undisturbed condition than areas that are relatively flat and easily accessible for humans (Balkenhol 2009).

Building density.–Balkenhol (2009) reported that building density strongly influenced movements and population genetic structure in wolverines. Koskela et al.'s (2013b) results also indicated that in eastern Finland wolverines avoided settlements. May et al. (2006, 2008) reported that in Norway that wolverines avoided areas with human structures (e.g., houses, cabins).

Road density.–Wolverine detections appeared to be negatively associated with higher levels of road density (Carroll et al. 2001). The addition of road density to their multiple regression model for wolverine resulted in a better model as measured by the AIC statistic. Female wolverines in British Columbia were positively associated with roadless areas and negatively associated with recently logged areas during summer (Krebs et al. 2007). At home-range and landscape scales in Norway, dens were generally located far from public roads (7.5 km; 0.5 SE) and private roads and/or recreational cabins (1.4 km; 0.1 SE) (May et al. 2012). At subbasin and watershed scales, Rowland et al.'s (2003) study showed that road-density class was a good indicator of the distribution of wolverine observations. The distribution of wolverines in northwestern Ontario was limited by human activities, including road-building (Bowman et al. 2010).

Habitat modeling work by Carroll et al. (2001) showed that wolverine occurrences were negatively associated with road densities >1.7 km/km^2. However, Rowland et al. (2003) suggested that this threshold may be lower, because wolverine abundance estimates in their watershed-scale models varied between low road densities (<0.44 km/km^2) and moderate road densities (0.44–1.06 km/km^2). Results from Dawson et al. (2010) in lowland boreal forests of central Canada were consistent with predictions for the interior northwest area of the United States (Rowland et al. 2003). The mean road density for all wolverines in Dawson et al. (2010) was 0.43 km/km^2, and for the 2 wolverines whose home ranges had higher road densities than the suggested threshold of 0.44 km/km^2, the risk of mortality due to anthropogenic factors appeared to increase. Singleton et al. (2002) estimated the effect of road density on landscape permeability for wolverines based on results reported in published literature (Figure 10-2).

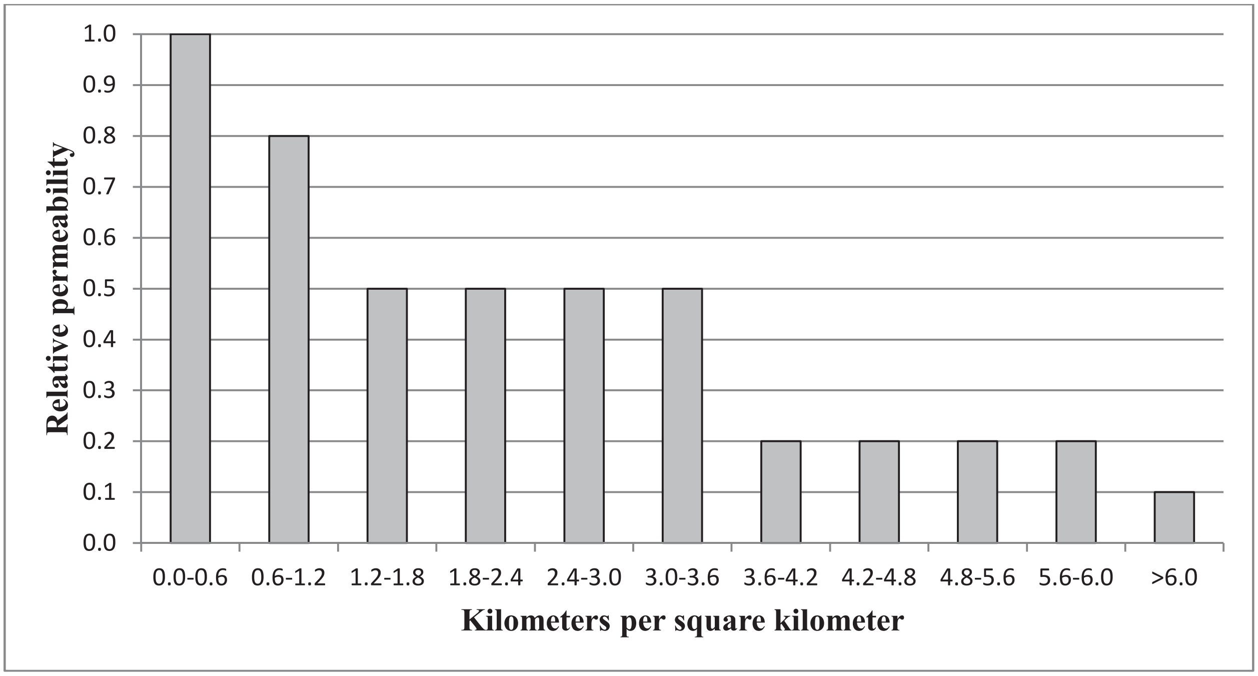


Figure 10-2. Effect of road density on relative permeability of the landscape for wolverines (from Singleton et al. 2002).

Winter recreation.– Helicopter skiing and backcountry skiing were negatively associated with habitat use by female wolverines in British Columbia during winter (Krebs et al. 2007). However, the causal factors associated with these patterns are not well understood (see Copeland et al. 2007, Krebs et al. 2007).

Land cover.–With few exceptions, wolverine reproductive dens have been located in alpine, subalpine, taiga, or tundra habitat (Pulliainen 1968, Lee and Niptanatiak 1996, Landa et al. 1998, Magoun and Copeland 1998). Rarely have dens been reported in low-elevation, densely forested habitats, although wolverines occupy these habitats.

Virtually all of the wolverine records located by Aubry et al. (2007) in the Pacific and Rocky Mountain states were within or near alpine areas (with the exception of northern Idaho and western Montana). Snow-tracking by Wright and Ernst (2004a) in northern Alberta and British Columbia suggested that wolverines selected the densest climax conifer stands for travel in search of food. Additionally, Wright and Ernst (2004b) reported wolverine food caches were located exclusively in old conifer forest stands or in mixed stands dominated by conifers.

Wolverines in Ontario appeared to avoid deciduous forest and observations were more closely associated with mature coniferous forest (Bowman et al. 2010). These authors speculated that this avoidance may have been associated with faster rates of snow melt under deciduous forest canopy. Jost et al. (2007) demonstrated that conifer forest cover was an important variable in the retention of snow. Conifer forests were also consistently used by wolverines in Montana (70% of observations [Hornocker and Hash 1981], in Idaho (70.2 % of observations [Copeland 1996]), in south-central Alaska (Gardner 1985), and in the Yukon (Banci 1987). Koskela et al. (2013b) reported the wolverines avoided deciduous forests and young forests in eastern Finland while preferring coniferous and mixed forests (Table 10-1).

Table 10-1. Model-averaged coefficients for the best wolverine model from Koskela et al. (2013). For landscape variables, negative values indicate avoidance, positive values refer to selection. For distance to settlements, negative value indicates selection while positive values indicate avoidance.

Variables	Selection coefficients
Deciduous forests	–34.571
Mixed forests	2.361
Coniferous forests	0.442
Young forests	–0.467
Wetlands and bogs	0.139
Settlements	0.0005

Rocky talus areas were preferred during summer in south-central Alaska and Idaho (Gardner 1985, Copeland 1996) and avoided in the Yukon (Banci 1987). Whitman et al. (1986) found that all forest types were avoided by wolverines during summer in south-central Alaska.

Forest edge.–A multiple regression model developed for wolverine by Carroll et al. (2001) included forest edge (areas ≤100 m of ecotones between forest and non-forest). Female wolverines move to higher-elevation environments, at or just below tree line, for denning and rearing kits (Magoun and Copeland 1998, Krebs and Lewis 2000, Lofroth 2001, Mattsing 2008, May et al. 2012).

Moose winter range.–Large ungulates consistently comprise a majority of wolverines' diet (Rausch and Pearson 1972, Hornocker and Hash 1981, Banci 1987, Magoun 1987, Lofroth et al. 2007). In British Columbia wolverines fed primarily on moose (*Alces americanus*) and mountain goat (*Oreamnos americanus*) carrion in winter, usually scavenged as remains of wolf (*Canis lupus*) predation or avalanche-killed animals (Lofroth et al. 2007). Moose winter ranges, which likely provide ungulate carrion, were used extensively by wolverines in winter in British Columbia (Krebs et al. 2007), consistent with other North American studies (Hornocker and Hash 1981, Whitman et al. 1986, Banci and Harestad 1990). Lofroth and Krebs (2007) considered areas with moderate to high abundance of moose (i.e., >10/km^2) as contributing to good habitat for wolverines.

Bayesian network

Occurrence and abundance of wolverines were assumed to vary across the Kenai Peninsula in response to landscape variables included in an environmental index (i.e., land cover, snow depth and persistence, winter habitat quality for moose), a disturbance index (i.e., density of buildings, density of roads, winter recreation activity based on land form), and a topographic index (i.e., elevation, terrain ruggedness, den site location based on land form).

Land cover.–Data describing land cover on the Kenai Peninsula were taken from the National Land Cover Database (Homer et al. 2007, Selkowitz and Stehman 2011) by Begley et al. (2017, Chapter 2). Land cover classes used in this analysis and their associated value to wolverines were (Figure 10-3):

- water (NLCD code 10, 11) – none
- ice/snow (12) – none
- developed (20) – none
- barren (30) – low
- deciduous forest (41) – low
- planted/cultivated (80) – low
- wetlands (90) – low
- shrubland (50) – moderate
- herbaceous upland (70) – moderate
- evergreen forest (42) – high
- mixed forest (43) – high

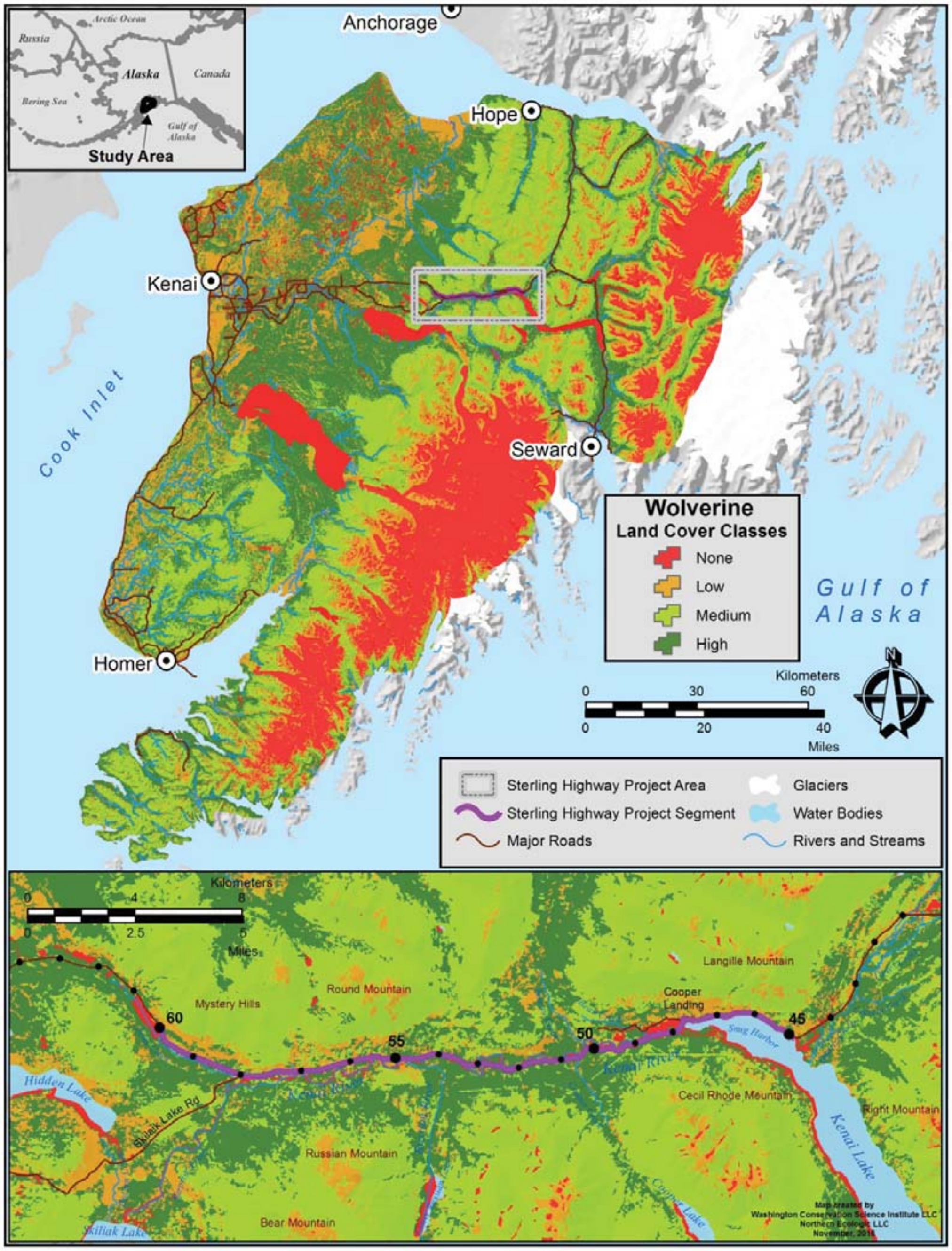


Figure 10-3. Land cover classes used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA. Land cover classes used in this analysis and their associated value to wolverines were water (NLCD code 10, 11) – none, ice/snow (12) – none, developed (20) – none, barren (30) – low, deciduous forest (41) – low, planted/cultivated (80) – low, wetlands (90) – low, shrubland (50) – moderate, herbaceous upland (70) – moderate, evergreen forest (42) – high, and mixed forest (43) – high,.

Snow cover and persistence.–McAfee et al. (2013) used observational data to describe the relationship between average monthly temperature across Alaska and the fraction of wet days in each month receiving snow (i.e., the snow-day fraction). Because they wanted to avoid the potentially large errors associated with solid precipitation measurement, their equations used the fraction of wet days in a month receiving snow, rather than the total amount of precipitation. These equations were evaluated by mapping the mean differences between estimated and observed snow-day fractions and comparing them with site characteristics such as elevation, mean average temperature, average precipitation amount and the relationship between average monthly temperature and the temperature on precipitation days. The result of their work provides a reasonable characterization of snow-day fraction throughout Alaska, including the Kenai Peninsula (Chapter 2; Begley et al. 2017) (Figure 10-4). Habitat value for wolverines was assumed to increase as snow depth and persistence increased.

Winter habitat quality for moose.–Gaines et al. (2017a) analyzed locations of female moose obtained from collars equipped with global positioning systems to describe landscape use patterns of these animals on the Kenai Peninsula. We used the results of their analysis to describe classes of habitat quality for moose during the winter (Chapter 2; Begley et al. 2017) (Figure 10-5). Habitat value for wolverines was assumed to increase as winter habitat value for moose increased.

Density of buildings.–Begley et al. (2017, Chapter 2) used tax records from the Kenai Peninsula Borough to create a database of buildings on the Kenai Peninsula. We used the results of that effort to describe classes of density of buildings and associated effect on wolverine habitat quality: 0 buildings/km^2 – none; >0–15 buildings/km^2 – low; >15 buildings/km^2 – high (Figure 10-6). Habitat value for wolverines was assumed to decrease as density of buildings increased.

Density of roads.–Begley et al. (2017, Chapter 2) used digital databases from the Kenai Peninsula Borough and the Chugach National Forest to create a database of roads on the Kenai Peninsula. We used the results of that effort to describe classes of density of roads and associated effect on wolverine habitat quality: 0 roads/km^2 – none; >0–1.5 roads/km^2 – low; >15 roads/km^2 – high (Figure 10-7). Habitat value for wolverines was assumed to decrease as density of roads increased.

Land forms – recreation index.–Work by Poe (2008) documented that land forms (i.e., terrain features) influenced use of the landscape by back-country winter recreationists on the Kenai Peninsula. Begley et al. (2017, Chapter 2) used the Topographic Position Index GIS routine of Jenness (2007) and a digital elevation model to create a digital map of land forms on the Kenai Peninsula. We used the results of those efforts to group the 10 Jenness land forms to characterize valley bottoms, side slopes, and mountain tops. These 3 land form groups were then assigned a relative value to describe their suitability for winter recreation: side slopes – low; valley bottoms – moderate; alpine mountain tops – high (Figure 10-8). Habitat value for wolverines was assumed to decrease as potential for winter recreation increased.

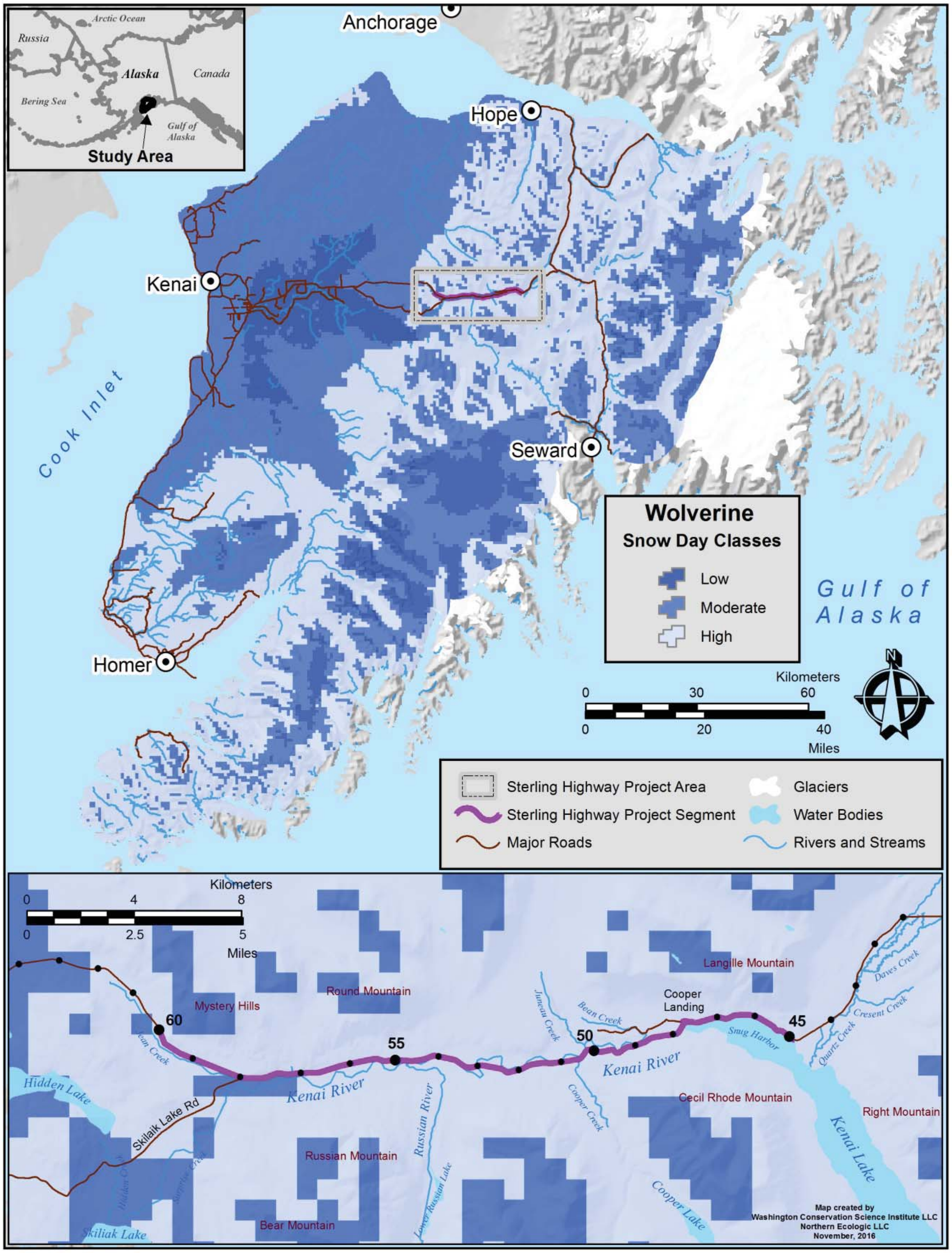


Figure 10-4. Snow-days classes and their associated value to wolverines used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA.

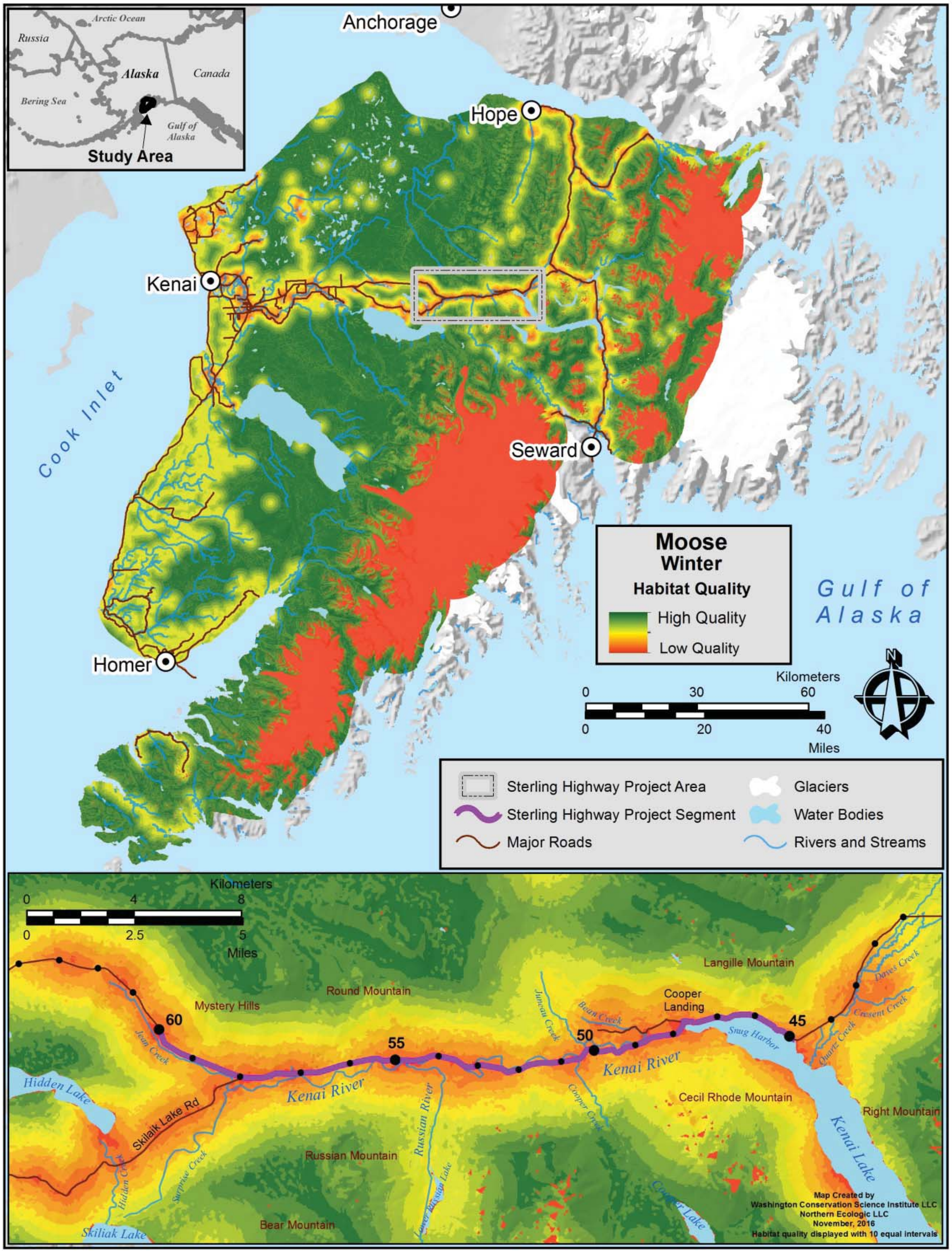


Figure 10-5. Classes of winter habitat quality for moose used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA.

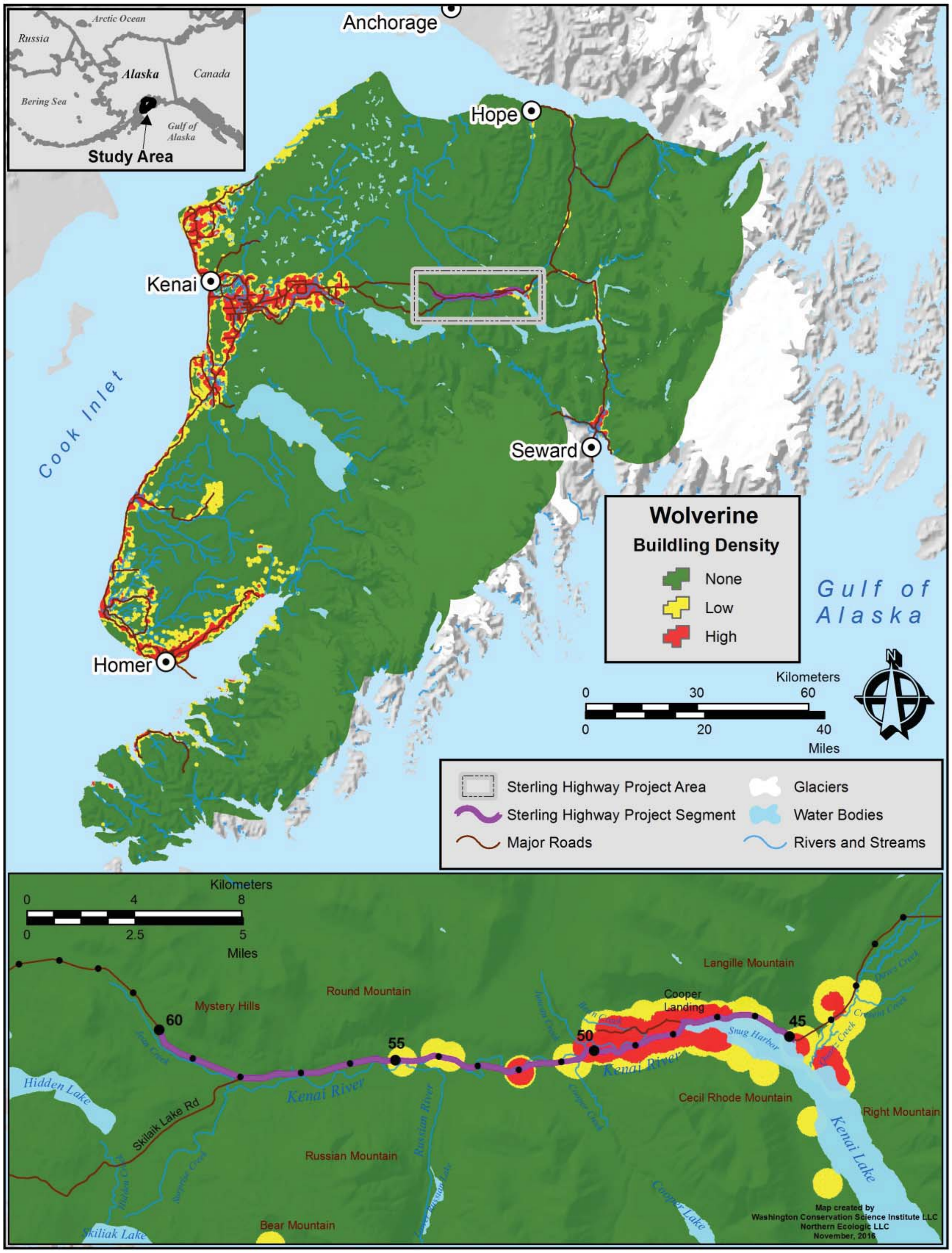


Figure 10-6. Classes of density of buildings and their associated value to wolverines used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA. Classes of density of buildings were: 0 buildings/km^2 – none; >0–15 buildings/km^2 – low; >15 buildings/km^2 – high.

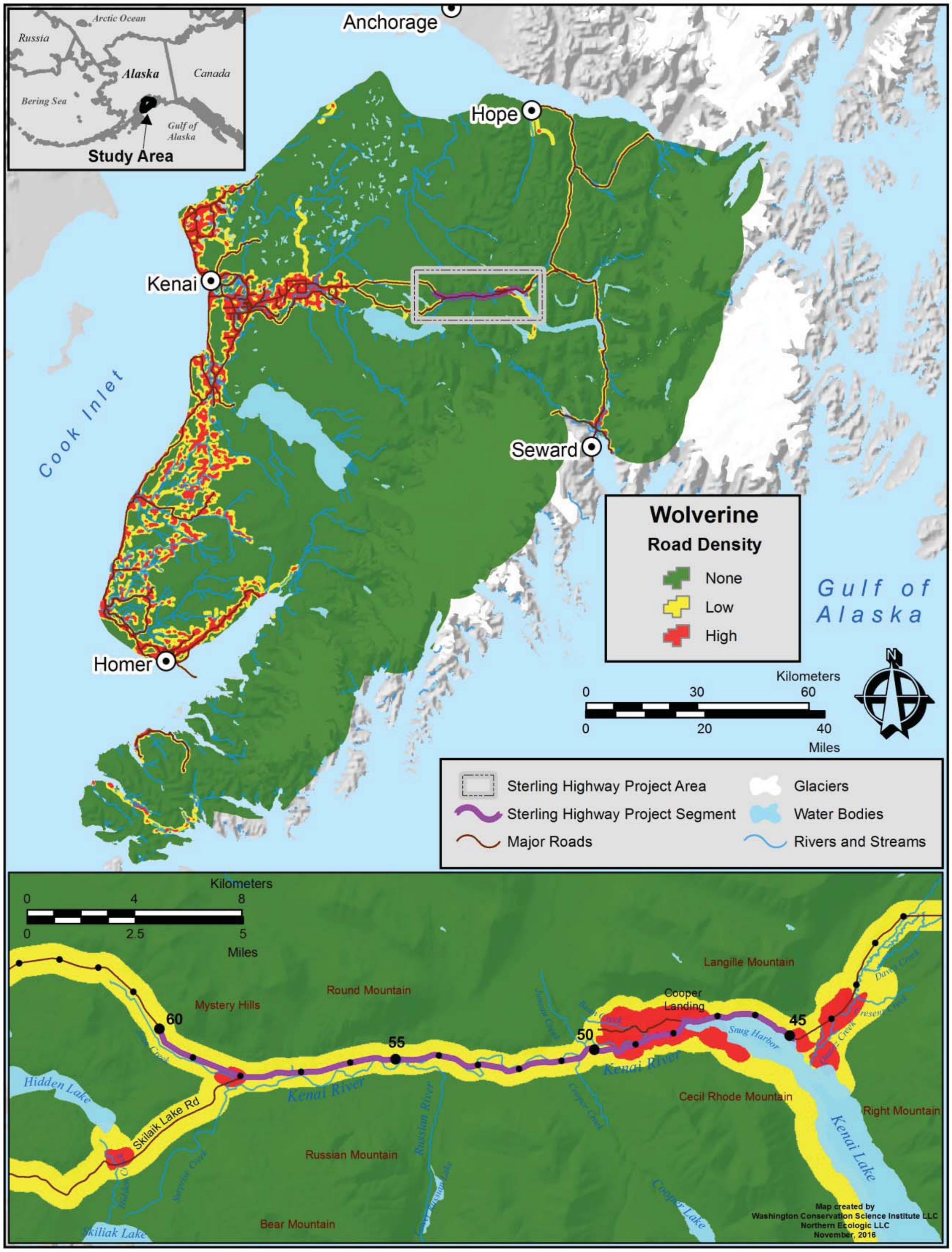


Figure 10-7. Classes of density of roads and their associated value to wolverines used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA. Classes of density of roads were: 0 roads/km^2 – none; >0–1.5 roads/km^2 – low; >1.5 roads/km^2 – high.

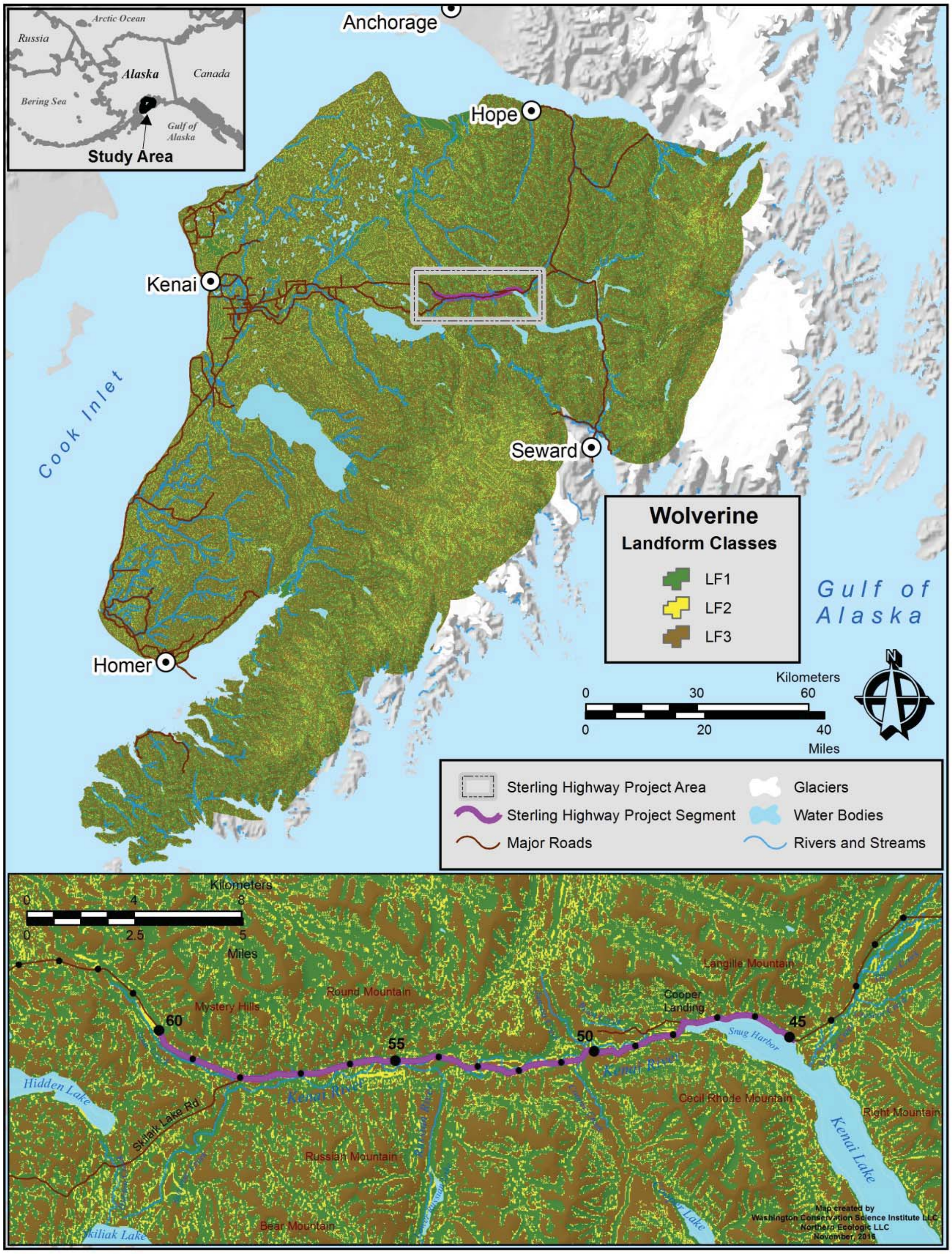


Figure 10-8. Classes of land forms used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA. The classes were LF1 valley bottoms; LF2 side slopes, LF3 alpine mountain tops.

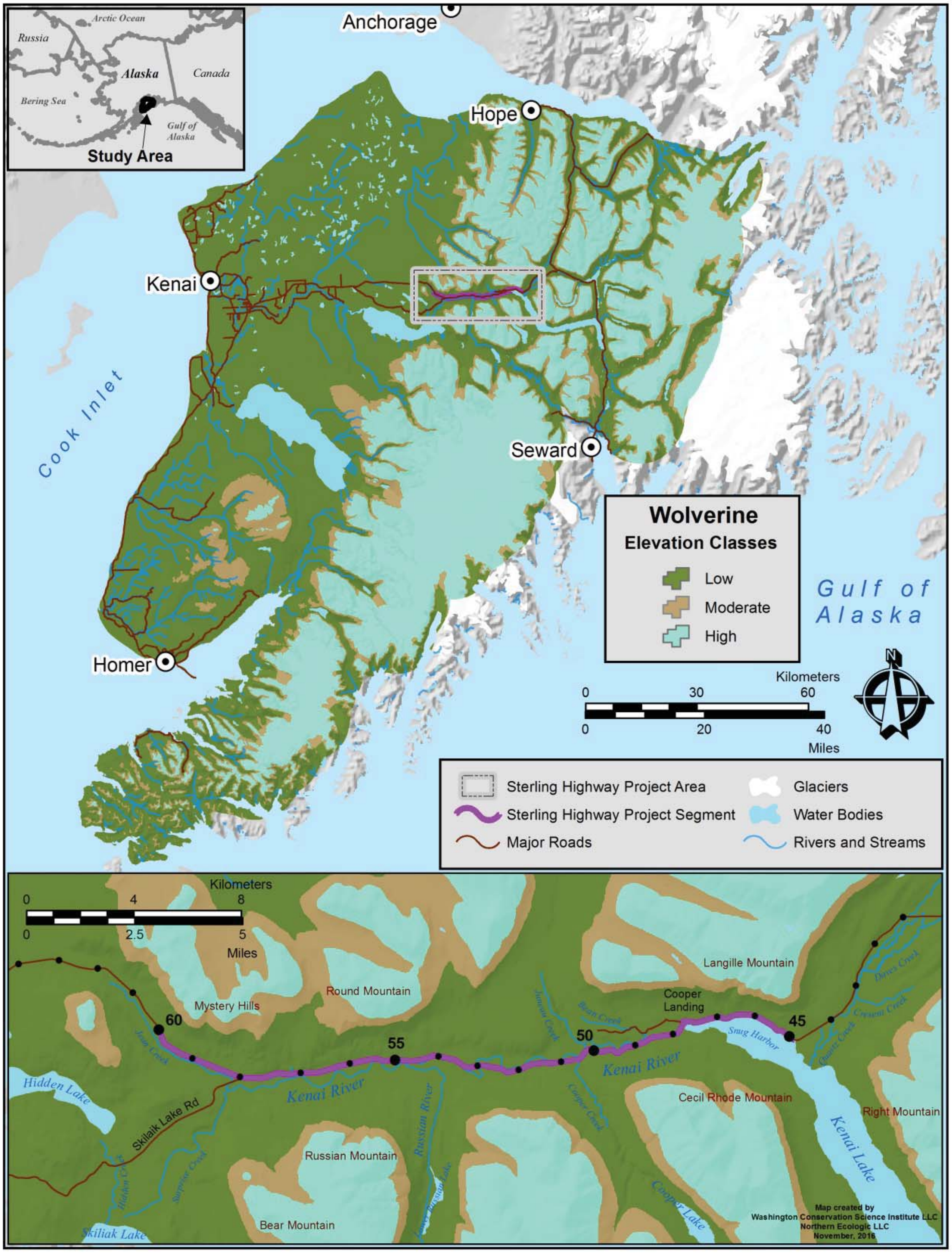


Figure 10-9. Classes of elevation used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA. The classes were <500 m – low; 500–700 m – moderate; >700.

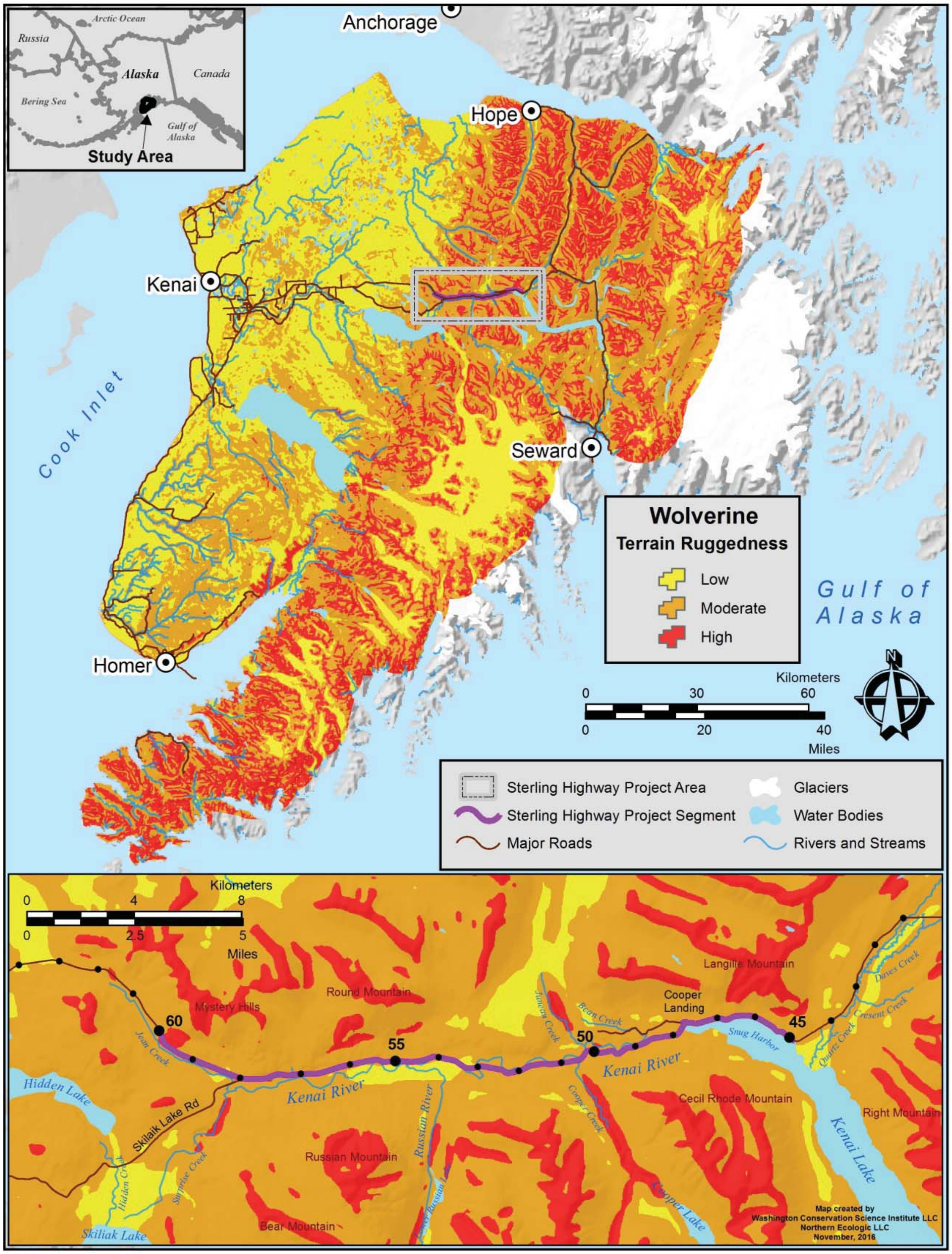


Figure 10-10. Classes of terrain ruggedness used in the habitat quality index model for wolverine on the Kenai Peninsula, Alaska, USA. The classes were <0.001 – low; 0.001–0.027 – moderate; >0.027 – high.

Elevation.–Begley et al. (2017, Chapter 2) used a digital elevation model to generate a digital elevation map of the Kenai Peninsula. Elevation classes were described based on the natural history of wolverines and assigned a relative habitat value: <500 m – low; 500–700 m – moderate; >700 m – high (Figure 10-9). Habitat values for wolverines were assumed to increase increase as elevation increased.

Terrain ruggedness.–Begley et al. (2017, Chapter 2) used a digital elevation model and a GIS process described by Sappington et al. (2007) to characterize terrain ruggedness on the Kenai Peninsula. Classes of terrain ruggedness index values were described based on the natural history of wolverines and assigned a relative habitat value: <0.001 – low; 0.001–0.027 – moderate; >0.027 – high (Figure 10-10). Habitat values for wolverines were assumed to increase as terrain ruggedness increased.

Den-site location based on land form.–Begley et al. (2017) used the Topographic Position Index GIS routine of Jenness (2007) and a digital elevation model to create a digital map of land forms on the Kenai Peninsula. We used the results of those efforts to group the 10 Jenness land forms to characterize valley bottoms, side slopes, and mountain tops. These 3 land form groups were then assigned a relative value to describe their suitability for wolverine den sites: valley bottoms – low; side slopes – moderate; alpine mountain tops – high (Figure 10-8). Habitat values for wolverines were assumed to increase as potential for denning habitat increased.

Bayesian network.–A BN was constructed to provide a framework to incorporate the preceding variables into a model of habitat quality for wolverines on the Kenai Peninsula (Figure 10-11).

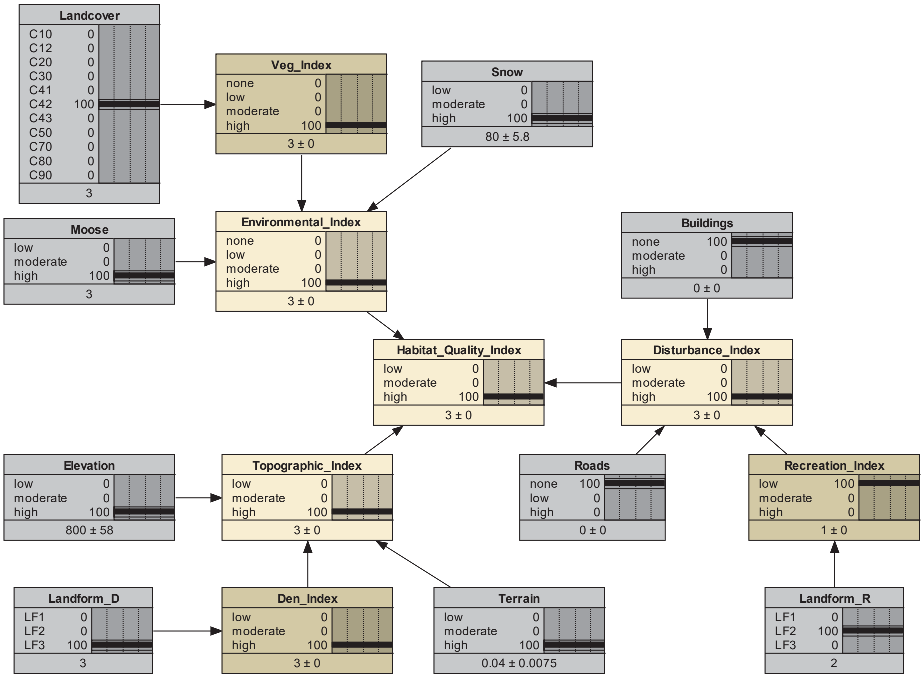


Figure 10-11. Bayesian network as a framework for a model of habitat quality for wolverines on the Kenai Peninsula, Alaska, USA.

Effect of Variables

Sensitivity analysis showed that elevation, terrain ruggedness, and land cover were the primary variables that contributed the most to the Habitat Quality Index followed by snow depth and persistence (Table 10-2, Figure 10-12). Land form, as a predictor of denning habitat and winter recreation potential, and moose winter habitat quality were moderate contributors to the Habitat Quality Index. Density of roads and buildings were more minor contributors to the Habitat Quality Index. A similar pattern of the effect of landscape variables on genetic connectivity of wolverines in Idaho, Montana, and Wyoming was reported by Balkenhol (2009) (Figure 10-13).

Table 10-2. Sensitivity of predictions of the Habitat Quality Index for wolverine to variance in primary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

Variable	Variance reduction
Elevation	0.0217
Terrain	0.0217
Land cover	0.0197
Snow	0.0129
Land form (denning)	0.0065
Land form (recreation)	0.0063
Moose	0.0059
Roads	0.0014
Buildings	0.0005

Of the secondary variables, the Topographic_Index and Environmental_index were the major contributors to the Habitat Quality Index followed by a minor contribution from the Disturbance_Index (Table 10-3, Figure 10-14).

Resistance to Movement

Our assignment of resistance values to different landscape features (Table 10-4) generated a resistance surface in which much of the undeveloped, forested, landscape had low resistance for wolverine dispersal (Figure 10-15). Densely developed areas, wetlands, open water, ice and snow fields, and major roads were features we assigned a high level of resistance. This resulted in a pattern is which lowland areas and valley bottoms typically had moderate to high resistance, and mountainous areas had low resistance.

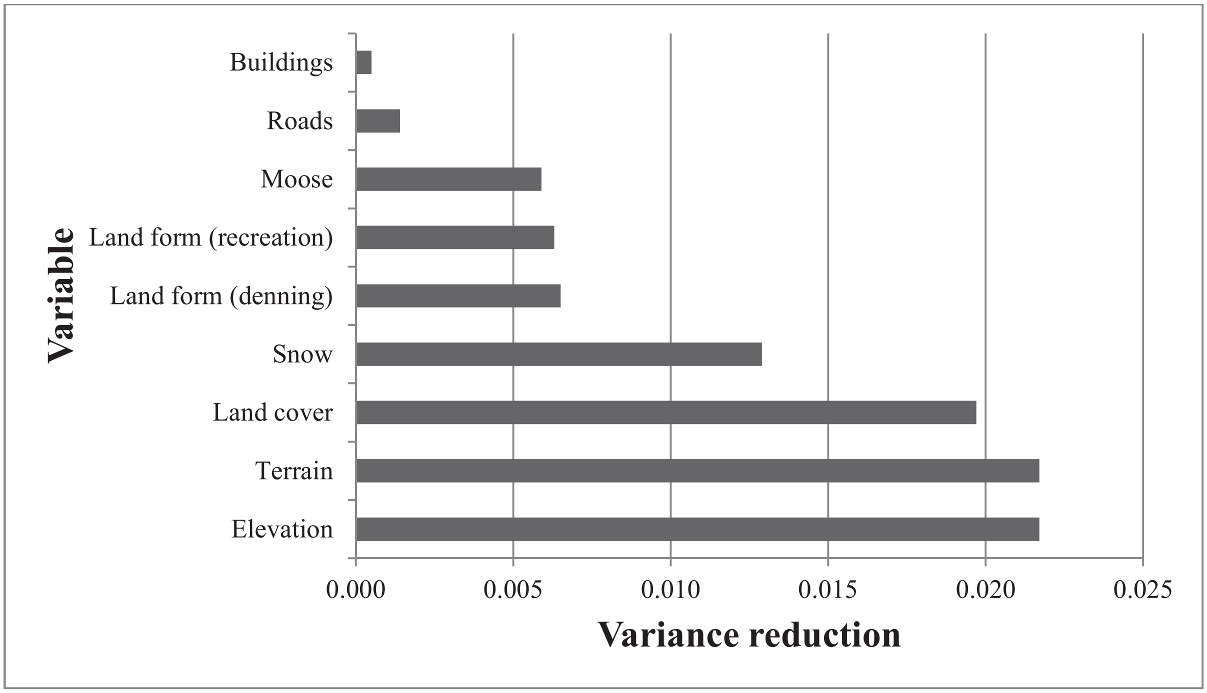


Figure 10-12. Sensitivity of predictions of the Habitat Quality Index for wolverine to variance in primary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

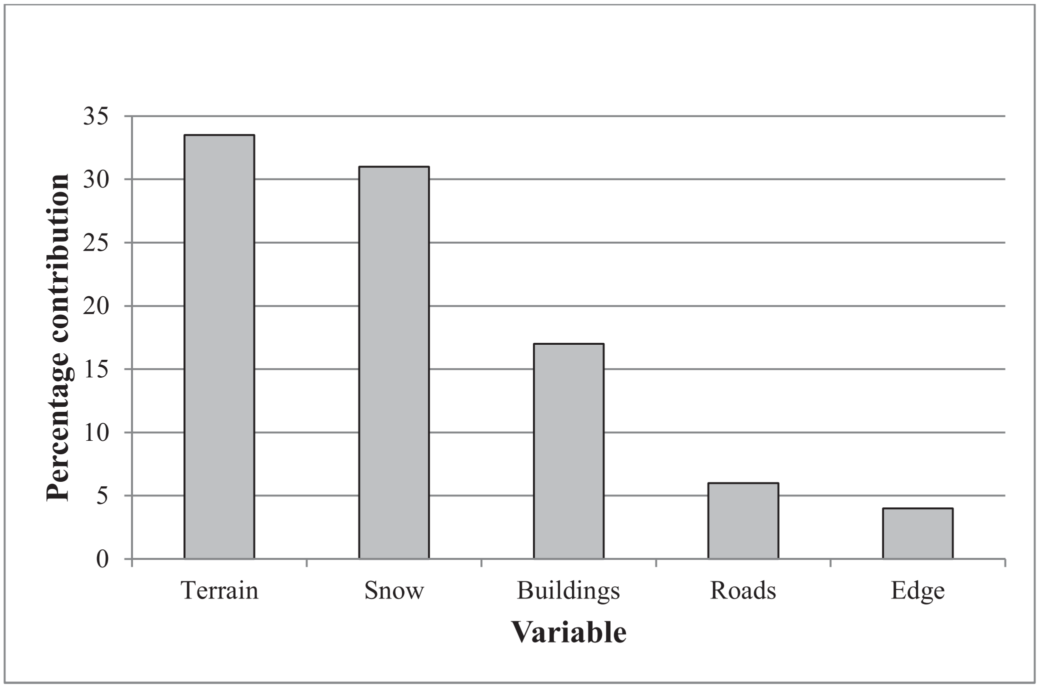


Figure 10-13. Relative importance of variables in a model of genetic connectivity of wolverines in Idaho, Montana, and Wyoming (from Balkenhol 2009).

Table 10-3. Sensitivity of predictions of the Habitat Quality Index for wolverine to variance in secondary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

Variable	Variance reduction
Topographic_Index	0.1184
Environmental_Index	0.1006
Disturbance_Index	0.0218

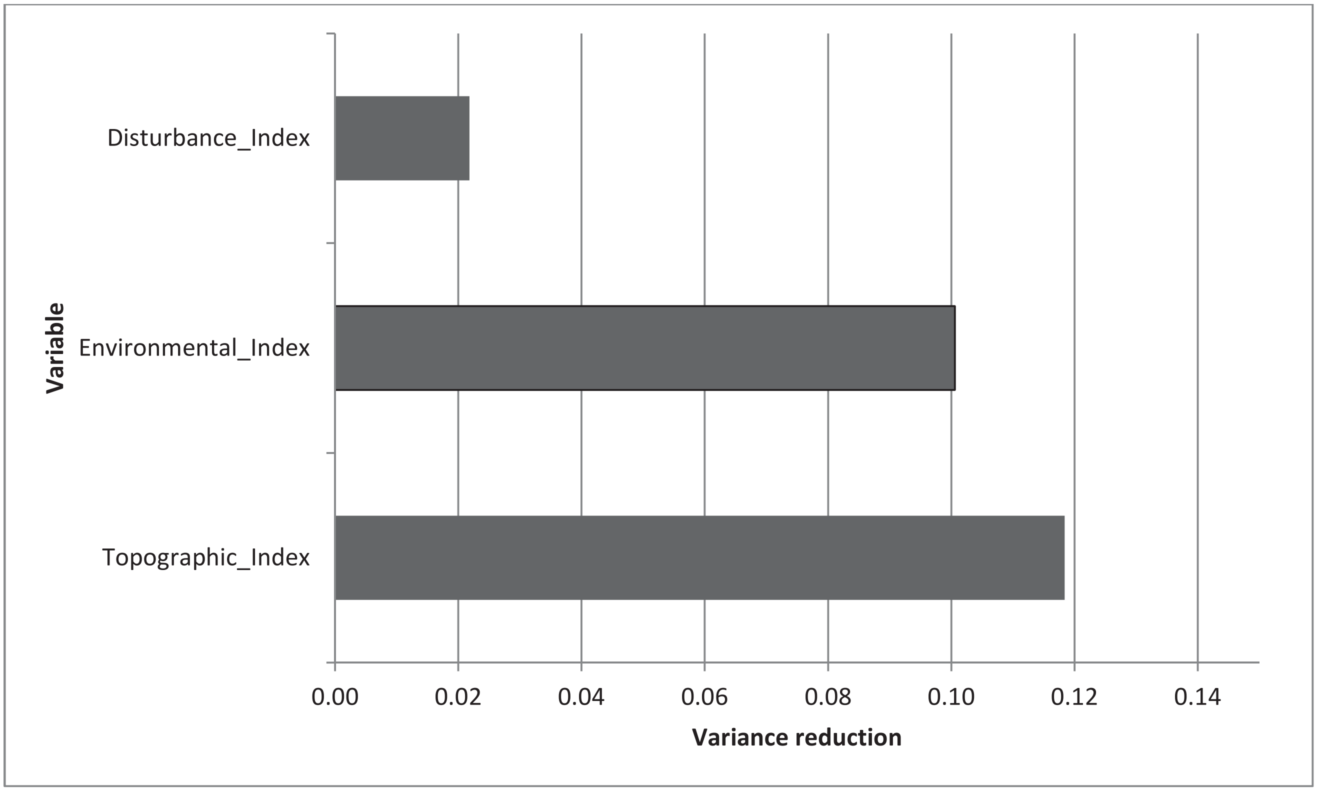


Figure 10-14. Sensitivity of predictions of the Habitat Quality Index for wolverine to variance in secondary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

Table 10-4. Landscape features and resistance values used to model habitat connectivity for wolverines on the Kenai Peninsula, Alaska, USA.

Data Layer	Class Description	Class ID	Resistance value
Landcover	Water	11	200
Landcover	Ice-snow	12	100
Landcover	Developed	21	100
Landcover	Developed	22	100
Landcover	Developed	23	100
Landcover	Developed	24	100
Landcover	Barron	31	25
Landcover	Deciduous forest	41	15
Landcover	Evergreen forest	42	0
Landcover	Mixed forest	43	0
Landcover	Shrubland	51	10
Landcover	Shrubland	52	10
Landcover	Herbaceous upland	71	20
Landcover	Herbaceous upland	72	20
Landcover	Cultivated	81	50
Landcover	Cultivated	82	50
Landcover	Wetland	90	75
Landcover	Wetland	95	75
Moose	RSF = 0	1	50
Moose	RSF = >0 - 83	2	25
Moose	RSF = 83 - 96	3	10
Moose	RSF = 96 - 100	4	0
Snow	<60	1	50
Snow	60-70	2	25
Snow	>70	3	0
Elevation	<500 m	1	50
Elevation	500 - 700 m	2	25
Elevation	>700 m	3	0
Landform_D	Valley bottoms	1	20
Landform_D	Side slopes	2	10

Table 10-4. Landscape features and resistance values used to model habitat connectivity for wolverines on the Kenai Peninsula, Alaska, USA.

Data Layer	Class Description	Class ID	Resistance value
Landform_D	Mountain tops	3	0
Terrain	<0.001	1	50
Terrain	0.001-0.027	2	25
Terrain	>0.027	3	0
Buildings	0	1	0
Buildings	>0 - 15	2	20
Buildings	>15	3	100
Roads	0	1	0
Roads	0-1.5	2	20
Roads	>1.5	3	100
Landform_R	Valley bottoms	1	10
Landform_R	Side slopes	2	20
Landform_R	Mountain tops	3	0

Core Areas

Patterns of habitat quality for wolverines on the Kenai Peninsula were closely associated with high-elevation areas with persistent spring snow cover (Figure 10-16). Consequently, core areas were concentrated north to south in the center of the Kenai Peninsula (Figure 10-17). Thirty-six core areas for wolverines were modeled and mapped across the Kenai Peninsula. Core areas varied in size from 5.3–173.3 km^2 ($\overline{x}$ = 21.0 km^2) with a mean habitat quality index value of 88.95 (on a 0–100 scale).

Potential Movement Corridors

Analysis of least-cost corridors showed multiple potential corridors for wolverines from MP 45–60 of the Sterling Highway in the vicinity of Cooper Landing (Figure 10-18). This analysis revealed potential crossing points in the vicinity of MP 48, 50–51, 53, 54–55, and 58–59. We used circuit theory to estimate the effective resistance of the landscape within these

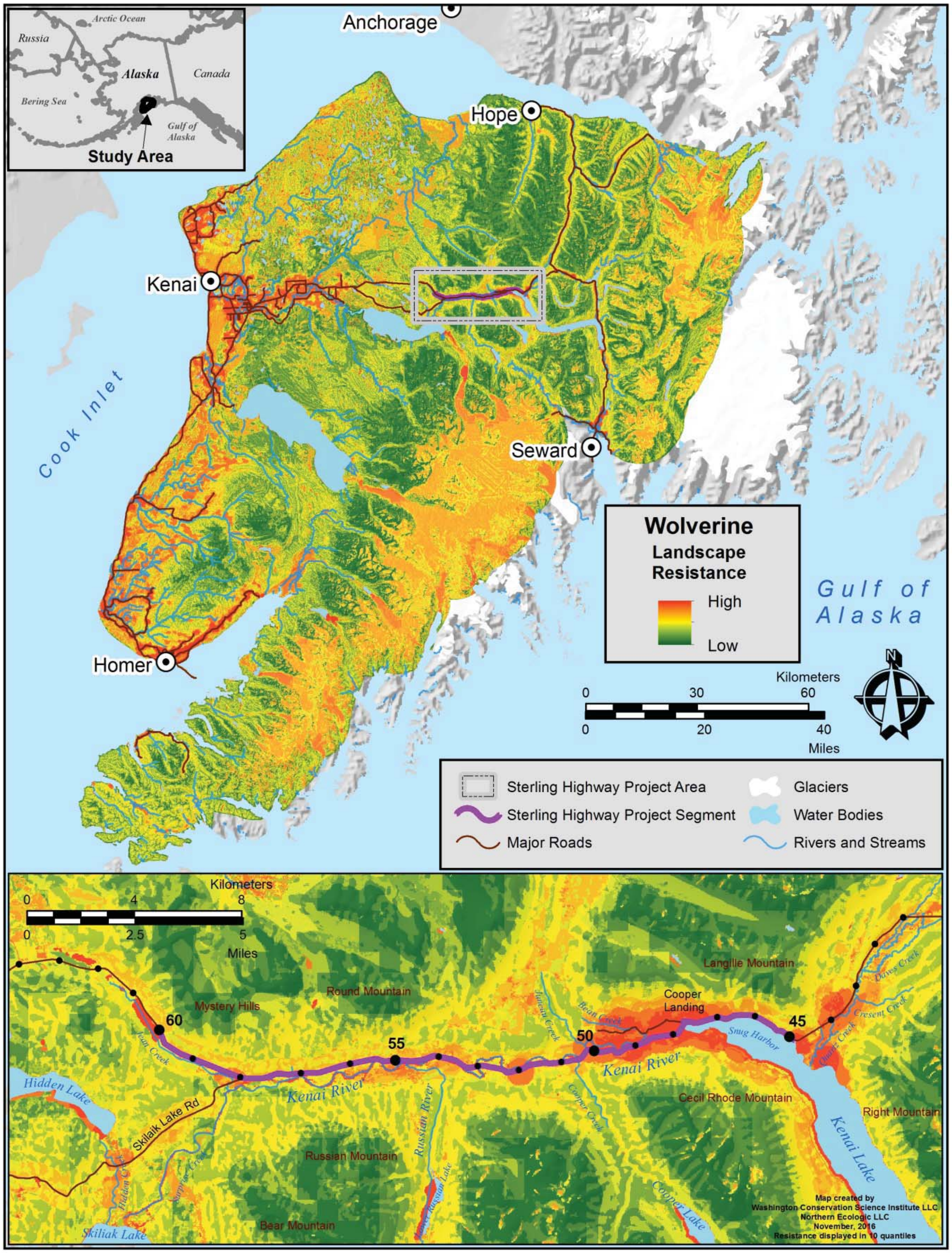


Figure 10-15. Resistance surface used to model habitat connectivity for wolverines on the Kenai Peninsula, Alaska, USA.

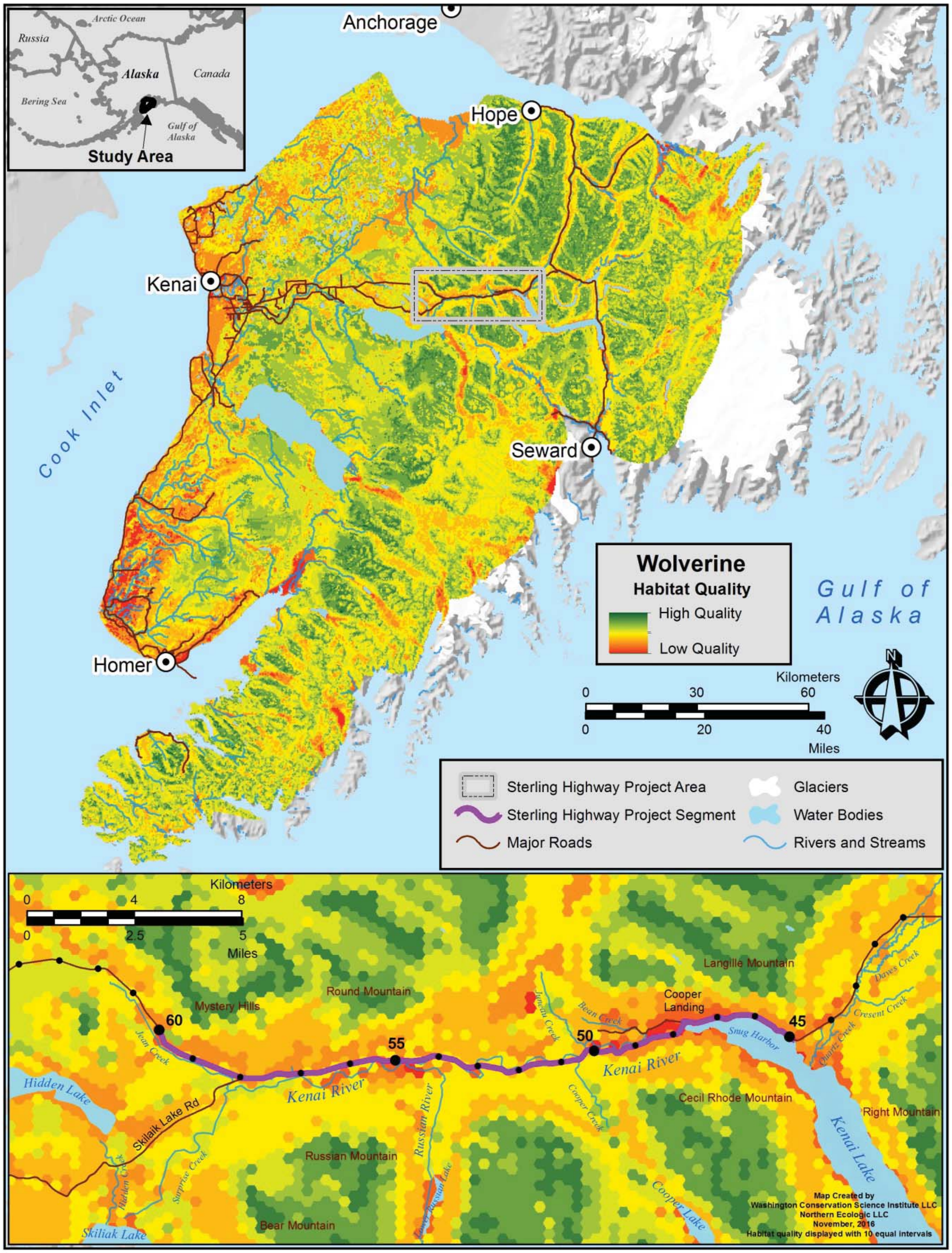


Figure 10-16. Map of habitat quality used to model habitat connectivity for wolverines on the Kenai Peninsula, Alaska, USA.

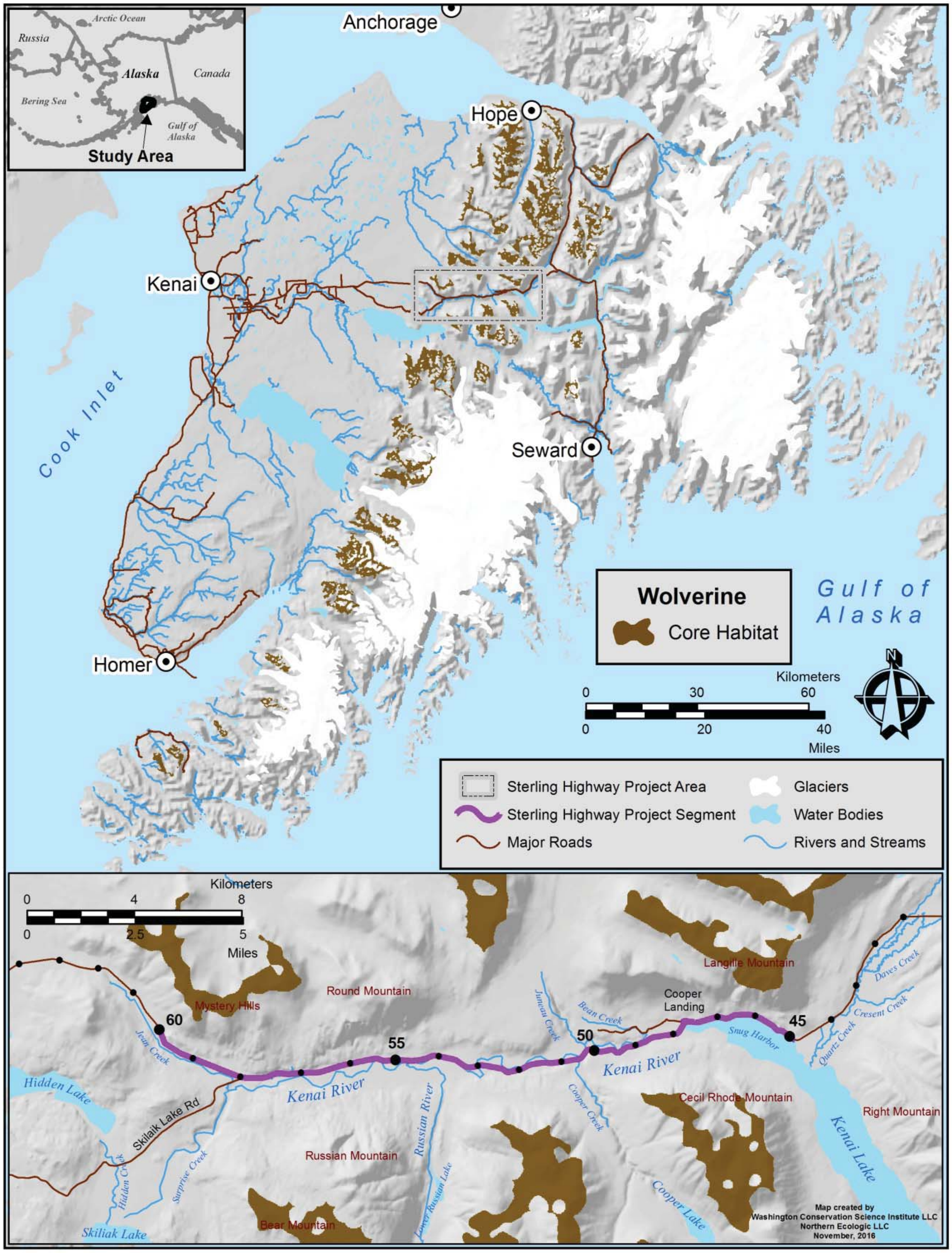
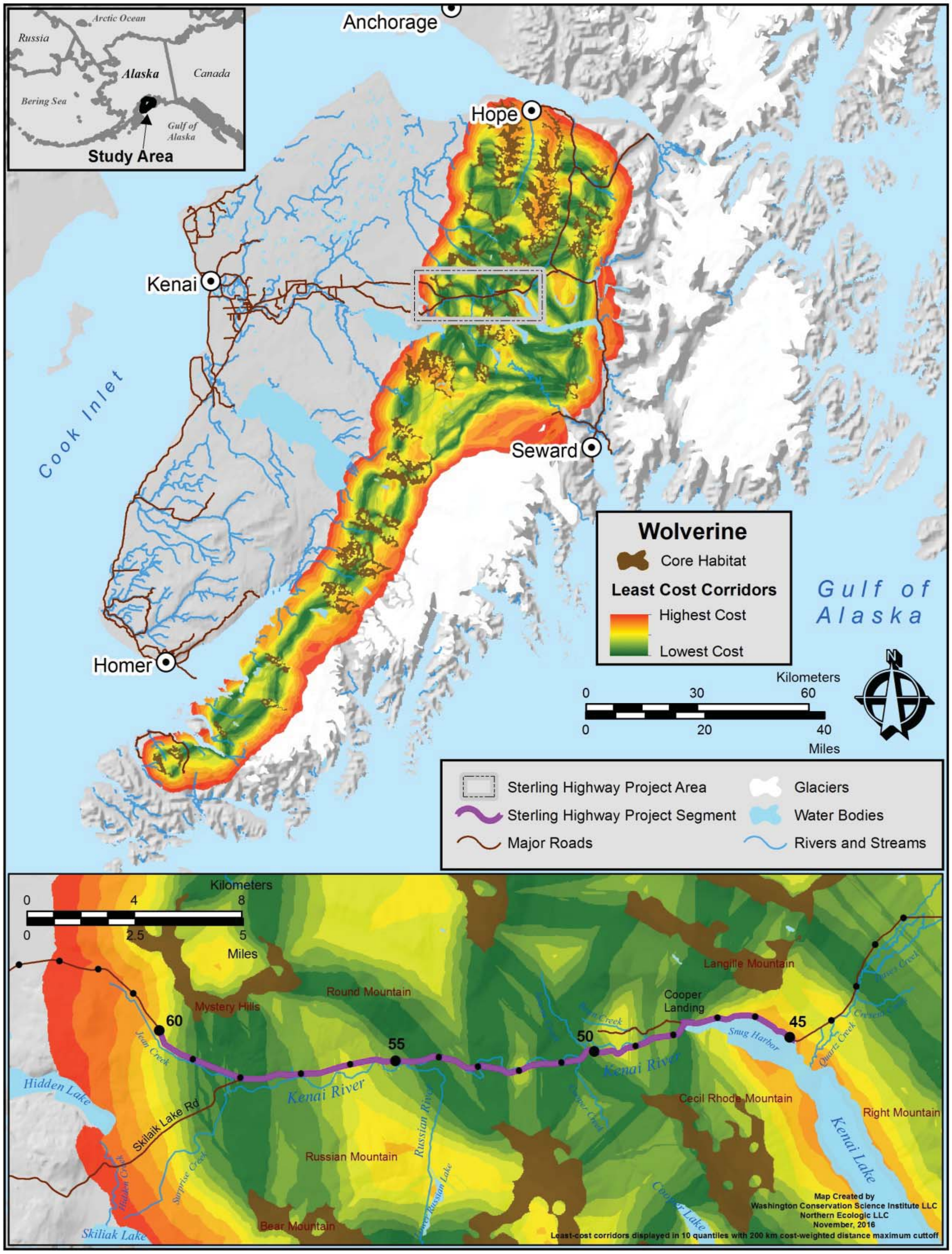


Figure 10-17. Core areas used to model habitat connectivity for wolverines on the Kenai Peninsula, Alaska, USA.



Map Created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016

Least-cost corridors displayed in 10 quantiles with 200 km cost-weighted distance maximum cuttoff

Figure 10-18. Core areas for wolverines and potential least-cost corridors for their movement across the Sterling Highway in the vicinity of Cooper Landing, Kenai Peninsula, Alaska, USA.

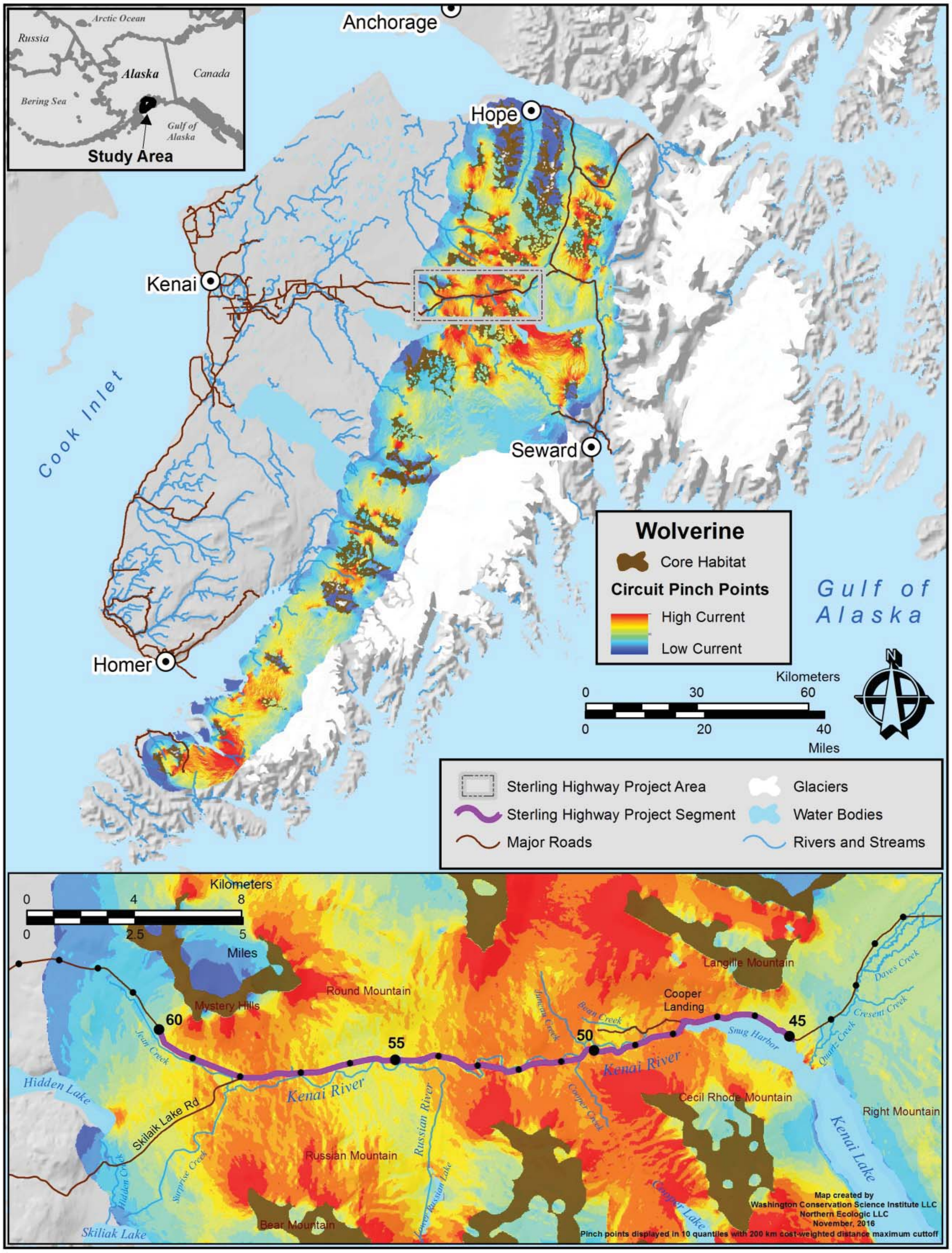


Figure 10-19. Core areas for wolverines and the potential primary and secondary pinch points for their movement across the Sterling Highway in the vicinity of Cooper Landing, Kenai Peninsula, Alaska, USA.

corridors between all pairs of core areas (all-to-one mode in the Circuitscape software; McRae and Shah 2011). This analysis prioritized a single potential crossing point between MP 52–53 (Figure 10-19).

Based on these analyses, potential north-south movements of wolverines across the Sterling Highway in the vicinity of Cooper Landing revealed 1 primary pinch point where animals were most likely to concentrate their crossings (MP 52–53). Potential secondary crossing points for wolverines were located at MP 48 at the outlet of Kenai Lake, between MP 51–52, and between MP 57–58 near the junction of the Sterling Highway and Skilak Lake Road.

Discussion

Habitat Quality Model

Management of natural resources, including wildlife populations and their habitat, often includes determining the best approaches to meet multiple, and often conflicting, environmental and social objectives. For example, providing suitable transportation networks may conflict with conserving biological diversity. Decision support systems, such as our habitat quality model, can be useful tools in land use planning for forecasting and hindcasting the effects of management options on wildlife.

For wolverine, associations with habitat variables were well described in the scientific literature and reported findings were consistent across studies. In our analysis, the conditional probabilities used for developing estimates of habitat quality from the states of the habitat variables within the BN were quite robust. Furthermore, conditional probabilities need not be exact to be useful. For many applications, approximate probabilities, even subjective ones that are based on the best available knowledge, give very good results (Wooldridge 2003). BNs are generally quite robust to imperfect knowledge. Often the combination of several strands of imperfect knowledge can allow us to make surprisingly strong conclusions.

BNs have some key advantages over other approaches of estimating habitat quality. They provide a useful communication medium that clearly displays how habitat conditions influence wildlife populations. Recently, BNs have been used by ecologists to depict the response of wildlife species and ecosystems to differing conditions, and also as decision-aiding tools to help managers evaluate alternative natural resource management actions (e.g., Interior Columbia Basin Ecosystem Management Project, Pacific Northwest Region eastside land management plan revisions [Marcot et al. 2001, Suring et al. 2011, Gaines et al. 2017b]). Descriptions and guidelines for their use and construction have been published (Marcot et al. 2006, Jensen and Nielsen 2007, Chen and Pollino 2011).

Although the use of BNs in ecological and environmental applications is growing (McCann et al. 2006), there are some limitations to their use in ecological modeling (Howes et al. 2010). Construction of conditional probability tables that specify the probability of outcomes associated with variable states and their relationships can be cumbersome and unwieldy, especially when the number of probabilities to estimate is large (Marcot et al. 2006, McCann et al. 2006). In our application the number of probabilities within each conditional probability table was constrained to ≤3 to ensure that this did not occur. The requirement by the BN that all continuous variables be discrete may also lower the precision of predictions, and the difficulty of handling feedback loops is also a limitation in ecological studies (Nyberg et al. 2006). BNs prove to be most useful for developing a consistent and transparent interpretation of likely responses when some knowledge of the causal structure is known. However, they provide little insight regarding unknown dependencies. Another important consequence of their rigid structure is that it is difficult to capture relationships between variables which have a temporal element (i.e. change over time).

Wolverine Habitat Relationships

Roads, human infrastructure, and human population density are associated with decreased habitat use by wolverines (Krebs et al. 2007) and reduced levels of gene flow (Kyle and Strobeck 2002). Fine-scale examination of wolverine genetic structure suggested that transportation systems have limited female movements leading to sex-biased dispersal and gene flow in the Canadian Rocky Mountain Parks (Sawaya and Clevenger 2014). Restricted female movements and sex-biased population structure has been documented in other carnivore species (Proctor et al.2005) and this demographic fragmentation can reduce meta-population viability. Although wolverines avoid roads, they do continue to attempt road crossings during foraging and dispersal (Landa et al. 1998, Packila et al. 2007). Wolverines approaching the Trans-Canada Highway made repeated approaches and retreats with limited actual crossings, 1 of which resulted in a wolverine mortality (Austin 1998). Five percent of the wolverine mortality recorded during 12 North American radiotelemetry studies conducted between 1972 and 2001 was attributed to wildlife-vehicle collisions (Krebs et al. 2004). However, wildlife crossing structures can help to restore demographic and genetic connectivity (Sawaya et al. 2013, 2014). Recent data suggest that female wolverines use wildlife crossing structures, albeit infrequently (Clevenger 2013).

Human actions likely will be a controlling factor in the success and persistence of the wolverine population on the Kenai Peninsula. The cumulative effects of harvest, habitat alteration, road construction, and increased traffic volumes on wolverines are not fully understood. As a result, wolverines on the Kenai Peninsula may necessitate particular conservation emphasis (Tomasik and Cook 2005). Our specific objective in this work was to identify potential movement corridors for wolverine on the Kenai Peninsula so that resource managers could include that information in planning for habitat management, resource development, and infrastructure development (including transportation). We identified specific areas within MP 45–60 on the Sterling Highway that may be suitable for practices to mitigate the effects of highway development on wolverines in the vicinity of MP 48, 50–51, 53, 54–55, and 58–59 (Figure 10-18). Our analysis subsequently prioritized a single potential crossing point between MP 52–53 (Figure 10-19).

Management Implications

Most juvenile female wolverines exhibit natal area fidelity and establish home-ranges adjacent to their mothers (Magoun 1985), although some females have been observed to disperse far beyond their natal range. Wolverines, particularly juveniles, have the potential to disperse at high rates and long distances depending upon the availability of food and other habitat attributes (Vangen et al. 2001). Gene flow among wolverine populations is primarily accomplished by long-range dispersal between low-density populations, which requires large areas of continuous habitat and extensive travel corridors. Human settlement and high-traffic roadways may function as effective barriers to dispersal (Banci 1987, May et al. 2006). The apparent availability of refugia on the Kenai Peninsula highlights the need to maintain the ability of wolverines to move from refugia to supplement subpopulations where human-caused mortality occurs. The areas on the Kenai Peninsula that experience high trapping mortality must rely on immigration from local refugia or via the 18 km-wide isthmus to mainland Alaska. This restriction was reflected in results of mitochondrial DNA analysis that indicated wolverines on the Kenai Peninsula have lower haplotype and nucleotide diversity than mainland wolverines but not enough to be considered a different subspecies (Tomasik and Cook 2005). Even so, the Kenai Peninsula population of wolverines maintains a disproportionate amount of the North American mitochondrial diversity (Tomasik and Cook 2005).

Transportation projects that may affect the ability of wolverines to maintain movement patterns are occurring throughout wolverine range in North America (Clevenger 2013). As a result, highway crossing structures have been identified as 1 of 3 recommended strategies for the conservation of wolverines (Inman 2013). Transportation departments and land managers should begin proactively identifying critical dispersal corridors across highways in the remaining areas of contiguous habitat for potential opportunities for highway mitigation in the short and long term (Clevenger 2013). Maintaining wolverine populations in large areas of contiguous habitat, such as the Kenai Peninsula, and facilitating connectivity among habitat patches will help to sustain viable wolverine populations (McKelvey et al. 2011).

Huijser and Paul (2008) noted in their literature review that wolverine have been observed using underpasses in Banff National Park; however, the number of observations was considered too low to conclude that wolverines will readily use crossing structures. Clevenger et al. (2011) and Clevenger (2013) also reported consistent use of underpasses and occasional use of overpasses by wolverines. Clevenger and Huijser (2011) recommended that wildlife crossing structures for rare, mid-sized carnivores such as wolverine, be also designed for larger animals to increase probability of them being used. They recommended landscape bridges from 70–>100 m (230–>328 ft) wide, wildlife overpasses 40–70 m (131–230 ft) wide, and viaducts or flyovers (Clevenger and Huijser 2011).

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Appendix – Wolverine

Table A10-1. Parameter values assigned in the core mapper software to identify core habitats for wolverines on the Kenai Peninsula, Alaska, USA.

Analysis strata	Moving window radius (m)[a]	Minimum average habitat value[b]	Minimum habitat value per pixel[c]	Expand cores by this cost weighted distance (m)	Minimum size of core areas (ha)[d]
Wolverine run 6	200	86	75	0	500

[a] Smaller values result in larger numbers of more-detailed core areas.

[b] Average habitat value in the moving window around a pixel must be greater than this for the pixel to be considered 'core'.

[c] Pixel value must be greater than this to be 'core'.

[d] Core areas smaller than this will be eliminated at end of the run.

Table A10-2. Conditional probability table for the Veg_Index node in the Bayesian Network forwolverines on the Kenai Peninsula, Alaska, USA.

Variable states	
Veg_Index	Probability of outcome
C10 - water	Very_low
C12 - Ice-snow	Very_low
C20 - Developed	Very_low
C30 - Barron	Low
C41 - Deciduous forest	Low
C42 - Evergreen forest	High
C43 - Mixed forest	High
C50 - Shrubland	Moderate
C70 - Herbaceous upland	Moderate
C80 - Cultivated	Low
C90 - Wetlands	Low

Table A10-3. Conditional probability table for the Environmental_Index node in the Bayesian Network for wolverines on the Kenai Peninsula, Alaska, USA.

Variable states			Probability of outcome			
Veg_Index	Moose	Snow	Very low	Low	Moderate	High
Very low	Very low	Low	0.6	0.4	0.0	0.0
Very low	Very low	Moderate	0.4	0.3	0.3	0.0
Very low	Very low	High	0.4	0.2	0.2	0.2
Very low	Low	Low	0.4	0.6	0.0	0.0
Very low	Low	Moderate	0.4	0.3	0.3	0.0
Very low	Low	High	0.3	0.3	0.2	0.2
Very low	Moderate	Low	0.3	0.4	0.3	0.0
Very low	Moderate	Moderate	0.3	0.3	0.4	0.0
Very low	Moderate	High	0.3	0.2	0.2	0.3
Very low	High	Low	0.4	0.4	0.1	0.1
Very low	High	Moderate	0.3	0.3	0.3	0.1
Very low	High	High	0.2	0.2	0.2	0.4
Low	Very low	Low	0.2	0.8	0.0	0.0
Low	Very low	Moderate	0.2	0.4	0.4	0.0
Low	Very low	High	0.2	0.3	0.3	0.2
Low	Low	Low	0.0	1.0	0.0	0.0
Low	Low	Moderate	0.0	0.6	0.4	0.0
Low	Low	High	0.0	0.4	0.3	0.3
Low	Moderate	Low	0.0	0.8	0.2	0.0
Low	Moderate	Moderate	0.0	0.4	0.6	0.0
Low	Moderate	High	0.0	0.3	0.4	0.3
Low	High	Low	0.0	0.7	0.2	0.1
Low	High	Moderate	0.0	0.4	0.4	0.2
Low	High	High	0.0	0.2	0.3	0.5
Moderate	Very low	Low	0.2	0.4	0.4	0.0
Moderate	Very low	Moderate	0.1	0.3	0.6	0.0
Moderate	Very low	High	0.1	0.2	0.4	0.3
Moderate	Low	Low	0.0	0.6	0.4	0.0
Moderate	Low	Moderate	0.0	0.2	0.8	0.0
Moderate	Low	High	0.0	0.2	0.4	0.4
Moderate	Moderate	Low	0.0	0.4	0.6	0.0
Moderate	Moderate	Moderate	0.0	0.0	1.0	0.0
Moderate	Moderate	High	0.0	0.0	0.6	0.4
Moderate	High	Low	0.0	0.4	0.4	0.2
Moderate	High	Moderate	0.0	0.0	0.8	0.2
Moderate	High	High	0.0	0.0	0.4	0.6
High	Very low	Low	0.1	0.4	0.3	0.2
High	Very low	Moderate	0.1	0.2	0.4	0.3
High	Very low	High	0.1	0.1	0.2	0.6
High	Low	Low	0.0	0.5	0.3	0.2
High	Low	Moderate	0.0	0.2	0.4	0.4
High	Low	High	0.0	0.1	0.2	0.7
High	Moderate	Low	0.0	0.2	0.4	0.4
High	Moderate	Moderate	0.0	0.0	0.6	0.4
High	Moderate	High	0.0	0.0	0.2	0.8
High	High	Low	0.0	0.2	0.3	0.5
High	High	Moderate	0.0	0.0	0.4	0.6
High	High	High	0.0	0.0	0.0	1.0

Table A10-4. Conditional probability table for the Den_Index node in the Bayesian Network for wolverines on the Kenai Peninsula, Alaska, USA.

Variable states	
Landform_D	Probability of outcome
LF1 - Valley bottoms	Low
LF2 - Side slopes	Moderate
LF3 - Mountain tops	High

Table A10-5. Conditional probability table for the Topographic_Index node in the Bayesian Network for wolverines on the Kenai Peninsula, Alaska, USA.

Variable states			Probability of outcome		
Elevation	Terrain	Den_Index	Low	Moderate	High
Low	Low	Low	1.00	0.00	0.00
Low	Low	Moderate	0.80	0.20	0.00
Low	Low	High	0.80	0.15	0.05
Low	Moderate	Low	0.60	0.40	0.00
Low	Moderate	Moderate	0.40	0.60	0.00
Low	Moderate	High	0.40	0.40	0.20
Low	High	Low	0.50	0.30	0.20
Low	High	Moderate	0.30	0.40	0.30
Low	High	High	0.20	0.30	0.50
Moderate	Low	Low	0.60	0.40	0.00
Moderate	Low	Moderate	0.40	0.60	0.00
Moderate	Low	High	0.40	0.40	0.20
Moderate	Moderate	Low	0.20	0.80	0.00
Moderate	Moderate	Moderate	0.00	1.00	0.00
Moderate	Moderate	High	0.00	0.80	0.20
Moderate	High	Low	0.20	0.40	0.40
Moderate	High	Moderate	0.00	0.60	0.40
Moderate	High	High	0.00	0.40	0.60
High	Low	Low	0.50	0.30	0.20
High	Low	Moderate	0.30	0.40	0.30
High	Low	High	0.20	0.30	0.50
High	Moderate	Low	0.20	0.40	0.40
High	Moderate	Moderate	0.00	0.60	0.40
High	Moderate	High	0.00	0.40	0.60
High	High	Low	0.10	0.30	0.60
High	High	Moderate	0.00	0.20	0.80
High	High	High	0.00	0.00	1.00

Table A10-6. Conditional probability table for the Recreation_Index node in the Bayesian Network for wolverines on the Kenai Peninsula, Alaska, USA.

Variable states	
Landform_R	Probability of outcome
LF1 - Valley bottoms	Moderate
LF2 - Side slopes	Low
LF3 - Mountain tops	High

Table A10-7. Conditional probability table for the Disturbance_Index node in the Bayesian Network for wolverines on the Kenai Peninsula, Alaska, USA.

Variable states			Probability of outcome		
Buildings	Roads	Recreation_Index	Low	Moderate	High
None	None	Low	1.00	0.00	0.00
None	None	Moderate	0.80	0.20	0.00
None	None	High	0.80	0.15	0.05
None	Low	Low	0.60	0.40	0.00
None	Low	Moderate	0.40	0.60	0.00
None	Low	High	0.40	0.40	0.20
None	High	Low	0.50	0.30	0.20
None	High	Moderate	0.30	0.40	0.30
None	High	High	0.20	0.30	0.50
Moderate	None	Low	0.60	0.40	0.00
Moderate	None	Moderate	0.40	0.60	0.00
Moderate	None	High	0.40	0.40	0.20
Moderate	Low	Low	0.20	0.80	0.00
Moderate	Low	Moderate	0.00	1.00	0.00
Moderate	Low	High	0.00	0.80	0.20
Moderate	High	Low	0.20	0.40	0.40
Moderate	High	Moderate	0.00	0.60	0.40
Moderate	High	High	0.00	0.40	0.60
High	None	Low	0.50	0.30	0.20
High	None	Moderate	0.30	0.40	0.30
High	None	High	0.20	0.30	0.50
High	Low	Low	0.20	0.40	0.40
High	Low	Moderate	0.00	0.60	0.40
High	Low	High	0.00	0.40	0.60
High	High	Low	0.10	0.30	0.60
High	High	Moderate	0.00	0.20	0.80
High	High	High	0.00	0.00	1.00

Table A10-8. Conditional probability table for the Habitat_Quality_Index node in the Bayesian Network for wolverines on the Kenai Peninsula, Alaska, USA.

Variable states			Probability of outcome		
Environmental_Index	Topographic_Index	Disturbance_Index	Low	Moderate	High
Very low	Low	Low	1.00	0.00	0.00
Very low	Low	Moderate	0.90	0.10	0.00
Very low	Low	High	0.90	0.05	0.05
Very low	Moderate	Low	0.70	0.30	0.00
Very low	Moderate	Moderate	0.60	0.40	0.00
Very low	Moderate	High	0.50	0.40	0.10
Very low	High	Low	0.50	0.20	0.30
Very low	High	Moderate	0.60	0.10	0.30
Very low	High	High	0.50	0.20	0.30
Low	Low	Low	1.00	0.00	0.00
Low	Low	Moderate	0.80	0.20	0.00
Low	Low	High	0.80	0.15	0.05
Low	Moderate	Low	0.60	0.40	0.00
Low	Moderate	Moderate	0.40	0.60	0.00
Low	Moderate	High	0.40	0.40	0.20
Low	High	Low	0.35	0.35	0.30
Low	High	Moderate	0.40	0.20	0.40
Low	High	High	0.10	0.30	0.60
Moderate	Low	Low	0.60	0.40	0.00
Moderate	Low	Moderate	0.40	0.60	0.00
Moderate	Low	High	0.40	0.40	0.20
Moderate	Moderate	Low	0.20	0.80	0.00
Moderate	Moderate	Moderate	0.00	1.00	0.00
Moderate	Moderate	High	0.00	0.80	0.20
Moderate	High	Low	0.20	0.40	0.40
Moderate	High	Moderate	0.00	0.60	0.40
Moderate	High	High	0.00	0.40	0.60
High	Low	Low	0.60	0.30	0.10
High	Low	Moderate	0.30	0.40	0.30
High	Low	High	0.40	0.20	0.40
High	Moderate	Low	0.20	0.40	0.40
High	Moderate	Moderate	0.00	0.60	0.40
High	Moderate	High	0.00	0.40	0.60
High	High	Low	0.05	0.15	0.80
High	High	Moderate	0.00	0.20	0.80
High	High	High	0.00	0.00	1.00

Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 11 – Movement Patterns and Potential Corridors for Dall sheep on the Kenai Peninsula, Alaska, USA

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Introduction

Dall sheep (*Ovis dalli*) are largely animals of alpine habitat, while the closely related Stone sheep (*Ovis dalli stonei*) are less restricted and often venture into subalpine shrub lands and even lower forested areas (Bunnell 2005). Similar to Dall sheep, stone sheep are habitat specialists requiring steep slopes and high elevations with access to escape terrain to easily evade predators (Walker et al. 2007). They appear to select and use the landscape similar to other mountain sheep (Geist 1971, Bleich et al. 1997, Rachlow and Bowyer 1998). Summer and winter ranges of both subspecies are often discrete. Summer ranges are typically at higher elevations, often remote, frequently near escape terrain, and always support graminoid forage (grasses, sedges, and rushes), a variety of forbs, and low shrubs (e.g., *Dryas, Salix, Vaccinium, and Empetrum*) (Lord and Luckhurst 1974).

Dall sheep in the Kenai Mountains on the Kenai Peninsula are at the southern extent of their range in Alaska (McDonough 2011). Early accounts on the Kenai Peninsula indicated that people associated with mining activities largely decimated Dall sheep in the area through market hunting and poaching (Bowyer et al. 2000). Range-wide, Dall sheep have experienced a 54% contraction in their range (Laliberte and Ripple 2004). They currently occupy 3 adjacent, but distinct, ranges on the Kenai Peninsula in the vicinity of Kenai Lake and Kenai River near the village of Cooper Landing, Alaska (Nichols 1978). Approximately 1,600 Dall sheep were counted on the Kenai Peninsula in 1992. Limited counts since then indicate that the population has decreased to between 800–1,200. The annual harvest by hunters from this population has averaged 12 rams from 2005–2010.

Male and female Dall sheep spatially segregate during spring and summer (Rachlow and Bowyer 1998). Females concentrate near steep, rugged terrain where predation risk is reduced but forage is less abundant and of lower quality (Bleich et al. 1997). The larger males forage in areas further from escape habitat that is of higher quality. Males and females begin to associate during the rut in the fall and but as winter approaches, they separate again (Geist 1971).

Wild sheep show strong fidelity to seasonal ranges (Geist 1971, Festa-Bianchet 1986). In this analysis, habitat quality was modeled for winter and summer seasons for Dall sheep. Similar to other ungulate species, winter is generally considered 1 of the most energetically demanding periods of the year for Dall sheep. The lambing period in June and July can also be a stressful time as sheep are particularly vulnerable to noise and visual disturbance at this time (Paquet and Demarchi 1999, Blood 2000).

In late winter, Dall sheep require access to areas with vegetation not covered by snow for foraging. Typically, alpine areas with vegetation exposed by wind and/or solar radiation in late winter allow Dall sheep easy access to low-growing forage (Walker et al. 2007). Where snow accumulates, the energetic costs to Dall sheep of removing snow cover from the vegetation beneath often overwhelms the nutritional benefit gained. Areas like these used for late winter feeding generally cover a small percentage of the annual range of Dall sheep; access to late winter habitat is considered to be a limiting factor for Dall sheep (Barichello et al. 1987, Walker et al. 2007). Identification and protection of late winter habitat is considered to be critical to maintaining sheep populations (Barker 2012).

Lambing habitat for Dall sheep has been characterized by steep, rugged terrain intermixed with forage, including grasses and dryas (Rachlow and Bowyer 1998). Such habitat typically is located at high elevation and free of snow.

Mortality of Dall sheep resulting from wildlife-vehicle collisions (WVCs) was reported by Hoefs and McTaggart Cowan (1979) in Kluane National Park, Yukon Territory, Canada and by Blood (2000) along the Alaska Highway. In some cases in Denali National Park, Alaska, vehicle traffic impeded Dall sheep from crossing roads during migration (Singer and Beattie 1986). Dalle-Molle and van Horn (1991) also reported reluctance by Dall sheep to cross the road during migration in Denali National Park. Proximity to, and degree of traffic on roads increased the degree of avoidance of roads by bighorn sheep (*Ovis canadensis*) (MacArthur et al. 1979, Miller and Smith 1985, Papouchis et al. 2001). Bighorn sheep had higher mean heart rates when they were disturbed on flat terrain or when they were <200 m from a road (MacArthur et al. 1979). The ease of crossing a road by an individual may depend on previous exposure to traffic, including disruption of daily and seasonal movement patterns (Demarchi and Hartwig 2004). Movement delays and repeated road crossing attempts expose Dall sheep to increased probability of mortality from WVCs and predation, as well as increased energetic costs, and potential reduced productivity in the population (Geist 1971). Mortality for WVCs is likely additive and not compensatory (Heimer 1992).

Wild sheep do not readily expand their ranges or colonize new areas (Geist 1971, Worley et al. 2004), which makes them especially susceptible to local anthropogenic and environmental stressors. Understanding patterns of population connectivity can facilitate management and mitigation of negative impacts to populations (Roffler et al. 2014). Our specific objective in this work was to use the habitat relationships of Dall sheep to identify their potential movement corridors on the Kenai Peninsula so that resource managers can include that information in planning for habitat management, resource development, and infrastructure development (including transportation) (Riley et al. 2002). Specifically we wanted to identify areas within milepost (MP) 45–60 on the Sterling Highway that may be suitable for practices to mitigate the potential effects of highway development on Dall sheep.

Methods

Habitat Quality Model

We expressed the relationships among Dall sheep, characteristics of land cover classes, and other landscape characteristics and described the resulting habitat quality through Bayesian Networks (BN) using the Netica® shell (Norsys Software Corporation, Vancouver, British Columbia, Canada). BNs provided a structured tool for integrating information on habitat associations to assist in describing habitat quality upon which to base development of potential movement corridors. BNs depict probabilistic relations among causal variables and use Bayesian statistics to calculate probabilities of population presence in response to a given set of habitat conditions (Marcot 2006). The habitat relationships expressed in the BN throughout this analysis were developed from application of findings reported in the scientific literature (i.e., field data were not used).

Applying the Model

BNs used in habitat-related analyses are typically applied to the values of variables within spatially registered polygons. To create a series of polygons, we placed approximately 144,000 hexagons, each 13.9 ha in size, across the study area. This size was selected to provide a degree of precision across the landscape within a database that was small enough to facilitate efficient processing. The mean of continuous variables and the values of categorical variables with the largest area within each hexagon were assigned to each hexagon. The BN was then applied to each hexagon and a value depicting quality of habitat within each hexagon was calculated.

Effect of Variables

Sensitivity analysis was performed in Netica® to determine how much the values of a selected node were influenced by a single finding at each of the other nodes. Sensitivity analysis in BNs evaluates the degree to which variation in the outcome variable (i.e., Habitat Quality Index) is explained by other variables (Marcot 2012). Sensitivity analyses can help identify the relative influence of each variable on the model outcome and can be conducted on any dependent node (Marcot et al. 2001, Marcot 2006). Variance reduction was calculated as the reduction in the variation of the value of the Habitat Quality Index by each of the input variables using a routine in the Netica® shell. The results of these analyses were used to quantitatively compare and rank the effect of input variables on the outcome of the model. Sensitivity analyses are useful for determining which habitat attributes might be prioritized for management for greatest effectiveness in conservation or restoration planning.

Resistance Surfaces by Variable

We generally followed the process outlined by Beier et al. (2007) to move from the range of estimated relative probability of use for each variable used in the RSF calculations for Dall sheep to the development of resistance surfaces.

We used the inverse of the mean relative probability of use to generate resistance values for each variable. Through this subjective translation (Beier et al. 2007), we assumed that pixels with higher habitat values afforded lower costs to movement than those with low habitat values. Resistance reflects the ecological cost of Dall sheep traveling through a pixel. In general, resistance increases with the energetic cost of travel through the pixel. Resistance decreases as the quality of habitat increases in a pixel; it is not necessarily related to the speed of travel through the pixel.

Core Areas

We followed a convention similar to that established by WHCWG (2010) and used the term core area to describe high-quality habitats between which we evaluated movement patterns for focal species. Core areas were generated using the Core Mapper tool from the Gnarly Landscape Utilities ArcGIS toolbox applied to the results of the BN model with probability of use scaled from 0-100 (Shirk and McRae 2013). Core habitat areas for Dall sheep were defined as significant habitat areas that are expected or known to be important based on habitat association modeling (WHCWG 2010). To meet that criterion we described potential core habitat as areas having a habitat value >50 (on a 0 – 100 scale). We then calculated the proportion of habitat within a circular moving window with a radius of 5,000 m (i.e., the probable distance Dall sheep on the Kenai Peninsula will move [Nichols 1978]). This step generated a surface representing where the largest concentrations of good habitat existed. We removed cells from the initial maps of core areas if the average habitat value of the window centered on a particular cell was <65 (on a 0 – 100 scale). This prevented habitat cores from being identified in areas where high-quality habitat was not sufficiently concentrated.

Potential Movement Paths

Connectivity among habitat patches for animals within a landscape depends on characteristics of the landscape (structural connectivity) and on aspects of the mobility of the animal (functional connectivity) (Adriaensen et al. 2003). Least-cost modeling has been used to incorporate detailed information about the landscape as well as behavioral aspects of the animal to describe connectivity. Cost-weighted distance approaches to estimate movement corridors of animals represent the least accumulative cost required to move between a specified source and a specified destination (Beier et al. 2007). This method provides a flexible tool that provides insights into the relationship between dispersal and landscape characteristics. This method identifies a set of near-optimal corridors for the landscape linkage network, with emphasis on corridors with the least cumulative cost-weighted distances (Chetkiewicz et al. 2006, Beier et al. 2008).

While these least-cost models implicitly assume animals have perfect knowledge of the landscape, current flow models assume they do not have knowledge of potential movements more than 1 step ahead (Newman 2005). Real-world movement behavior of animals like Dall sheep may fall somewhere between these extremes (McRae et al. 2008, Richard and Armstrong 2010). While shortest-path methods have been used to develop empirical multivariate models of habitat connectivity (Schwartz et al. 2009, Richard and Armstrong 2010), predictions from current flow-based models are highly correlated with observed genetic distance in several plant and animal populations and may better reflect actual movement corridors (McRae et al. 2008, Lee-Yaw et al. 2009, Shirk et al. 2010).

Circuit theory has been applied to connectivity analyses in other fields (McRae et al. 2008), and has been used to model gene flow in heterogeneous landscapes (McRae 2006, McRae and Beier 2007). Because connectivity increases with multiple pathways in circuit networks, distance metrics based on electrical connectivity are applicable to processes that respond positively to increasing connections and redundancy (McRae et al. 2008). Circuit theory is based in Markovian random walk theory and describes every movement as a random choice with movement in every direction equally probable. The landscape then acts as an electrical-resistance surface or, inversely, as a conductance surface, as the current travels outward to surrounding cells from the source patch of core habitat. The areas of least resistance or greatest conductance across the landscape are the most probable areas for movement. This theory can be applied to predict movement patterns of random walkers moving across complex landscapes, to generate measures of connectivity or isolation of habitat patches, and to identify important connective elements (e.g., corridors) for conservation planning.

The resistance distance concept of circuit theory incorporates multiple pathways connecting nodes, with resistance distances measured between core area pairs decreasing as more connections are added (McRae et al. 2008). Therefore, the resistance distance does not reflect the distance traveled or movement cost accrued by an individual animal. Rather, it incorporates both the minimum movement distance or cost and the availability of alternative pathways. As additional linkages are added, individuals do not necessarily travel shorter distances, but have more pathways available to them. Current density can be used to identify landscape corridors or ‘‘pinch points,’’ (i.e., features through which moving animals have a high likelihood – or necessity – of passing). High current through these pinch points indicates that stopping the flow through these points, or maintaining it, will have a high impact on connectivity.

To identify potential movement corridors, we used a combination of least-cost modeling and circuit theory (McRae et al. 2008) using the Linkage Mapper Toolkit (McRae and Kavanagh 2011) in ArcGIS 10.3. These analyses were performed by applying the final map of core habitat to identify start and end locations for building the corridor network from the resistance layers. We used the one-to-many criterion, whereby 1 source was connected to all end nodes in an iterative fashion. Circuit theory supplemented least-cost analyses to identify important areas for prioritization of conservation connectivity associated with the Sterling Highway (McRae et al. 2008).

The Pinchpoint Mapper module (McRae 2012) of Linkage Mapper was used to apply circuit theory through the program Circuitscape (McRae and Shah 2009) to identify and map "pinch points" (i.e., constrictions) within the resulting corridors. Circuitscape calculates the resistance of the landscape to movement between each pair of core areas (analogous to electrical resistance in a circuit diagram), allowing for multiple pathways between core areas. The pinch points we identified represented where loss of a small area could disproportionately compromise connectivity of the broader landscape. Using this hybrid approach, we merged least-cost corridors with pinch points to identify and display the most efficient movement corridors and the critical areas within them that contributed the most to habitat connectivity (McRae and Kavanagh 2011).

Results

Habitat Quality Model

The habitat quality model combined the effects of forage availability (nutrition) and avoidance of predation on Dall sheep. The model reflected that Dall sheep are generally found in subalpine and alpine habitats where they graze on alpine vegetation (primarily graminoids, forbs, sedges, and rushes) near or in steep, rocky terrain (Bowyer et al. 2000). Unlike bighorn sheep, they also consume lichen and moss (Seip and Bunnell 1985a). Areas not used by Dall sheep in the model were generally forested, had limited escape cover, or did not support adequate forage (Simmons 1982).

Habitat relationships

*Snow Cover.–*Stone sheep selected ranges with the highest quality available forage; in winter, snow severely restricted the area that provided available food in northern British Columbia (Seip and Bunnell 1985b). Although Barker (2012) did not measure for snow depth on his Yukon study area, he reported selection by Dall sheep in late winter for convex topography which may, in turn, relate to selection for ridges, which are often windswept and are relatively free of snow. Barker (2012) also noted selection for southerly aspects (and against northerly aspects) which may also relate to snow depth, with south-facing slopes receiving more solar radiation, and consequently accumulating less snow (Hiemstra et al. 2006).

Areas with lower snow cover were selected by Dall sheep in Denali National Park, Alaska prior to lambing (Rachlow and Bowyer 1998). Dall sheep in Kluane National Park, Yukon, spent 70% of their time foraging in areas with little or no snow (i.e., <5 cm deep), and <10% of their time in areas with snow depth >15 cm (Hoefs and Mct. Cowan 1979). The average snow depth in areas used by Stone sheep during the winter in British Columbia was 16.5 cm and the depth where they ceased digging for food was 32.4 cm (Seip 1983). Geist (1971) reported that sheep preferred feeding in snow <25 cm deep.

Movement of Dall sheep in Kluane National Park, Yukon was restricted by snow depths >50 cm (Hoefs 1975). Deep snow and lack of wind have also contributed to large die-off's of Dall sheep in the Yukon (Burles and Hoefs 1984) and in Alaska (Murie 1944, Scott et al. 1950). On the Kenai Peninsula, snow cover in valleys is too deep by January for Dall sheep to cross (Nichols 1973). In late winter, the snow pack is so hard on much of the Kenai Peninsula that sheep are not able to dig through it so they are confined to small areas of open ridgetops where wind has exposed vegetation.

Landform.–In winter Stone sheep preferred ridges, mountain tops, and sloped hillsides, selecting against concave or gully-like topography (Walker et al. 2007).

Land cover.–Wood et al. (2010), Parker and Sittler (2013), and Sittler et al. (2015) reported avoidance of conifer stands relative to their availability by Stone sheep in northeast British Columbia, Canada and selection for alpine areas. Walker et al. (2007) reported the most notable consistency exhibited across all groups of Stone sheep was avoidance of or indifference towards subalpine spruce vegetation. Forested areas general have limited graminoid understory and extremely poor visibility, both of which likely contributed to strong avoidance. Decreased visibility across and through forested areas has been well documented to negatively affect habitat selection (Tilton and Willard 1982, Smith et al. 1999) and foraging efficiency of bighorn sheep (Risenhoover and Bailey 1985).

Stone sheep ewes with, and without, lambs spent most of their time in herbaceous and shrub habitats (Parker and Walker 2007, Wood et al. 2010) while site selection varied by group (Walker et al. 2006, Table 11-1). Walker et al. (2007) also noted that groups of Stone sheep selected for dry alpine vegetation more than any other vegetation type during winter and summer. Greater cover of forage (grass and dryas) was selected by sheep prior to lambing in Denali National Park, Alaska (Rachlow and Bowyer 1998). Stone sheep in British Columbia avoided riparian habitats unless they used mineral licks in these areas or passed through them while accessing seasonal ranges (Walker et al. 2007, Ayotte et al. 2008, Sittler et al. 2015).

Table 11-1. Differences in ground cover used by groups of Stone sheep ewes in the Besa-Prophet area of northern British Columbia, Canada (from Walker et al. 2006).

Cover class	Percentage of ground cover by group	
	Ewes with lambs	Ewes without lambs
Herbaceous	63 ± 5.1	73 ± 4.0
Shrub	9.2 ± 2.9	22 ± 3.9
Tree	1.5 ± 0.8	1.5 ± 0.6
Moss/lichen	22.0 ± 5.2	20.0 ± 4.5
Soil/rock	44.0 ± 5.2	26.0 ± 4.0

Aspect.–Barker (2012) reported selection by Dall sheep for southerly aspects (and against northerly aspects) in the Dawson region of the Yukon Territory, Canada. Wood et al. (2010), Parker and Sittler (2013), and Sittler et al. (2015) noted selection of Stone sheep for south to west aspects year round in northeast British Columbia, Canada. This selection may have reflected patterns in vegetation growth, with more forage available on sunnier slopes (Walker et al. 1993). Sheep may have also gained a thermal advantage from selecting for southerly aspects (Demarchi et al. 2000). Much of the time during winter Stone sheep were located on south or west facing slopes and ridges, avoiding north and east aspects (Luckhurst 1973, Walker et al. 2007).

Topographic ruggedness.–Topography ranked consistently better than other variables for describing habitat selection by Stone sheep regardless of season in British Columbia (Walker et al. 2007). Selection for rugged topography by Dall sheep in the Dawson region of the Yukon Territory, Canada, likely related to predation risk management (Barker 2012). Stone sheep always selected for steeper more rugged terrain in northeast British Columbia, Canada (Parker and Sittler 2013, Sittler et al. 2015). Terwilliger (2005) reported that terrain ruggedness significantly improved a model predicting total sheep density when considered with normalized difference vegetation index (NDVI) in Wrangell-St. Elias National Park and Preserve in Alaska.

Elevation.–In most seasons Stone sheep selected for higher elevations in northeast British Columbia, Canada (Walker et al. 2007, Parker and Sittler 2013, Sittler et al. 2015). They were at their lowest elevation in April (1,639 ± 19 m) and moved up in elevation each month until reaching their highest elevations in July (1,864 ± 29 m) and August (1,860 ± 26 m). This elevational movement occurred as they tracked the highest nutrient quality in newly emerging plants (Walker et al. 2006). Much of the time during winter, Stone sheep are located on slopes and ridges at <1,700 m elevation (Luckhurst 1973). Lambing habitat for Dall sheep in interior Alaska was typically >1,180 m and was free of snow (Rachlow and Bowyer 1998). However, in British Columbia of all the habitat attributes, the weakest consistency in seasonal selection by groups of Stone sheep between years was for elevation (Walker et al. 2007).

Escape terrain/slope.–The slope component of topography, particularly its role in defining escape terrain, has been well recognized as an integral component in the ecological relationships of mountain sheep (Geist 1971, Risenhoover and Bailey 1985, Rachlow and Bowyer 1998, Koizumi 2012). Sheep evade predation by fleeing to and in precipitous terrain (Geist 1971). Distance to escape terrain was useful in discriminating between randomly located sites and those used by Dall sheep during all periods of lambing in Denali National Park, Alaska (Rachlow and Bowyer 1998). Selection against areas distant from escape terrain in the Dawson region of the Yukon Territory, Canada, likely related to predation risk management (Barker 2012). Stone sheep used the steepest areas in late winter and spring and flatter areas in summer and fall in northeast British Columbia, Canada (Parker and Sittler 2013). Availability of escape terrain may be 1 of the limiting factors for Stone sheep populations (Walker et al. 2007).

Mean slope selected by Stone sheep ranged from 28°–36° (Sittler et al. 2015). The steepest location used by a collared individual was 61.3°. Demarchi and Hartwig (2004) described escape terrain for Dall sheep as areas with slope ranging from 27°–85°. The RTEC (2010) model developed for western British Columbia described escape terrain for Stone sheep as slopes >40°. Tolkamp (2003) described quality of escape terrain as optimal with slopes >60°, moderate to high with slopes between 40–60°, moderate to low with slopes between 30–40°, and very low with slopes <30°. Terwilliger (2005) described escape terrain in Wrangell-St. Elias National Park and Preserve in Alaska as areas with slope >30° plus a 150 meter buffer of >22% slope. Wood et al. (2010) reported Stone sheep used slopes >37% more frequently than all other slopes in northeast British Columbia.

Dall sheep observed in the Central Brooks Range, Anaktuvuk Pass, Alaska, were a mean distance of 247.4 (SE = ±36.5) m away from escape terrain (Lawler 2004). Stone sheep females showed strongly significant selection for locations <100 m from escape terrain polygons in all seasons in northeast British Columbia (Wood et al. 2010). Stone sheep ewes with lambs were never observed >69 m (mean = 8.6 m, SE = ±2.1) from escape features in northeast British Columbia, Canada (Walker et al. 2006, Parker and Walker 2007). Groups of Stone sheep ewes without lambs were never observed >150 m (mean = 14.0 m, SE = ±3.5) from escape features. These means were closer than the 20.5 m reported for Dall sheep in Alaska (Rachlow and Bowyer 1998) and farther than the 2.4 m for maternal Dall sheep in the Yukon (Corti and Shackleton 2002).

Habitats >500 m from escape terrain were assumed to have limited value for sheep (RTEC 2010, Table 11-2). Demarchi and Hartwig (2004) described an escape terrain buffer for Dall sheep to be 300 m.

Table 11-2. Model parameters for escape terrain for Stone sheep in western British Columbia (RTEC 2010).

Distance to escape terrain (m)	Value (1 = high; 12 = very low)
<170	1
171 – 270	2
271 – 500	7
>500	12

Patch size (escape terrain).–Size of escape terrain was generally not included as a measure of escape features in previous evaluations of the relationship of sheep to escape terrain. However, patch size of escape terrain was the single most important variable describing distribution of Stone sheep in northeast British Columbia (Walker et al. 2006). Ewes with lambs used patches of escape terrain with a mean of 1.7 ha (SE ±0.48; range 0.01–12.00 ha). Ewes without lambs used patches of escape terrain with a mean of 0.41 ha (SE ±0.121; range 0.002–4.500 ha). Extirpation rates and variability in lamb density decreased in desert bighorn sheep with increasing size of escape terrain (McKinney et al. 2003). Also, patch size of escape terrain has been positively correlated with total population size, female population size, and lamb population size of desert bighorn sheep (McKinney et al. 2003).

Bayesian network

The literature indicates that the occurrence and abundance of Dall sheep likely varied across the Kenai Peninsula in response to landscape variables included in a forage index (i.e., land cover, snow depth and persistence, landform), a topographic index (i.e., elevation, aspect, terrain ruggedness), and a predation index (i.e., distance to escape terrain, patch size of escape terrain). Roffler et al. (2017) found that in their models of habitat selection for males and females, most coefficients were similar, suggesting little difference in summer habitat selection between sexes at the landscape scale. A combined model therefore may be used to predict the relative probability of resource selection by Dall sheep regardless of sex or reproductive status.

Snow depth and persistence.–McAfee et al. (2013) used observational data to describe the relationship between average monthly temperature across Alaska and the fraction of wet days in that month receiving snow (i.e., the snow-day fraction). Because they wanted to avoid the potentially large errors associated with solid precipitation measurement, their equations used the fraction of wet days in a month receiving snow, rather than the total amount of precipitation. These equations were evaluated by mapping the mean differences between estimated and observed snow-day fractions and comparing them with site characteristics such as elevation, mean average temperature, average precipitation amount and the relationship between average monthly temperature and the temperature on precipitation days. The result of their work provided a reasonable characterization of snow-day fraction throughout Alaska, including the Kenai Peninsula (Chapter 2; Begley et al. 2017) (Figure 11-1). Habitat value for Dall sheep increased as snow depth and persistence decreased.

Land cover.–Data describing land cover on the Kenai Peninsula were taken from the National Land Cover Database (Homer et al. 2007, Selkowitz and Stehman 2011) by Begley et al. (2017) (Chapter 2). Land cover classes (Figure 11-2) used in this analysis and their associated value to Dall sheep were:

- water (NLCD code 10, 11) – none
- ice/snow (12) – none
- developed (20) – none
- barren (30) – low
- deciduous forest (41) – low
- evergreen forest (42) – low
- mixed forest (43) – low
- planted/cultivated (80) – low
- wetlands (90) – low
- shrubland (50) – medium
- herbaceous upland (70) – high

Land forms.–Work by Walker et al. (2007) documented that land forms (i.e., terrain features) influenced use of the landscape by Stone sheep. Begley et al. (2017) (Chapter 2) used the Topographic Position Index GIS routine of Jenness (2007) and a digital elevation model to create a digital map of land forms on the Kenai Peninsula. We used the results of those efforts to group the 10 Jenness land forms to characterize valley bottoms (LF1), side slopes (LF2), and mountain tops (LF3). These 3 land form groups were then assigned a relative value to describe their suitability as habitat for Dall sheep: side slopes – moderate; valley bottoms – low; alpine mountain tops – high (Figure 11-3).

Elevation.–Begley et al. (2017) (Chapter 2) used a digital elevation model to generate a digital elevation map of the Kenai Peninsula. Elevation classes were described based on the natural history of Dall sheep and assigned a relative habitat value: <500 m – low; 500–700 m – moderate; >700 m – high (Figure 11-4). Habitat values for Dall sheep increased as elevation increased.

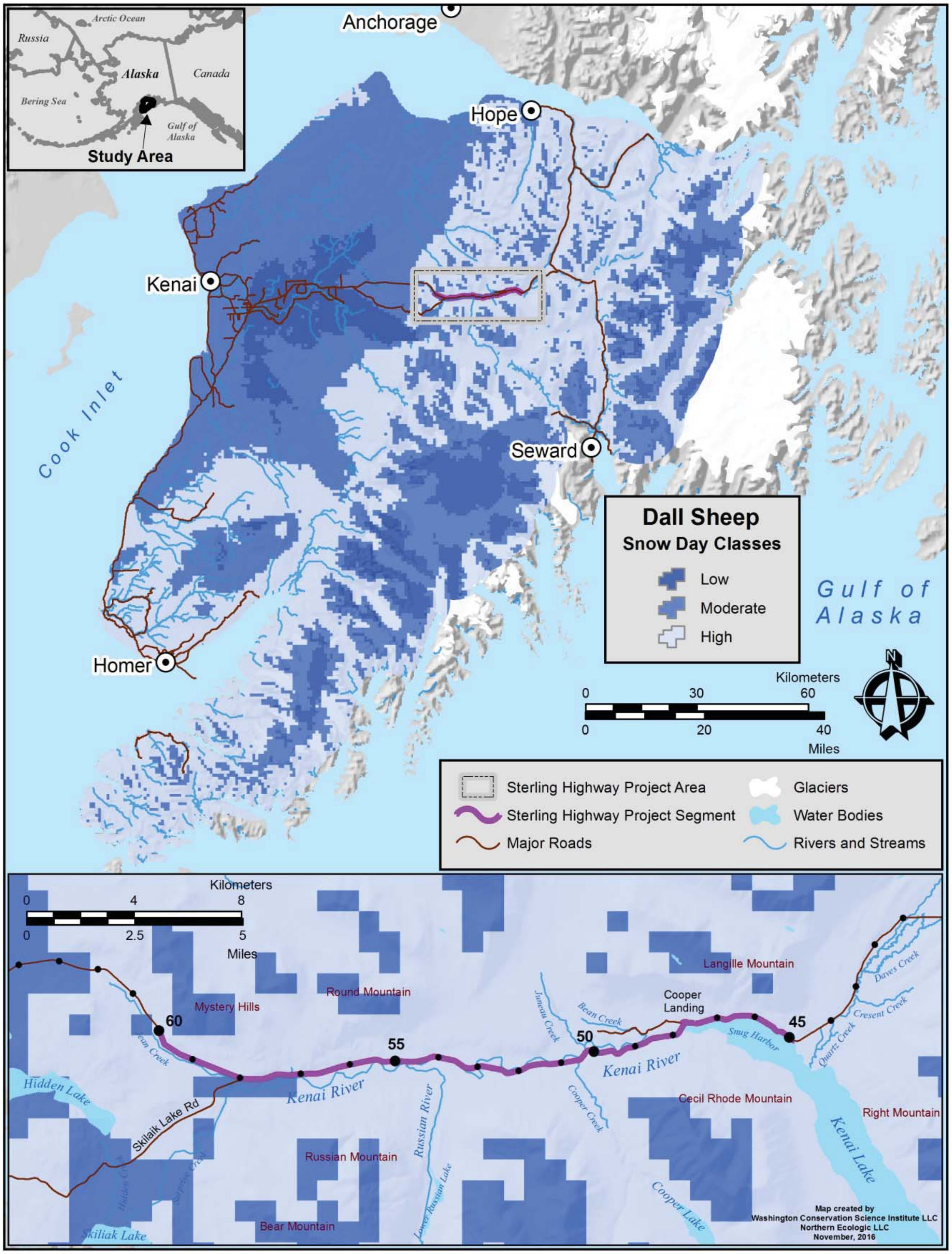

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Figure 11-1. Snow-days classes used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

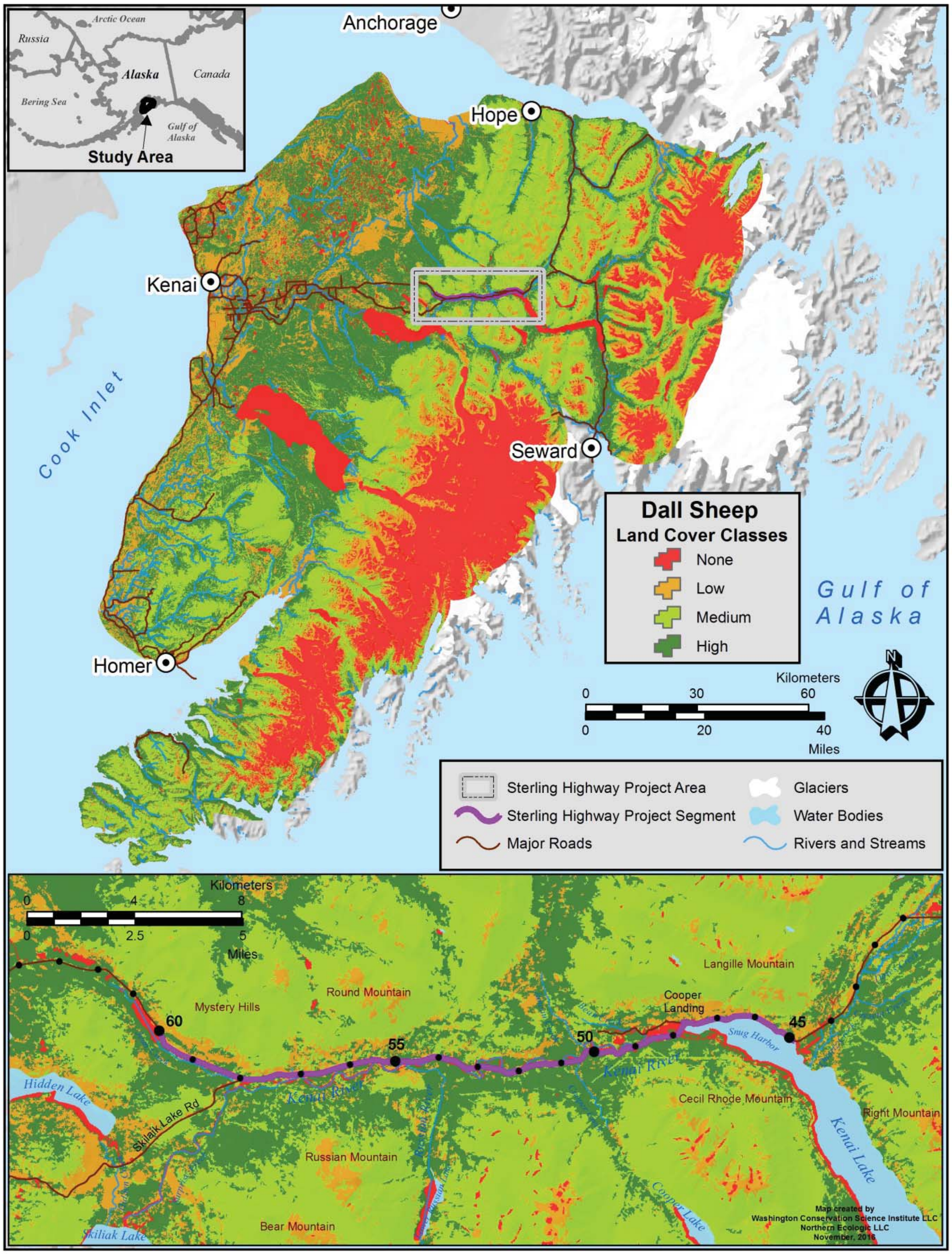

Figure 11-2. Land cover classes and their value as habitat used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

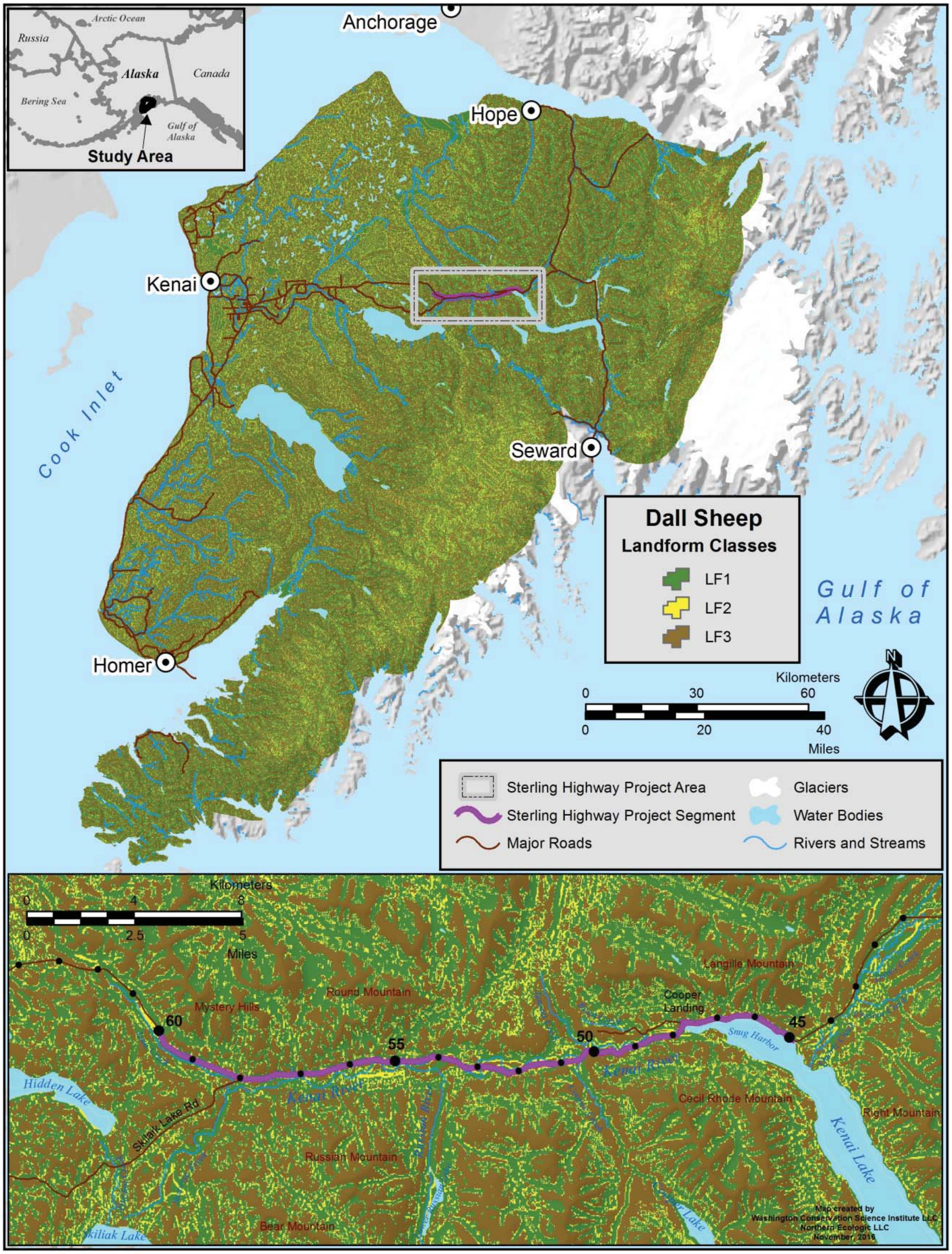

Figure 11-3. Classes of land forms used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

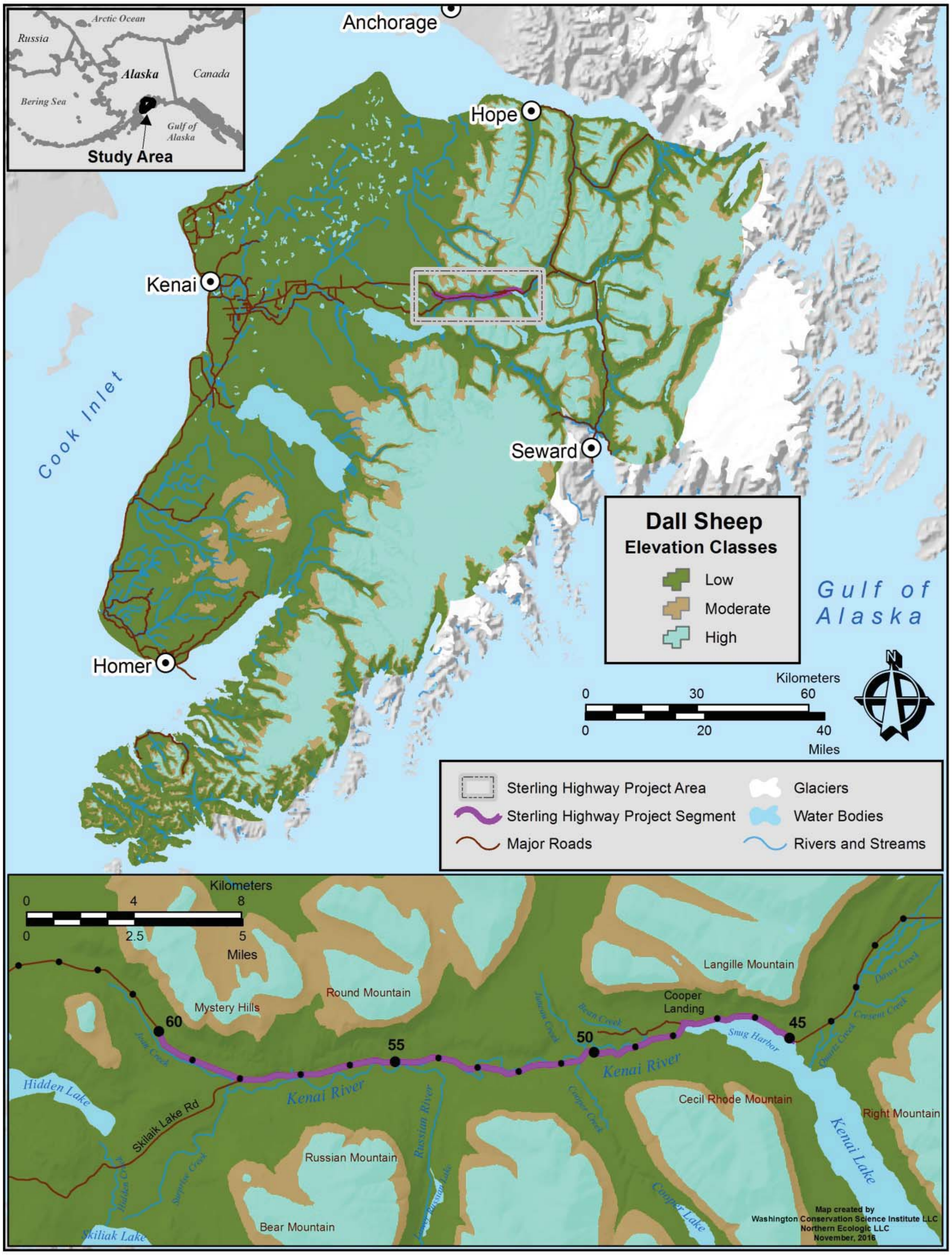

Figure 11-4. Classes of elevation used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

Aspect.–Begley et al. (2017) (Chapter 2) used a digital elevation model to characterize aspect classes on the Kenai Peninsula. Classes of aspect were described based on the natural history of Dall sheep and assigned a relative habitat value: south – high; west – moderate; east – low; north – very low (Figure 11-5). Habitat values for Dall sheep increased on south aspects and progressively decreased on west, east, and north aspects.

Terrain ruggedness.–A digital elevation model and a GIS process described by Sappington et al. (2007) was used to characterize terrain ruggedness on the Kenai Peninsula (Chapter 2; Begley et al. 2017). Classes of terrain ruggedness index values were described based on the natural history of Dall sheep and assigned a relative habitat value: <0.001 – low; 0.001–0.027 – moderate; >0.027 – high (Figure 11-6). Habitat values for Dall sheep increased as terrain ruggedness increased.

Escape terrain.–The digital elevation model was also used to characterize escape terrain for Dall sheep on the Kenai Peninsula (i.e., slopes ≥40°) (Chapter 2; Begley et al. 2017). Classes of escape terrain were described based on the natural history of Dall sheep and assigned a relative habitat value: ≤100 m from escape terrain – high; 100–250 m from escape terrain – moderate; 250–500 m from escape terrain – low; >500 m from escape terrain – very low (Figure 11-7). Habitat values for Dall sheep decreased as distance from escape terrain increased.

Patch size (escape terrain).–Begley et al. (2017) (Chapter 2) used GIS processes to characterize patch size of escape terrain for Dall sheep on the Kenai Peninsula. Classes of patch size of escape terrain were described based on the natural history of Dall sheep and assigned a relative habitat value: ≥2 ha – high; 0.5–2.0 ha – moderate; <0.5 ha – low (Figure 11-8). Habitat values for Dall sheep increased as size of patches of escape terrain increased.

Bayesian network.–A BN was constructed to provide a framework to incorporate the preceding variables into a model of habitat quality for Dall sheep on the Kenai Peninsula (Figure 11-9).

Effect of Variables

Sensitivity analysis showed that land cover was the primary variable that contributed the most to the Habitat Quality Index followed by escape terrain and snow depth (Table 11-3, Figure 11-10). Elevation was a moderate contributor to the Habitat Quality Index. Aspect, terrain ruggedness, land form, and patch size of escape terrain were minor contributors to the Habitat Quality Index.

Of the secondary variables, the Forage Index was the major contributor to the Habitat Quality Index followed by Predation Index and Topographic Index (Table 11-4, Figure 11-11).

Resistance to Movement

Our assignment of resistance values to different landscape features (Table 11-5) generated a resistance surface in which much of the high elevation, non-forested, landscape had low

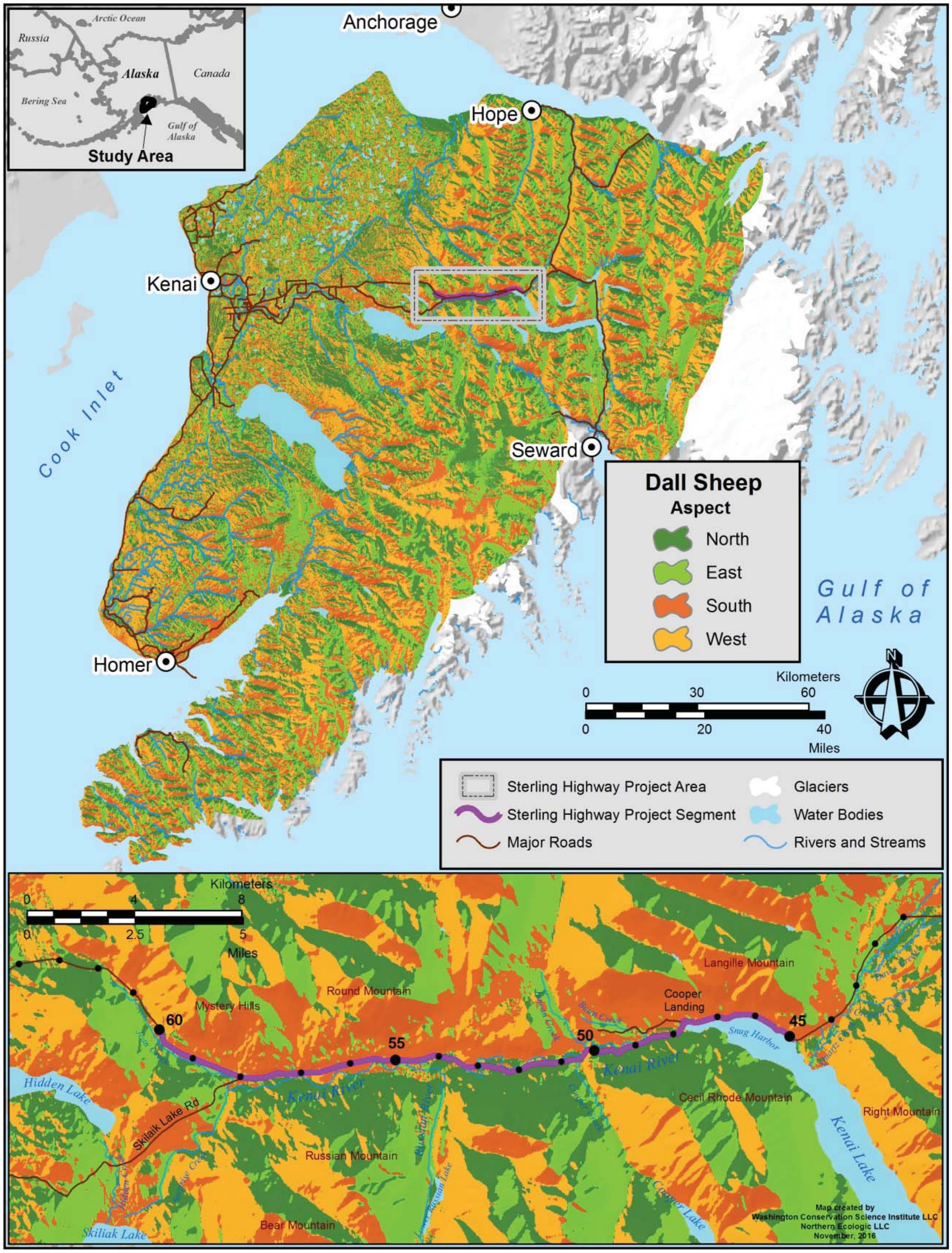

Figure 11-5. Classes of aspect used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

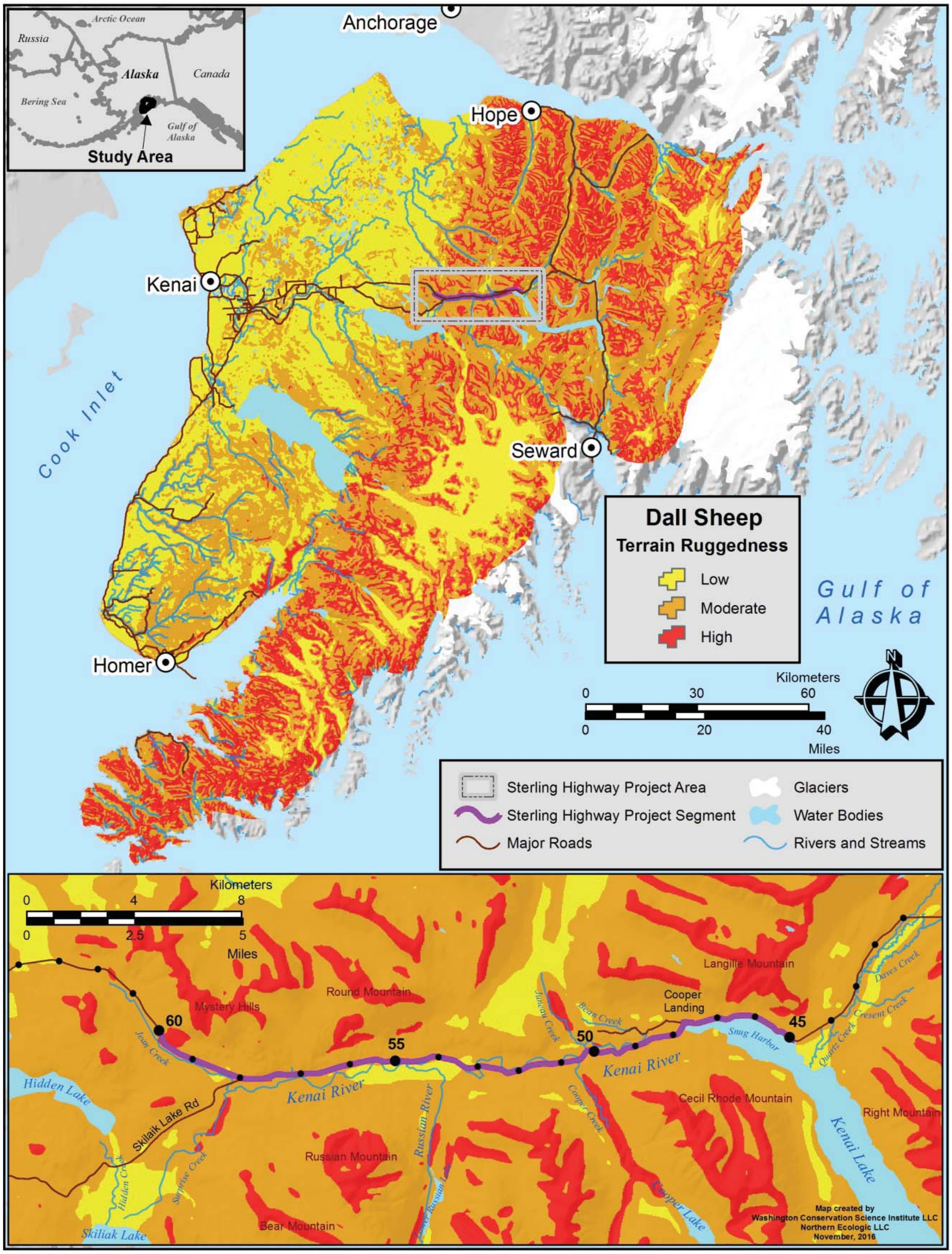

Figure 11-6. Classes of terrain ruggedness and their value as habitat used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

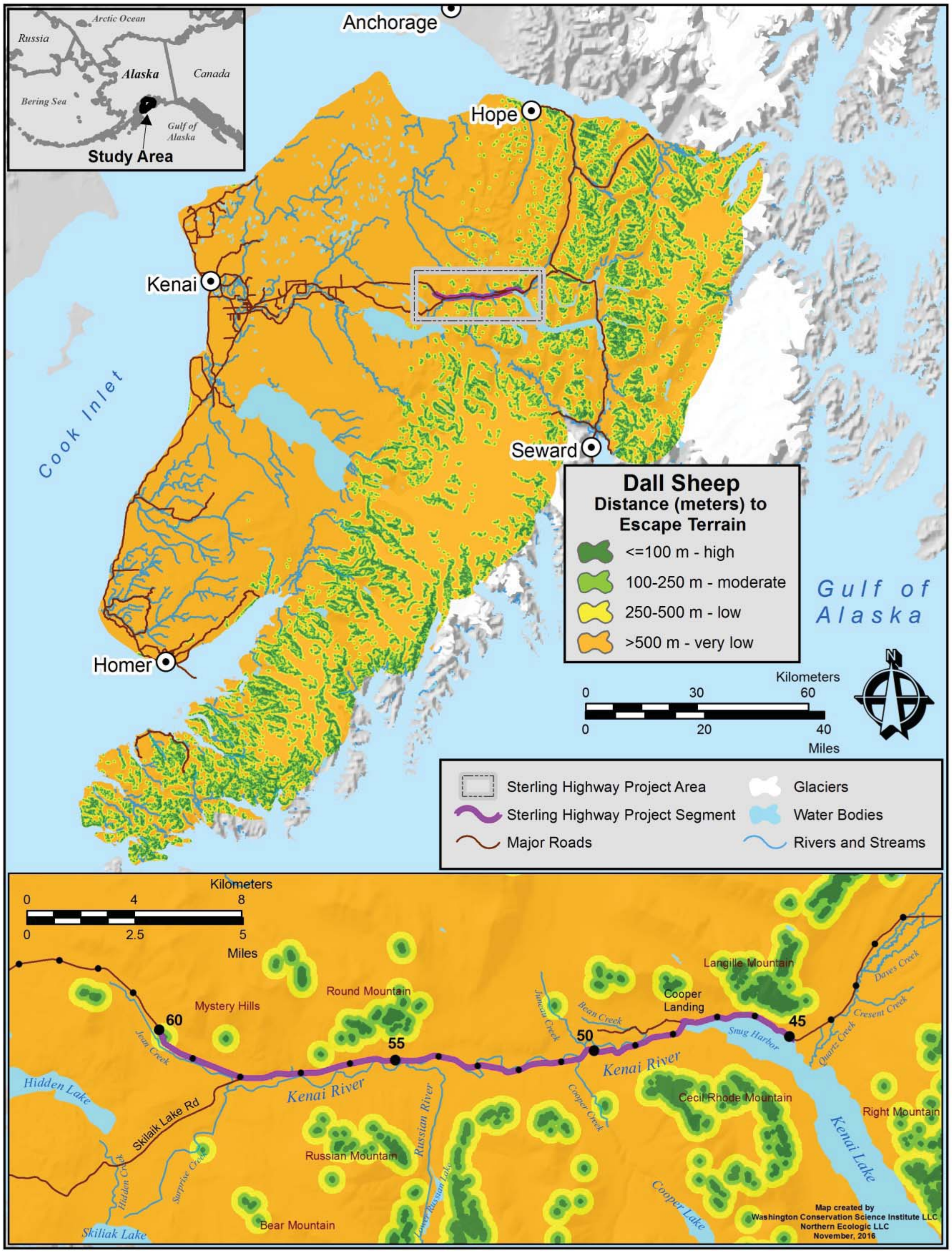

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Figure 11-7. Classes of escape terrain and their value as habitat used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

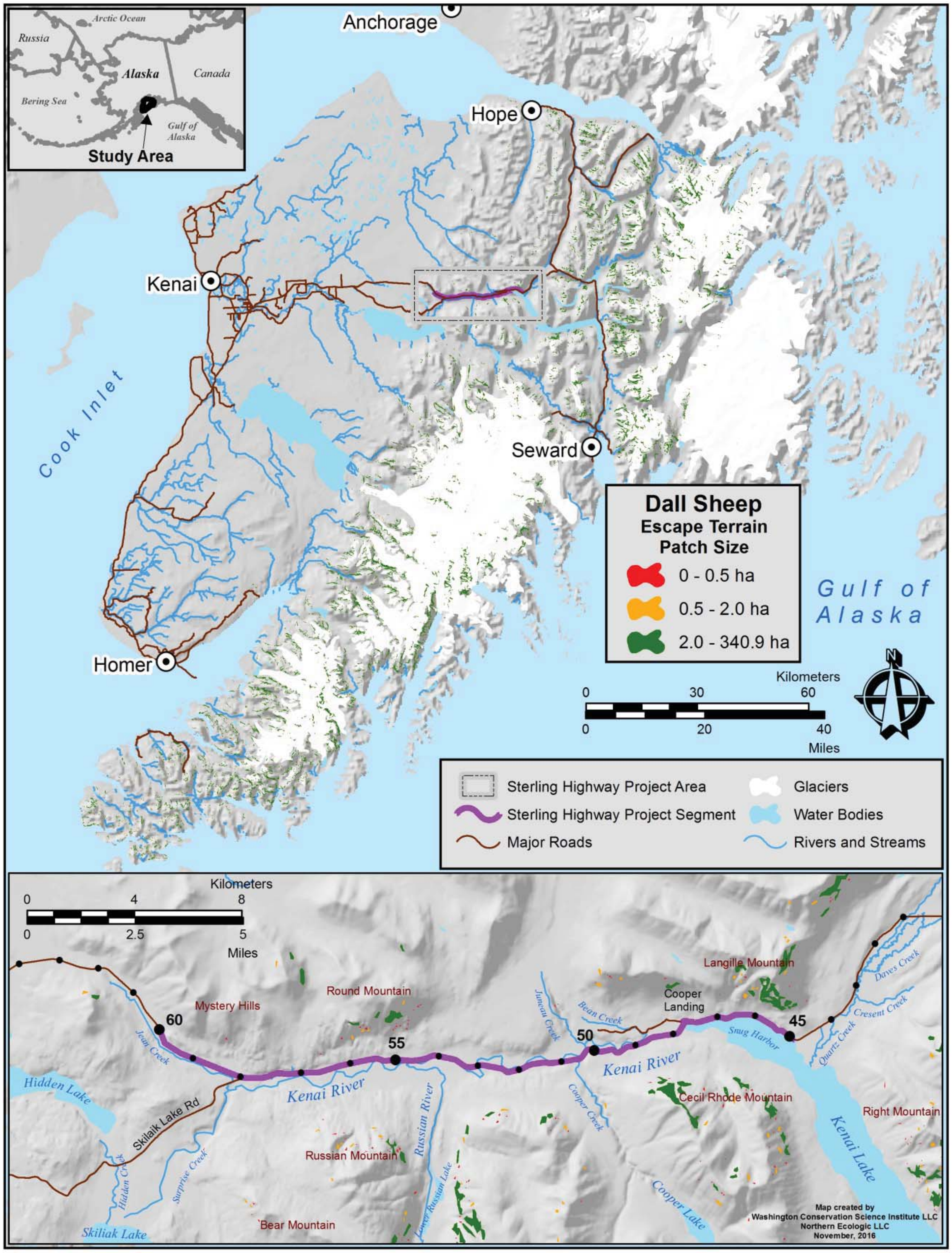

Figure 11-8. Classes of patch size of escape terrain used in the habitat quality index model for Dall sheep on the Kenai Peninsula, Alaska, USA.

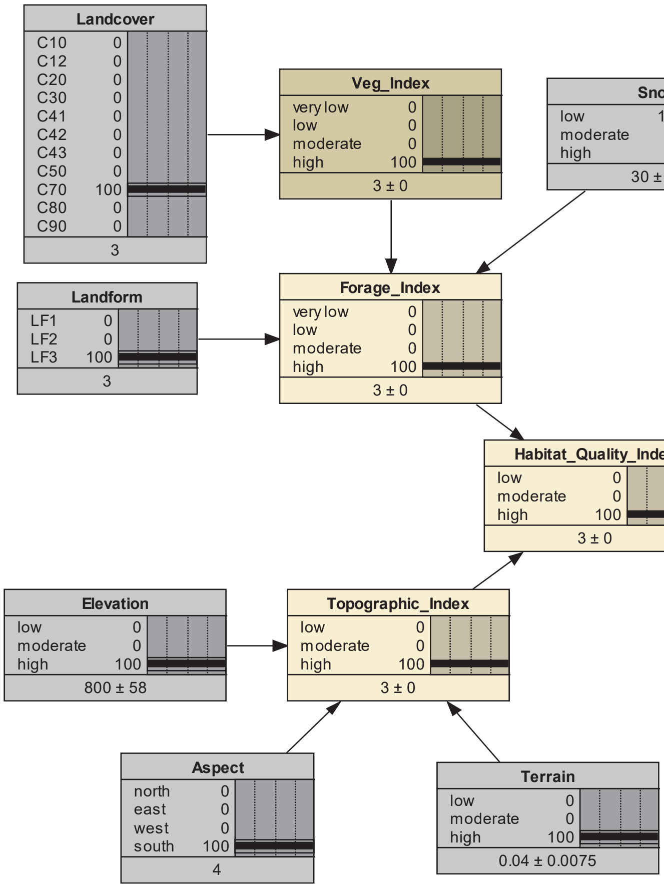

Figure 11-9. Bayesian network as a framework for a model of habitat quality for Dall sheep on the Kenai Peninsula, Alaska, USA.

Table 11-3. Sensitivity of predictions of the Habitat Quality Index for Dall sheep to variance in primary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

Variable	Variance reduction
Land cover (Vegetation Index)	0.0442
Snow	0.0115
Escape terrain	0.0080
Patch size (escape terrain)	0.0043
Elevation	0.0042
Aspect	0.0008
Terrain ruggedness	0.0007
Land form	0.0006

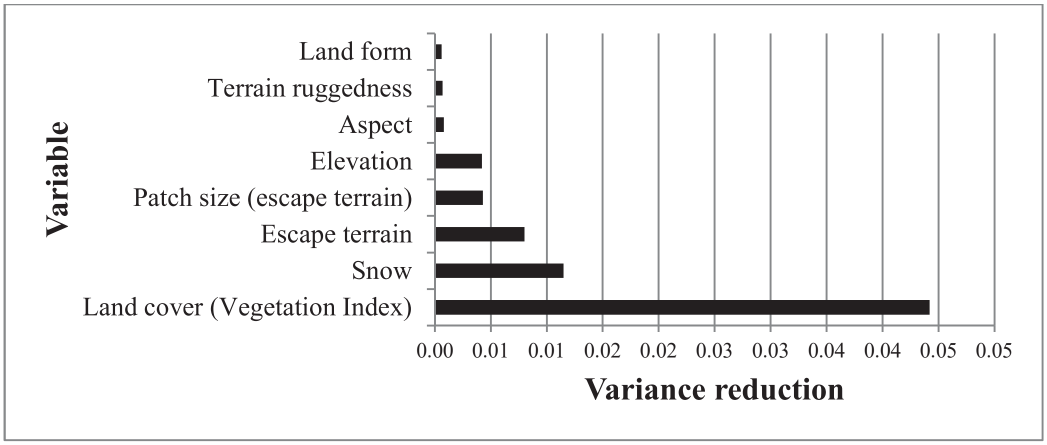

Figure 11-10. Sensitivity of predictions of the Habitat Quality Index for Dall sheep to variance in primary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

Table 11-4. Sensitivity of predictions of the Habitat Quality Index for Dall sheep to variance in secondary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

Variable	Variance reduction
Forage Index	0.1018
Predation Index	0.0186
Topographic Index	0.0151

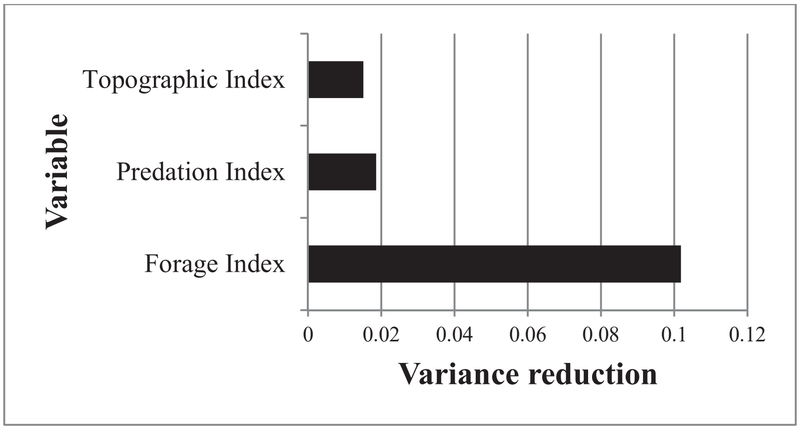

Figure 11-11. Sensitivity of predictions of the Habitat Quality Index for Dall sheep to variance in secondary input variables. Sensitivity was expressed as variance reduction and determined by a sensitivity routine in Netica©.

Table 11-5. Landscape features and resistance values used to model habitat connectivity for Dall sheep on the Kenai Peninsula, Alaska, USA.

Data Layer	Class Description	Class ID	Resistance value
Landcover	Water	11	200
Landcover	Ice-snow	12	100
Landcover	Developed	20	100
Landcover	Barron	31	5
Landcover	Deciduous forest	41	50
Landcover	Evergreen forest	42	50
Landcover	Mixed forest	43	50
Landcover	Shrubland	50	2
Landcover	Herbaceous upland	70	0
Landcover	Cultivated	80	50
Landcover	Wetland	90	75
Escape_Terrain	>500 m from escape terrain	1	100
Escape_Terrain	250-500 m from escape terrain	2	50
Escape_Terrain	100-250 m from escape terrain	3	10
Escape_Terrain	≤100 m from escape terrain	4	0
Snow	<60	1	0
Snow	60-70	2	25
Snow	>70	3	50
Elevation	<500 m	1	75
Elevation	500 - 700 m	2	10
Elevation	>700 m	3	0
Terrain	<0.001	1	75
Terrain	0.001-0.027	2	25
Terrain	>0.027	3	0

Table 11-5. Landscape features and resistance values used to model habitat connectivity for Dall sheep on the Kenai Peninsula, Alaska, USA.

Data Layer	Class Description	Class ID	Resistance value
Aspect	North - 0-45, 315-360, flat	1	50
Aspect	East- 45-135	2	25
Aspect	West - 225-315	3	10
Aspect	South - 135-225	4	0
Patch_Size	None	0	50
Patch_Size	<0.5 ha	1	10
Patch_Size	0.5-2.0 ha	2	5
Patch_Size	≥2 ha	3	0
Landform	Valley bottoms	1	50
Landform	Side slopes	2	0
Landform	Mountain tops	3	0

resistance for Dall sheep movements (Figure 11-12). Densely developed areas, wetlands, open water, ice and snow fields, low elevation, and areas far from escape terrain were features we assigned a high level of resistance. This resulted in a pattern is which lowland areas and valley bottoms typically had moderate to high resistance, and mountainous areas had low resistance.

Core Areas

Patterns of habitat quality for Dall sheep on the Kenai Peninsula were closely associated with high-elevation areas in proximity to escape terrain (Figure 11-13). Consequently, core areas were concentrated north to south in the center of the Kenai Peninsula (Figure 11-14). Seventy-two core areas for Dall sheep were modeled and mapped across the Kenai Peninsula. Core areas varied in size from 4.0–295.3 km^2 ($\overline{x}$ = 25.7 km^2) with a mean habitat quality index value of 63.2 (on a 0–100 scale).

Potential Movement Corridors

Analysis of least-cost corridors showed multiple potential corridors for Dall sheep from MP 45–60 of the Sterling Highway in the vicinity of Cooper Landing (Figure 11-15). This analysis revealed potential crossing points in the vicinity of MP 48, 54–55, and 56–57. We used circuit theory to estimate the effective resistance of the landscape within these corridors between all

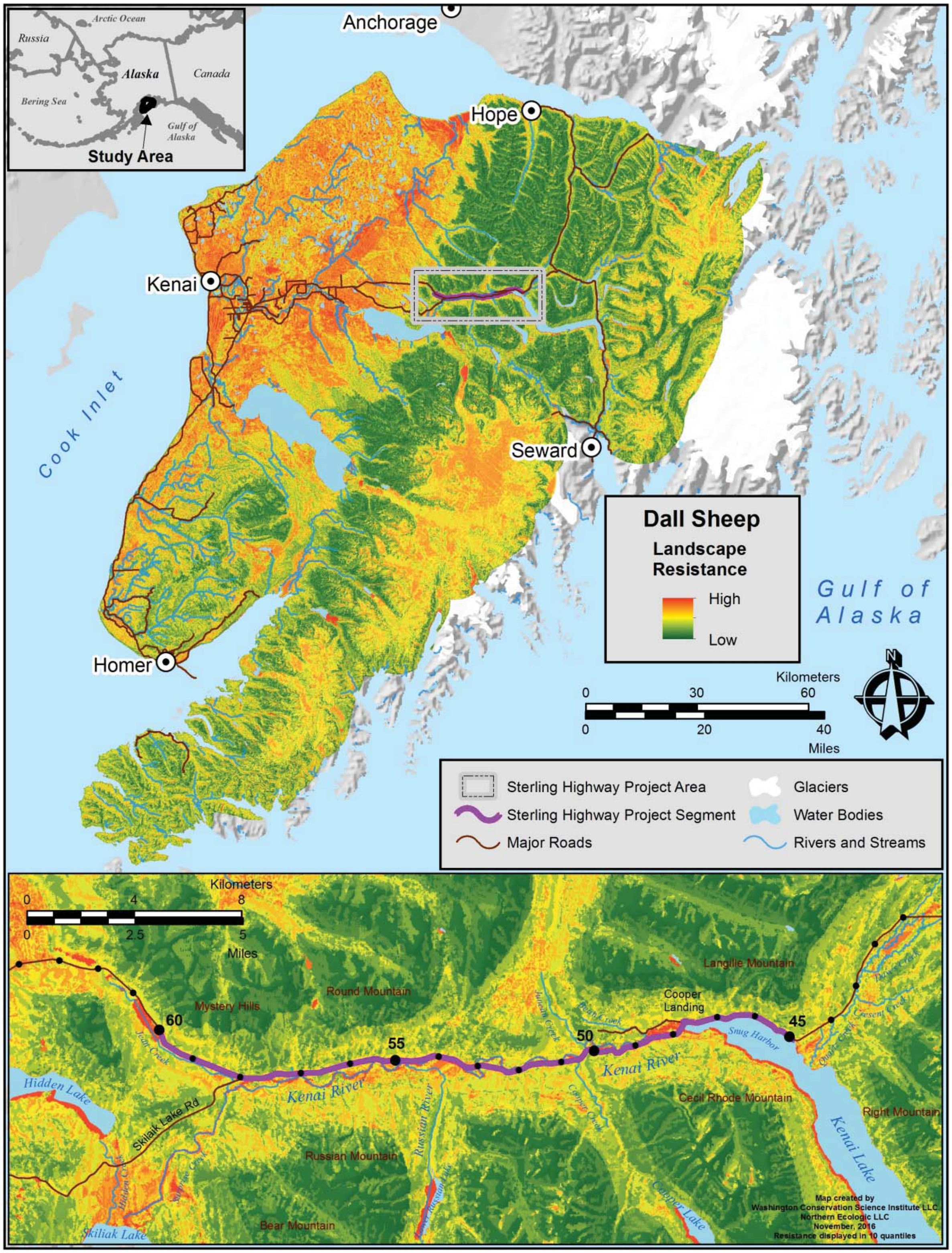

Figure 11-12. Resistance surface used to model habitat connectivity for Dall sheep on the Kenai Peninsula, Alaska, USA.

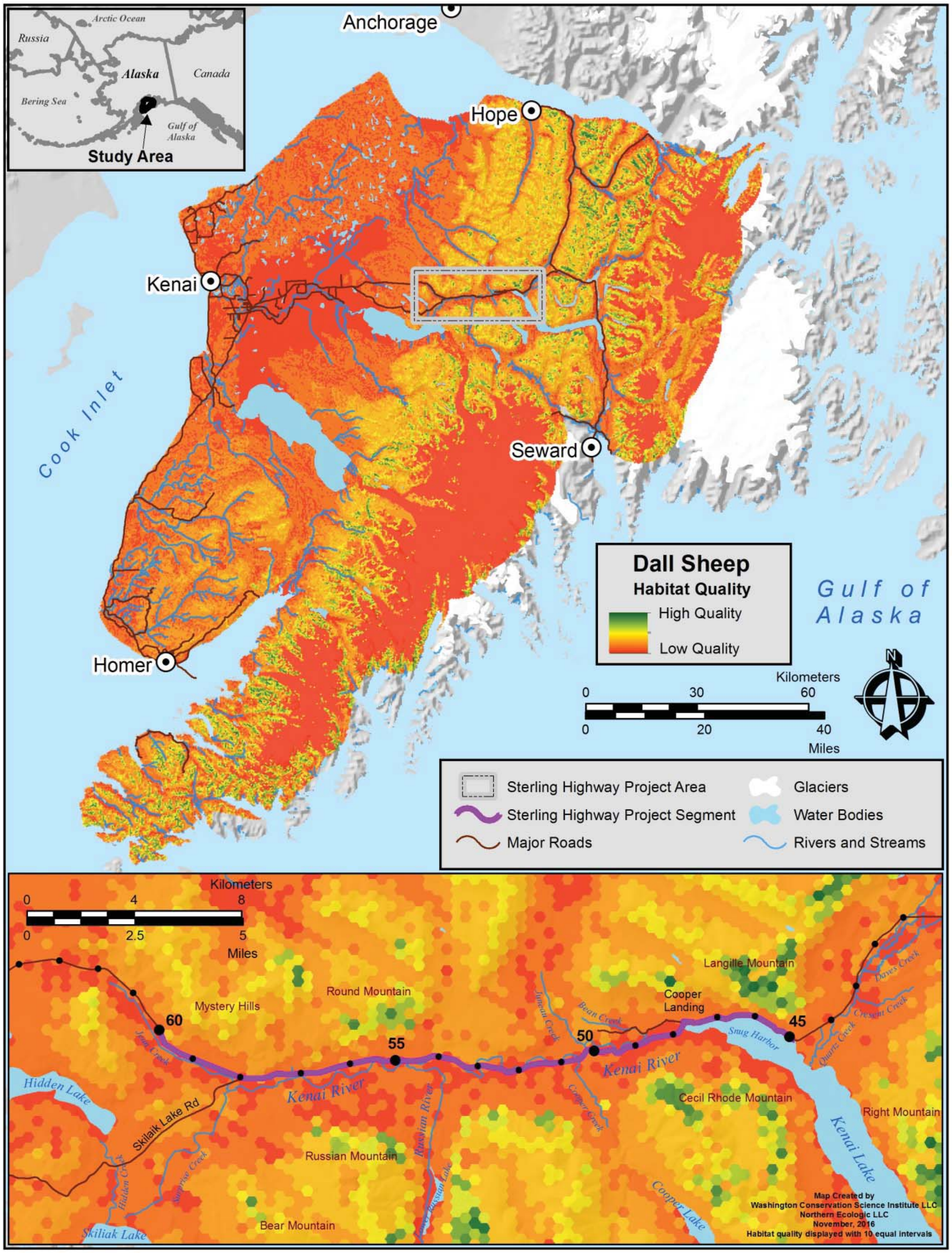

Figure 11-13. Habitat quality used to model habitat connectivity for Dall sheep on the Kenai Peninsula, Alaska, USA.

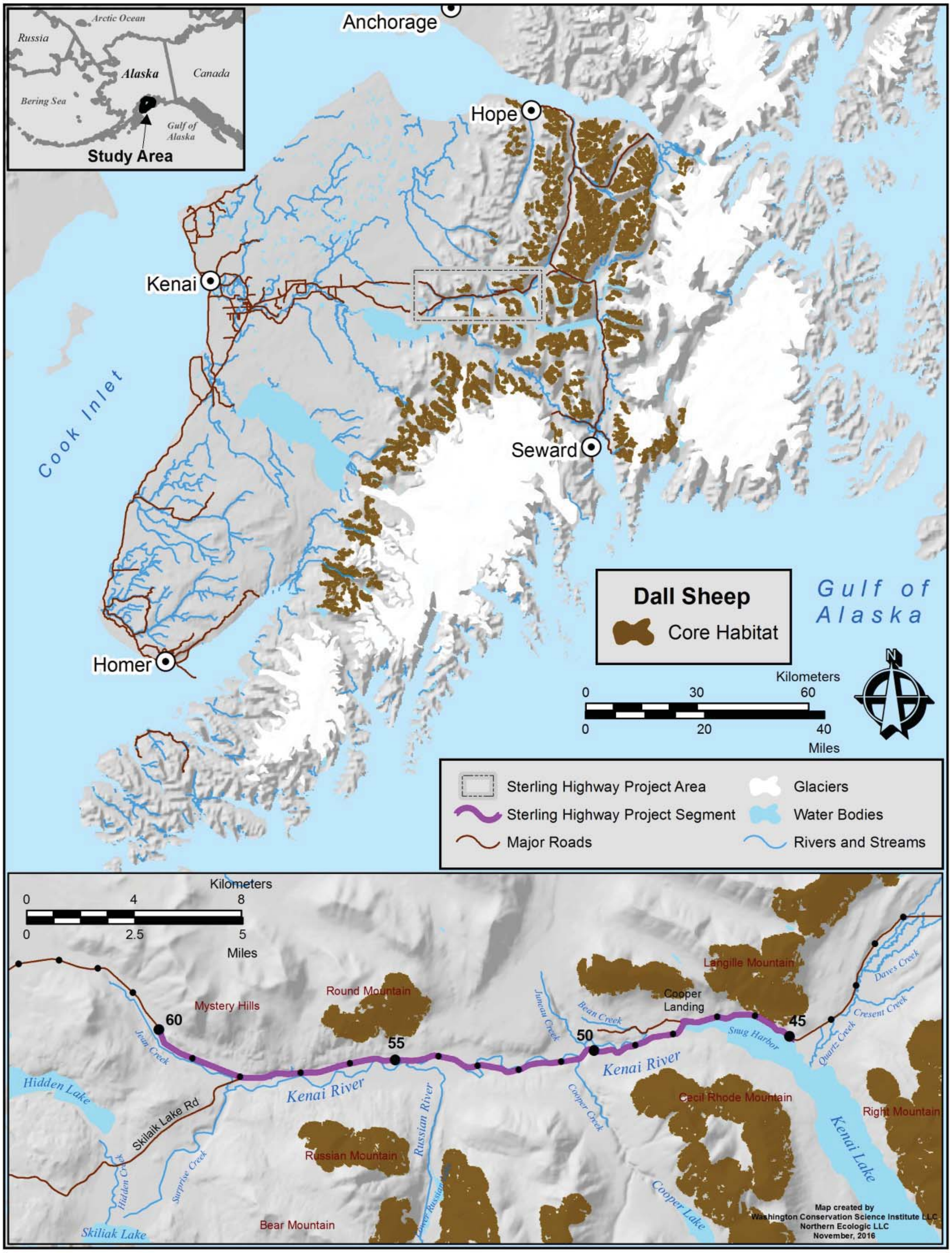

Figure 11-14. Core areas used to model habitat connectivity for Dall sheep on the Kenai Peninsula, Alaska, USA.

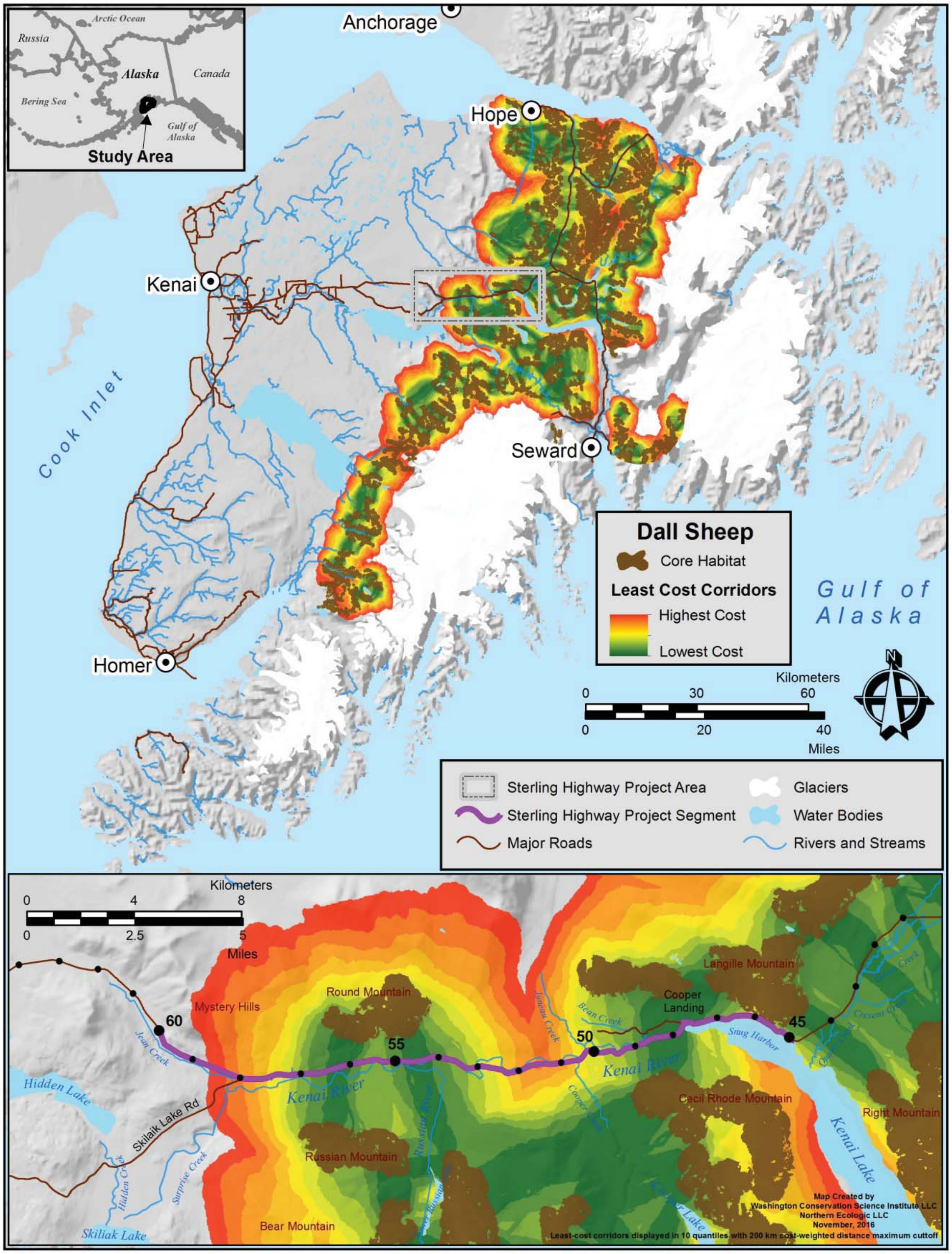

Figure 11-15. Core areas for Dall sheep and potential least-cost corridors for their movement across the Sterling Highway in the vicinity of Cooper Landing, Kenai Peninsula, Alaska, USA.

pairs of core areas (all-to-one mode in the Circuitscape software; McRae and Shah 2011). This analysis prioritized potential crossing points at MP 48 and MP 49 (Figure 11-16).

Based on these analyses, potential north-south movements of Dall sheep across the Sterling Highway in the vicinity of Cooper Landing revealed 3 potential crossing points (MPs 48, 54–55, 56) (Figure 11-15) and 1 primary pinch point where animals were most likely to concentrate their crossings (MP 48–49 near the outlet of Kenai Lake) (Figure 11-16).

Discussion

Associations of Dall sheep with habitat variables were described in the scientific literature and reported findings were consistent across studies. In our analysis, the conditional probabilities in the BN used for developing estimates of habitat quality from the states of the habitat variables were reasonably robust. Furthermore, conditional probabilities need not be exact to be useful. For many applications, approximate probabilities, even subjective ones that are based on the best available knowledge, give very good results (Wooldridge 2003). BNs are generally quite robust to imperfect knowledge. Often the combination of several strands of imperfect knowledge can allow us to make surprisingly strong conclusions.

BNs have some key advantages over other approaches of estimating habitat quality. They provide a useful communication medium that clearly displays how habitat conditions influence wildlife populations. Recently, BNs have been used by ecologists to depict the response of wildlife species and ecosystems to differing conditions, and also as decision-aiding tools to help managers evaluate alternative natural resource management actions (e.g., Interior Columbia Basin Ecosystem Management Project, Pacific Northwest Region eastside land management plan revisions [Marcot et al. 2001, Suring et al. 2011, Gaines et al. 2017]). Descriptions and guidelines for their use and construction have been published (Marcot et al. 2006, Jensen and Nielsen 2007, Chen and Pollino 2011).

Although the use of BNs in ecological and environmental applications is growing (McCann et al. 2006), there are some limitations to their use in ecological modeling (Howes et al. 2010). Construction of conditional probability tables that specify the probability of outcomes associated with variable states and their relationships can be cumbersome and unwieldy, especially when the number of probabilities to estimate is large (Marcot et al. 2006, McCann et al. 2006). In our application, the number of probabilities within each conditional probability table was constrained to ≤3 to ensure that this did not occur. The requirement by the BN that all continuous variables be discrete may also lower the precision of predictions, and the difficulty of handling feedback loops is also a limitation in ecological studies (Nyberg et al. 2006). BNs prove to be most useful for developing a consistent and transparent interpretation of likely responses when some knowledge of the causal structure is known. However, they provide little insight regarding unknown dependencies. Another important consequence of their rigid structure

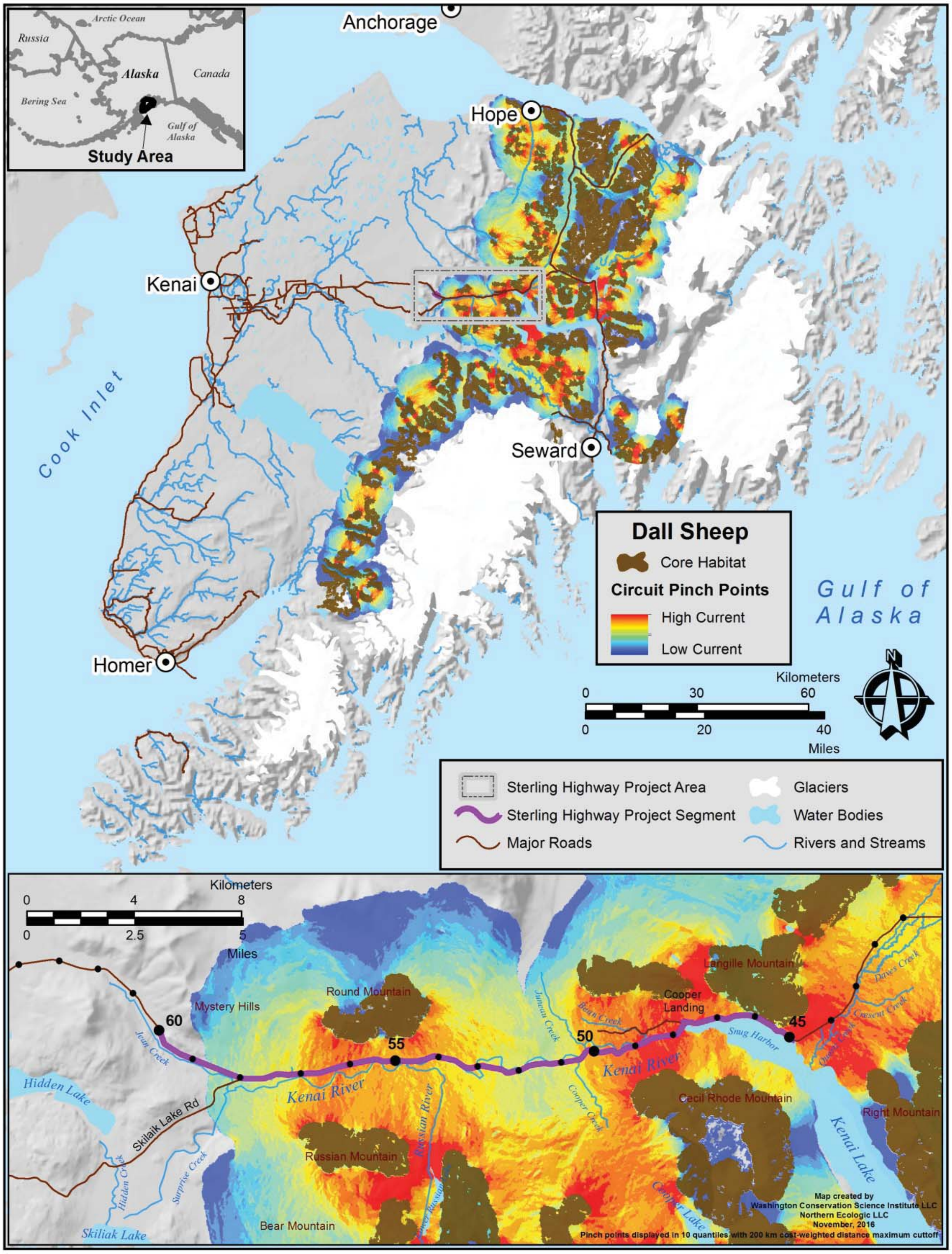

Figure 11-16. Core areas for Dall sheep and the potential primary pinch points for their movement across the Sterling Highway in the vicinity of Cooper Landing, Kenai Peninsula, Alaska, USA.

is that it is difficult to capture relationships between variables which have a temporal element (i.e. change over time).

Transportation corridors for highways have had negative effects on bighorn sheep in British Columbia, Canada and there is potential for similar effects on Dall sheep (Demarchi and Hartwig 2004). Approximately 5–10% of the bighorn sheep population near Radium Hot Springs, British Columbia dies yearly as a result of WVCs (Dibb 2006). A study of the reaction of Dall sheep to wildlife viewing from the Denali National Park road found that sheep were very responsive within 400 m of the road (alert 80%, flight 38%), when they were far from security habitat, and when they were crossing the road (Singer and Beattie 1986).

However, it should be noted that behavior of Dall sheep on the Kenai Peninsula may not be similar because Dall sheep in Denali National Park and Preserve have traditional migration routes through tundra habitat with higher densities of wolves (Miquelle et al. 1992, Rachlow and Bowyer 1998). Phillips et al. (2010) revealed that Dall sheep in Denali National Park responded negatively to increased traffic volumes by increasing their movement rates when approaching the road and shifting away from the road at higher traffic levels. Keller and Bender (2007) found that the time and number of attempts required by bighorn sheep to cross a road to a mineral site was positively related to the number of vehicles and people. Bighorn sheep, and likely Dall sheep, are a nondispersing species and generally do not explore new terrain (Geist 1971). When an area is associated with high disturbance, such as that related to a road like the Sterling Highway, Dall sheep may abandon use of the area, even if an immediate replacement for lost resources is not available (Papouchis et al. 2001).

Management Implications

The findings of Epps et al. (2005) linked a rapid reduction in genetic diversity in bighorn sheep (i.e., up to 15% in 40 years) to isolation of populations by highways and other developments that apparently eliminated gene flow. As with many large mammals, male Dall sheep are the initial dispersers (Geist 1971). However, Dall sheep exhibit a high degree of fidelity to seasonal ranges (males 88%; females 90%) (Geist 1971). Although Dall sheep on the Kenai Peninsula are not migratory, the combination of mortality from WVCs, range reduction resulting from reluctance to cross the Sterling Highway, and genetic isolation of subpopulations on the Kenai Peninsula may result in potential reductions in hunter harvest of Dall sheep and reduction in associated economic and social benefits.

Information is not available on the potential use of road crossing structures by Dall sheep. Until recently there was also limited interest in use of wildlife crossings by bighorn sheep. Limited information from the Banff National Park studies indicated that bighorn sheep used underpasses exclusively (Clevenger and Barrueto 2014). However, these investigators expected that the bighorn sheep may have only used underpasses because they were close to the bighorn sheep's escape terrain and other habitat attributes (Anthony Clevenger, personnel communication). Bighorn sheep may also have used overpasses if they were in proximity to bighorn sheep habitat. Overpasses appeared to promote desert bighorn sheep habitat connectivity in Arizona better than underpasses (Bristow and Crabb 2008, Gagnon et al. 2013). While proximity to escape terrain, sight ability, design of crossing structure, and presence of other animals may all be important factors affecting bighorn sheep use of highway crossing structures, placement of the structures relative to traditional travel corridors of bighorn sheep is likely the most important factor affecting their use (Bristow and Crabb 2008).

Clevenger and Huijser (2011) indicated that bighorn sheep tend to prefer large, open structures with good visibility. They recommended landscape bridges from 70–>100 m (230–>328 ft) wide, wildlife overpasses 40–70 m (131–230 ft) wide, and viaducts or flyovers (Clevenger and Huijser 2011). They also indicated that large underpasses may be sufficient for bighorn sheep if they are specifically adapted for their use. Although they recommend a minimum width of 12 m (39.3 ft) and minimum height of 4.5 m (14.8 ft), Clevenger and Huijser (2011) went on to say that these dimensions may not be sufficient to ensure regular use by individuals of all gender and age classes.

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Appendix – Dall Sheep

Table A11-1. Parameter values assigned in the core mapper software to identify core habitats for Dall sheep on the Kenai Peninsula, Alaska, USA.

Analysis strata	Moving window radius (m)[a]	Minimum average habitat value[b]	Minimum habitat value per pixel[c]	Expand cores by this cost weighted distance (m)	Minimum size of core areas (ha)[d]
DALL_33	5,000	50	65	10,000	400

[a] Smaller values result in larger numbers of more-detailed core areas.

[b] Average habitat value in the moving window around a pixel must be greater than this for the pixel to be considered 'core'.

[c] Pixel value must be greater than this to be 'core'.

[d] Core areas smaller than this will be eliminated at end of the run.

Table A11-2. Conditional probability table for the Veg_Index node in the Bayesian Network for Dall sheep on the Kenai Peninsula, Alaska, USA.

Variable states	
Veg_Index	Probability of outcome
C10 - water	Very_low
C12 - Ice-snow	Very_low
C20 - Developed	Very_low
C30 - Barron	Low
C41 - Deciduous forest	Low
C42 - Evergreen forest	Low
C43 - Mixed forest	Low
C50 - Shrubland	Moderate
C70 - Herbaceous upland	High
C80 - Cultivated	Low
C90 - Wetlands	Low

Table A11-3. Conditional probability table for the Environmental_Index node in the Bayesian Network for Dall sheep on the Kenai Peninsula, Alaska, USA.

Variable states			Probability of outcome			
Veg_Index	Snow	Landform	Very low	Low	Moderate	High
Very low	Low	LF1-Valley bottoms	1.0	0.0	0.0	0.0
Very low	Low	LF2-Side slopes	1.0	0.0	0.0	0.0
Very low	Low	LF3-Mountain tops	1.0	0.0	0.0	0.0
Very low	Moderate	LF1-Valley bottoms	1.0	0.0	0.0	0.0
Very low	Moderate	LF2-Side slopes	1.0	0.0	0.0	0.0
Very low	Moderate	LF3-Mountain tops	1.0	0.0	0.0	0.0
Very low	High	LF1-Valley bottoms	1.0	0.0	0.0	0.0
Very low	High	LF2-Side slopes	1.0	0.0	0.0	0.0
Very low	High	LF3-Mountain tops	1.0	0.0	0.0	0.0
Low	Low	LF1-Valley bottoms	0.0	0.7	0.2	0.1
Low	Low	LF2-Side slopes	0.0	0.6	0.3	0.1
Low	Low	LF3-Mountain tops	0.0	0.5	0.3	0.2
Low	Moderate	LF1-Valley bottoms	0.0	0.6	0.4	0.0
Low	Moderate	LF2-Side slopes	0.0	0.5	0.5	0.0
Low	Moderate	LF3-Mountain tops	0.0	0.4	0.5	0.1
Low	High	LF1-Valley bottoms	0.0	1.0	0.0	0.0
Low	High	LF2-Side slopes	0.0	1.0	0.0	0.0
Low	High	LF3-Mountain tops	0.0	1.0	0.0	0.0
Moderate	Low	LF1-Valley bottoms	0.0	0.3	0.4	0.3
Moderate	Low	LF2-Side slopes	0.0	0.2	0.4	0.4
Moderate	Low	LF3-Mountain tops	0.0	0.1	0.4	0.5
Moderate	Moderate	LF1-Valley bottoms	0.0	0.3	0.6	0.1
Moderate	Moderate	LF2-Side slopes	0.0	0.2	0.6	0.2
Moderate	Moderate	LF3-Mountain tops	0.0	0.1	0.6	0.3
Moderate	High	LF1-Valley bottoms	0.0	1.0	0.0	0.0
Moderate	High	LF2-Side slopes	0.0	1.0	0.0	0.0
Moderate	High	LF3-Mountain tops	0.0	1.0	0.0	0.0
High	Low	LF1-Valley bottoms	0.0	0.0	0.3	0.7
High	Low	LF2-Side slopes	0.0	0.0	0.1	0.9
High	Low	LF3-Mountain tops	0.0	0.0	0.0	1.0
High	Moderate	LF1-Valley bottoms	0.0	0.7	0.3	0.0
High	Moderate	LF2-Side slopes	0.0	0.6	0.4	0.0
High	Moderate	LF3-Mountain tops	0.0	0.5	0.5	0.0
High	High	LF1-Valley bottoms	0.0	1.0	0.0	0.0
High	High	LF2-Side slopes	0.0	1.0	0.0	0.0
High	High	LF3-Mountain tops	0.0	1.0	0.0	0.0

Table A11-4. Conditional probability table for the Topographic_Index node in the Bayesian Network for Dall sheep on the Kenai Peninsula, Alaska, USA.

Variable states			Probability of outcome		
Elevation	Terrain	Aspect	Low	Moderate	High
Low	Low	North	1.0	0.0	0.0
Low	Low	East	0.9	0.1	0.0
Low	Low	West	0.8	0.2	0.0
Low	Low	South	0.7	0.3	0.0
Low	Moderate	North	0.9	0.1	0.0
Low	Moderate	East	0.8	0.2	0.0
Low	Moderate	West	0.7	0.3	0.0
Low	Moderate	South	0.6	0.4	0.0
Low	High	North	0.8	0.2	0.0
Low	High	East	0.7	0.3	0.0
Low	High	West	0.6	0.4	0.0
Low	High	South	0.5	0.5	0.0
Moderate	Low	North	0.7	0.3	0.0
Moderate	Low	East	0.6	0.4	0.0
Moderate	Low	West	0.5	0.5	0.0
Moderate	Low	South	0.4	0.6	0.0
Moderate	Moderate	North	0.6	0.4	0.0
Moderate	Moderate	East	0.5	0.5	0.0
Moderate	Moderate	West	0.4	0.6	0.0
Moderate	Moderate	South	0.3	0.7	0.0
Moderate	High	North	0.5	0.5	0.0
Moderate	High	East	0.4	0.6	0.0
Moderate	High	West	0.3	0.5	0.2
Moderate	High	South	0.2	0.4	0.4
High	Low	North	0.4	0.6	0.0
High	Low	East	0.3	0.7	0.0
High	Low	West	0.2	0.8	0.0
High	Low	South	0.1	0.8	0.1
High	Moderate	North	0.3	0.6	0.1
High	Moderate	East	0.2	0.6	0.2
High	Moderate	West	0.1	0.5	0.4
High	Moderate	South	0.0	0.4	0.6
High	High	North	0.1	0.7	0.2
High	High	East	0.0	0.4	0.6
High	High	West	0.1	0.1	0.8
High	High	South	0.0	0.0	1.0

Table A11-5. Conditional probability table for the Predation_Index node in the Bayesian Network for Dall sheep on the Kenai Peninsula, Alaska, USA.

Variable states		Probability of outcome		
Escape terrain	Patch size	Low	Moderate	High
Very Low	None	1.0	0.0	0.0
Very Low	Low	0.9	0.1	0.0
Very Low	Moderate	0.8	0.2	0.0
Very Low	High	0.7	0.3	0.0
Low	None	1.0	0.0	0.0
Low	Low	0.8	0.2	0.0
Low	Moderate	0.7	0.3	0.0
Low	High	0.6	0.4	0.0
Moderate	None	1.0	0.0	0.0
Moderate	Low	0.2	0.8	0.0
Moderate	Moderate	0.0	1.0	0.0
Moderate	High	0.0	0.8	0.2
High	None	1.0	0.0	0.0
High	Low	0.0	0.3	0.7
High	Moderate	0.0	0.2	0.8
High	High	0.0	0.0	1.0

Table A11-6. Conditional probability table for the Habitat_Quality_Index node in the Bayesian Network for Dall sheep on the Kenai Peninsula, Alaska, USA.

Variable states			Probability of outcome		
Forage_Index	Topographic_Index	Predation_Index	Low	Moderate	High
Very low	Low	Low	1.0	0.0	0.0
Very low	Low	Moderate	1.0	0.0	0.0
Very low	Low	High	1.0	0.0	0.0
Very low	Moderate	Low	1.0	0.0	0.0
Very low	Moderate	Moderate	1.0	0.0	0.0
Very low	Moderate	High	1.0	0.0	0.0
Very low	High	Low	1.0	0.0	0.0
Very low	High	Moderate	1.0	0.0	0.0
Very low	High	High	1.0	0.0	0.0
Low	Low	Low	1.0	0.0	0.0
Low	Low	Moderate	0.9	0.1	0.0
Low	Low	High	0.8	0.2	0.1
Low	Moderate	Low	0.7	0.3	0.0
Low	Moderate	Moderate	0.6	0.4	0.0
Low	Moderate	High	0.5	0.4	0.1
Low	High	Low	0.8	0.2	0.1
Low	High	Moderate	0.5	0.4	0.1
Low	High	High	0.4	0.4	0.2
Moderate	Low	Low	0.7	0.3	0.0
Moderate	Low	Moderate	0.3	0.7	0.0
Moderate	Low	High	0.2	0.4	0.4
Moderate	Moderate	Low	0.3	0.7	0.0
Moderate	Moderate	Moderate	0.0	1.0	0.0
Moderate	Moderate	High	0.0	0.7	0.3
Moderate	High	Low	0.4	0.4	0.2
Moderate	High	Moderate	0.0	0.8	0.2
Moderate	High	High	0.0	0.3	0.7
High	Low	Low	0.6	0.3	0.1
High	Low	Moderate	0.3	0.4	0.3
High	Low	High	0.1	0.2	0.7
High	Moderate	Low	0.4	0.4	0.2
High	Moderate	Moderate	0.0	0.6	0.4
High	Moderate	High	0.0	0.2	0.8
High	High	Low	0.4	0.4	0.2
High	High	Moderate	0.0	0.4	0.6
High	High	High	0.0	0.0	1.0

Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 12 – Evaluation of Potential Movement Corridors for Focal Species on the Kenai Peninsula, Alaska, USA

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Introduction

Wildlife practitioners invest a substantial amount of resources toward the collection of monitoring data to estimate relationships between population parameters, animal behavior, and the environment in support of science-based decision making. We implemented a field-based monitoring program to evaluate the potential movement corridors we identified in our connectivity assessment of focal wildlife species. The analysis of Ford et al. (2009) indicated that camera-based monitoring for crossing structures was more cost-effective in the long-term and more efficiently detected crossing events for most large mammal species than other monitoring methods. Not surprisingly, remotely triggered cameras (hereafter, camera traps) have become an indispensable tool in a wildlife practitioner's ever-growing toolbox (e.g., Steenweg et al. 2017). Camera traps enable wildlife practitioners to monitor species across large spatial scales using a non-invasive, safe, and comparatively inexpensive approach. LaPoint et al. (2013) recommended use of unbaited camera traps to provide a test for within home-range movement corridors for resident mammals. They found through use of camera traps that least-cost path analysis predicted movement of animals. Following that approach, we assumed that if a model predicted movements well, most camera-based observations would lie in map cells with high predicted connectivity values.

Camera traps are automated cameras, triggered by movements, used to collect photographic or video evidence of the presence of animals in field research. They have become a valuable methodological tool that enables evaluations of the ecological relationships of species (Anile and Devillard 2016, Burton et al. 2015, O'Connell et al. 2010). It is a quantitative technique that has relatively low labor costs, is non-invasive, incurs minimal environmental disturbance (Silveira et al. 2003, Rowcliffe et al. 2008), is robust to variation in ground conditions and climate and, can be used to gain information on species that are difficult to observe by other methods under conditions where other field methods are more difficult to implement (Silveira et al. 2003, Rowcliffe et al. 2008). Furthermore, camera traps are equally efficient at collecting data by day and night.

A review of Meek et al. (2014), O'Connell et al (2010), and >80 journal papers published from 2001 through 2016 revealed that camera traps are most often used to estimate animal abundance, density, distribution, behavior, and associated biological diversity. However, 25 papers reported on using data from camera traps to describe habitat-use patterns. The techniques used in those papers have potential for application in our analysis of use of movement paths modeled for the 6 focal species. In most studies utilizing camera traps, investigators quantified the presence and absence of target species (McCallum 2012). Camera traps can therefore be used effectively to make comparisons between sites, thereby aiding conservation planning (Tobler et al. 2008), including evaluation of movement corridors for focal species on the Kenai Peninsula.

The objective of this work was to determine if focal species were more likely to occur within higher quality rankings of modeled movement corridors throughout the Sterling Highway project area. This analysis allowed us to evaluate how modeled corridors were selected by focal species as movement/use areas and if associated locations of mitigation measures are appropriate.

Methods

Camera Trapping

We considered a number of factors in the selection of the appropriate camera to achieve our study objective (Rovero et al. 2013). Those factors included trigger speed, recovery speed, flash type, detection zone, number of photos taken, sensitivity, flash intensity, power autonomy, image resolution, camera housing and sealing, and camera programming and setting (Rovero et al. 2013). We selected RECONYX PC900 HyperFire Professional High Output Covert IR cameras based on the recommendation of Kelly and Holub (2008).

Camera sampling locations were identified based on the following criteria: 1) within 1,500 m from the existing highway, 2) 20 stations located on both sides of the highway (north and south), 3) as equally distributed as possible within the corridor rankings for the focal species of interest (very high, high, moderate, low, outside corridor), 4) accessible areas on public (i.e., State, Federal, Borough) lands; private lands were avoided. Locations for cameras were separated by at least 500 m to decrease the potential for obtaining photographs of the same animal at multiple sample points while optimizing the chances of capturing photos of the target species (Long and Zielinski 2008, Symmank et al. 2014, TEAM Network 2011). Based on these criteria, 40 potential camera sites were identified within the project area (Figure 12-1).

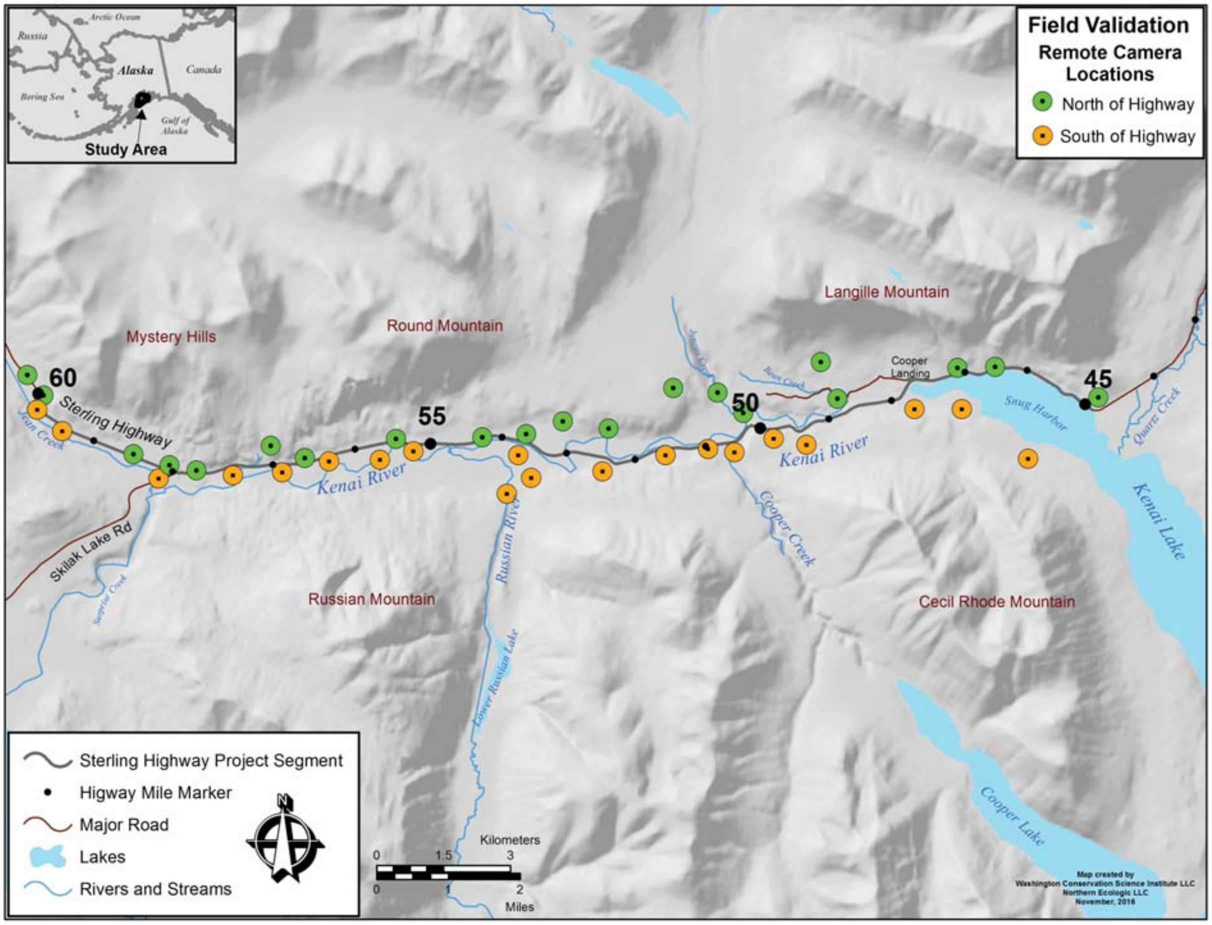

Figure 12-1. Location of camera trap locations within the Sterling Highway project area, Kenai Peninsula, Alaska, USA.

Factors that influenced the final selection of sample points included safety and access. Once a site was determined to be feasible, field personnel examined the area within 100 m of the identified point to determine the optimal location of the camera. The most ideal locations included wildlife trails, obvious movement corridors, and abundant wildlife sign. Other factors that were considered included terrain, density of the vegetation, and micro-habitats (Kays and Slauson 2008). Due to the density of the vegetation in many parts of the project area, the orientation of the camera was selected to maximize the field of view (Kays and Slauson 2008). Once a camera was installed, a photo of the site was taken and the camera checked for proper function. In addition, coordinates were taken at the site with a GPS and recorded.

We positioned cameras from 0.5 m to 2.0 m off the ground, mounted on a tree, and in a direction that maximized the field of view. Camera height was adjusted throughout the study period, as needed, depending on snow depth and other site features. At each camera station, small signs were installed on trees to alert people to the presence of the camera station and its purpose. Motion within an infrared beam triggered the cameras to take 5 photographs at roughly

0.2-second intervals. Cameras were equipped with a No-Glow High Output Covert infrared flash array that allowed continuous operation day and night. Each camera was programed to label images with the assigned station ID (e.g., STHI North 17) and to display the date and time. Cameras were operated from mid-October 2015 through early-November 2016.

We downloaded photographs from each camera onto a handheld computer once a week during the initial 4 weeks of the study. This was to ensure that cameras were functioning properly and to minimize data loss. At the end of this 4-week session, the efficacy of the cameras was evaluated and the camera check interval was reduced to every 2 weeks for the remainder of the 12-month study period unless an intense weather event necessitated a field check to verify that cameras were operating properly. We classified photographs to record the number of individuals by date, species, and direction of travel for each camera and loaded the information into a MS Access database.

Data Analysis

Numerous journal papers published from 2001 through 2016 reported on the use of a simple Relative Abundance Index (RAI) based on camera-trap encounter rates (e.g., Switalski and Nelson 2011, Rovero et al. 2014, Cusack et al. 2015). The use of RAI for ecological studies has been debated, particularly when comparing between species, because a large number of variables (e.g. body size, average group-size, behavior) are likely to affect trapping rates and detection probability and thus confound the relationship with actual abundance (Carbone et al. 2001, Jennelle et al. 2002, Treves et al. 2010). However, there is evidence for a linear relationship between RAI and abundance estimated through more rigorous methodologies (Rovero and Marshall 2009). Therefore, considering these aspects, comparison of RAI of single species among fixed camera trap locations within our study area was considered appropriate.

We defined RAI as the number of independent photographs of each focal species per 100 camera-trap days (O'Brien et al. 2003) and calculated RAI from the encounter rate of each focal species with each camera. Successive photographs of the same species were defined as independent groups when separated by > 20 minutes (Gray and Phan 2011).

Pearson's correlations were calculated between the RAI for each individual species and least-cost corridor (LCC) travel values for the same species at each camera site. The primary variable evaluated was the general LCC model (Chapter 13; Suring et al. 2017a). The magnitude of the Pearson correlation coefficient determined the strength of the correlation. Although there are not hard-and-fast rules for assigning strength of association to particular values, some general guidelines were provided by Cohen (1988) (Table 12-1). A moderate to strong correlation for a focal species would indicate that the movement paths we modelled were used more often than areas outside of the movement paths. Data were $\log_{10}$-transformed, when appropriate, to approximate a normal distribution of the residuals and equal variances. Statistical significance of correlation values were calculated at $\alpha = 0.05$.

Table 12-1. General guidelines for assigning strength of association between variables in an analysis of correlation after Cohen (1988).

Value of correlation coefficient	Strength of association between variables
$0.1 < \| r \| < 0.3$	Small/minor correlation
$0.3 < \| r \| < 0.5$	Medium/moderate correlation
$\| r \| > 0.5$	Large/strong correlation

Results

Camera-trap days for the 40 cameras ranged from 278 to 394. Seven cameras were not in operation from 9 to 51 days ($\overline{x}$ = 21.6). Reasons for missing data included memory card filled, memory card missing, and fallen camera-site tree. We recorded 433 independent observations of brown bears (*Ursus arctos)* with a range of observations per camera of 0 – 91 ($\overline{x}$ = 10.8). RAI per 100 camera-trap days for brown bears ranged from 0.00 – 23.16 ($\overline{x}$ = 2.8). We recorded 166 independent observations of black bears (*Ursus americanus perniger*) with a range of observations per camera of 0 – 27 ($\overline{x}$ = 4.2). RAI per 100 camera-trap days for black bears ranged from 0.00 – 6.94 ($\overline{x}$ = 1.1). We recorded 36 independent observations of Canada lynx (*Lynx canadensis)* with a range of observations per camera of 0 – 7 ($\overline{x}$ = 0.9). RAI per 100 camera-trap days for Canada lynx ranged from 0.00 – 1.89 ($\overline{x}$ = 0.2). We recorded 432 independent observations of moose (*Alces americanus*) with a range of observations per camera of 0 – 52 ($\overline{x}$ = 21.1). RAI per 100 camera-trap days for moose ranged from 0.00 – 13.30 ($\overline{x}$ = 2.8). Camera traps did not record observations of wolverines (*Gulo gulo katschemakensis*) or Dall sheep (*Ovis dalli kenaiensis*).

Evaluation of the relationship between number of animals expressed as RAI per 100 camera-trap days with LCC values revealed moderate negative relationships (i.e., as LCC values increased number of animals observed decreased) for brown bear and black bear (Table 12-2). The relationship for Canada lynx was a minor negative relationship that was not statistically significant. The relationship for moose was minor and positive but statistically non-significant for the general model. As a result, seasonal models were examined. All 4 seasonal models showed a minor relationship and were statistically non-significant. All models except the autumn seasonal model showed negative relationships.

Table 12-2. Association between number of animals detected at camera-trap sites and the value of the least-cost corridor at the camera-trap site.

Species Model	Pearson product-moment correlation coefficient r(df)	Effect size
Brown bear		
General	r (38) = -0.4485, p = 0.0037	Moderate[a]
Black bear		
General	r (38) = -0.3123, p = 0.0498	Moderate[a]
Canada lynx		
General	r (38) = -0.2215, p = 0.1706	Small[b]
Moose		
Female, spring	r (38) = -0.2433, p = 0.1303	Small[b]
Female, summer	r (38) = -0.1143, p = 0.4837	Small[b]
Female, autumn	r (38) = +0.1810, p = 0.2637	Small[b]
Female, winter	r (38) = -0.0533, p = 0.7439	Small[b]
General	r (38) = +0.1809, p = 0.2640	Small[b]

[a] statistically significant
[b] not statistically significant

Discussion

We used independent camera trap data for our focal species to validate our modeled movement corridors. We expected that focal species would be found more often in areas with high connectivity (i.e., low LCC values) (Rosenberg et al. 1997), and that is what we generally observed.

Pullinger and Johnson (2010) highlighted the importance of model evaluation when planning for habitat connectivity. It is important to determine if such models will help to improve placement of linkages and other mitigation practices through incorporation of habitat effects on movement, or if they may result in misleading and potentially costly recommendations for conservation of the species of interest (Driezen et al. 2007, Sawyer et al. 2011).

Brown bears and back bears had a moderate association with modeled movement paths. Movement paths associated with brown bears (Chapter 3; Suring et al. 2017b) were also consistent with linkage zones previously identified by Graves et al. (2007) in their work with movement of brown bears with GPS collars. Although the relationship of observations of

Canada lynx with modeled movement paths was minor, the nature of the relationship was consistent with selection of movement paths. The weakness of the relationship may have been related to the relatively small number of lynx observed (i.e., 36). Camera trapping of wolverines has been successful when camera sites have been baited (Stewart et al. 2016). The small populations of wolverines on the Kenai Peninsula coupled with the lack of bait at our camera-trap sites or location of our camera sites may have contributed to the lack of captures. Although Dall sheep on the Kenai Peninsula move between summer and winter ranges on an annual basis, very little is known about their movement patterns. The lack of observations of Dall sheep may indicate that there is very little movement across the current alignment of the Sterling Highway within the project area.

The association of observations of moose with modeled movement paths was generally minor and inconsistent. The associations in the spring, summer, and winter models were consistent with selection of movement paths. Movement patterns described in this analysis (Chapter 5; Gaines et al. 2017a) coincide with movement patterns described by Ernst et al. (2009). However, the autumn model and the general model were not consistent with selection of movement paths. The evaluation of movement corridors in the autumn may have been affected by changes in movement patterns of moose relative to the modeled movement corridors. Habitat quality for moose during autumn was better throughout the study area than during other seasons (Chapter 4; Gaines et al. 2017b). This may have resulted in moose not having a stronger association with the modeled movement corridors. Also, movement by bulls during the rut in the autumn increases dramatically, whereas those of cows decrease (Houston 1968, Phillips et al. 1973, Garner and Porter 1990). Yearlings and 2-year old moose exhibit increased movements in the autumn during dispersal and establishment of home ranges (Hundertmark 1997). Additionally, the autumn hunting season may have affected movement patterns of moose in relation to estimated movement paths.

Management Implications

Estimating movement corridors for focal species is just 1 step in a much larger process of planning and implementing connectivity and ultimately, conservation of populations of focal species (McClure et al. 2016). Connectivity models alone do not provide complete solutions to how best to conserve and manage populations of the species of interest. They are only tools capable of providing useful information to a planning process that includes many other aspects (e.g., land ownership, budget considerations, sociopolitical context). The accuracy of corridor model estimates that have been independently evaluated, as we have done here, is 1 of the major factors that will affect the success of conservation efforts.

Emphasis is often placed on identifying the most cost effective action that maximizes benefits (Naidoo et al. 2006, Carwardine et al. 2012, Auerbach et al. 2014). Understanding species movements enables planners and land managers to improve their understanding of potential issues, to use temporal and spatial knowledge of movements to identify alternative management scenarios, and also to recognize the challenges of achieving management objectives which may not be apparent if a species' movements are unknown (Allen and Singh 2016). Understanding movement also enables managers to identify concerns, such as barriers to movement (Seidler et al. 2015). This understanding then allows managers to prioritize the most effective management actions that have the highest chance of success (Game et al. 2013, Auerbach et al. 2014, Allen and Singh 2016).

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Habitat use and movement patterns of focal species on the Kenai Peninsula, Alaska, USA

Chapter 13 – Movement Corridor Hot Spots and Potential Mitigation of the Effects of the Sterling Highway Milepost 45–60 Project on Focal Species on the Kenai Peninsula, Alaska, USA

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Introduction

Linear transportation infrastructures, such as the Sterling Highway, intersect wildlife populations, causing wildlife-vehicle collisions (WVCs) and potentially disrupting movement patterns leading to short- and long-term population decline. Highways may affect all animals independently of their type of habitat or taxonomic group. However, studies have shown that certain groups, such as large mammals, are more readily affected (Rytwinski and Fahrig 2011, 2012). Mobility and minimum area of habitat also influence species sensitivity to roads, with the more mobile species and the ones needing larger habitat areas being affected more (Rytwinski and Fahrig 2011, 2012). To define and address such effects, mitigation efforts that are suitable for a wide range of species are needed.

We identified the most likely locations for wildlife crossings for 6 focal species along the Sterling Highway in an effort to conserve populations of species most susceptible to WVCs and disruption of movement patterns. Wildlife crossings and associated structures (e.g., fencing) are often built to mitigate the barrier effect of roads. There is compelling evidence that many wildlife species regularly and frequently use crossing structures (reviewed in van der Ree et al. 2007). Well-designed and maintained sections of fencing at least 5 km long in association with these structures greatly reduce rates of wildlife mortality and funnels animals towards the crossing structures (reviewed in Glista et al., 2009, Huijser et al.2016, Rytwinski et al. 2016).

Consequently, these practices have greatly expanded in the last 30 years (van der Ree et al. 2015). To be effective, crossings should be built as close as possible to natural corridors (i.e., integrated in the connectivity network species of interest). They need to have favorable landscape configuration and composition, and they must be short but with low gradients that provide good connections to the natural habitat (Clevenger and Huijser 2011, van der Ree et al. 2015). However, designing multiple corridors and crossing structures for single species based on ecological criteria can lead to extremely expensive costs for mitigation and is not recommended, except in special circumstances (Dilkina et al. 2017; Anthony Clevenger, personal communication).

Various species do not use or navigate through an area in identical ways. Multispecies connectivity planning strategies therefore are likely to present trade-offs relative to single species strategies. One advantage of multispecies strategies is that, in general, they should be more efficient than single species strategies at protecting biodiversity and entire communities (Early and Thomas 2007, Carroll et al. 2010, Schwenk and Donovan 2011). A possible disadvantage of a multispecies strategy is that it could be less effective for a particular species than a strategy designed specifically for that species. In general, the multispecies connectivity scenarios increased total cost of corridors for particular species relative to the connectivity scenarios derived for each species alone (Brodie et al. 2015). However, Dilkina et al. (2017) were able to incorporate budget constraints while optimizing corridors for multiple species that were close to the individual species movement-potential optima, but with substantial cost savings.

Our objectives in this Chapter were to identify hot spots for movement corridors in the project area from the results of individual analyses of the 6 focal species where mitigation practices may be focused and to review potential mitigation practices that may be effective for each of the 6 focal species. Our approach here was essentially based on overlapping corridors for focal species with the current alignment of the Sterling Highway. This approach identified locations for safe crossing opportunities for the 6 focal species and associated fences. The fences will keep animals from accessing the highway and getting hit, and they also help funnel wildlife to the safe crossing opportunities. The safe crossing opportunities allow for connectivity between the 2 sides of the highway, and they may also reduce intrusions in the fenced road corridor because it should be easier to cross the highway through a structure than it is to climb a fence or walk all the way to the end of a fence (Marcel Huijser, personnel communication).

Summary of Results by Focal Species

Brown Bear

Suring et al. (Chapter 3; 2017a) used resource selectin functions (RSFs) previously developed for brown bears on the Kenai Peninsula (Suring et al. 2006) in combination with least-cost corridor (LCC) and circuit theory analyses to estimate movement paths for brown bears. That analysis identified potential primary crossing points for female brown bears in the spring with cubs and without cubs and in the summer with cubs and without cubs were located at milepost (MP) 44 near Quartz Creek and between MPs 49 and 51 near Cooper Creek on the south and Juneau Creek on the north sides of the highway (Figure 13-1).

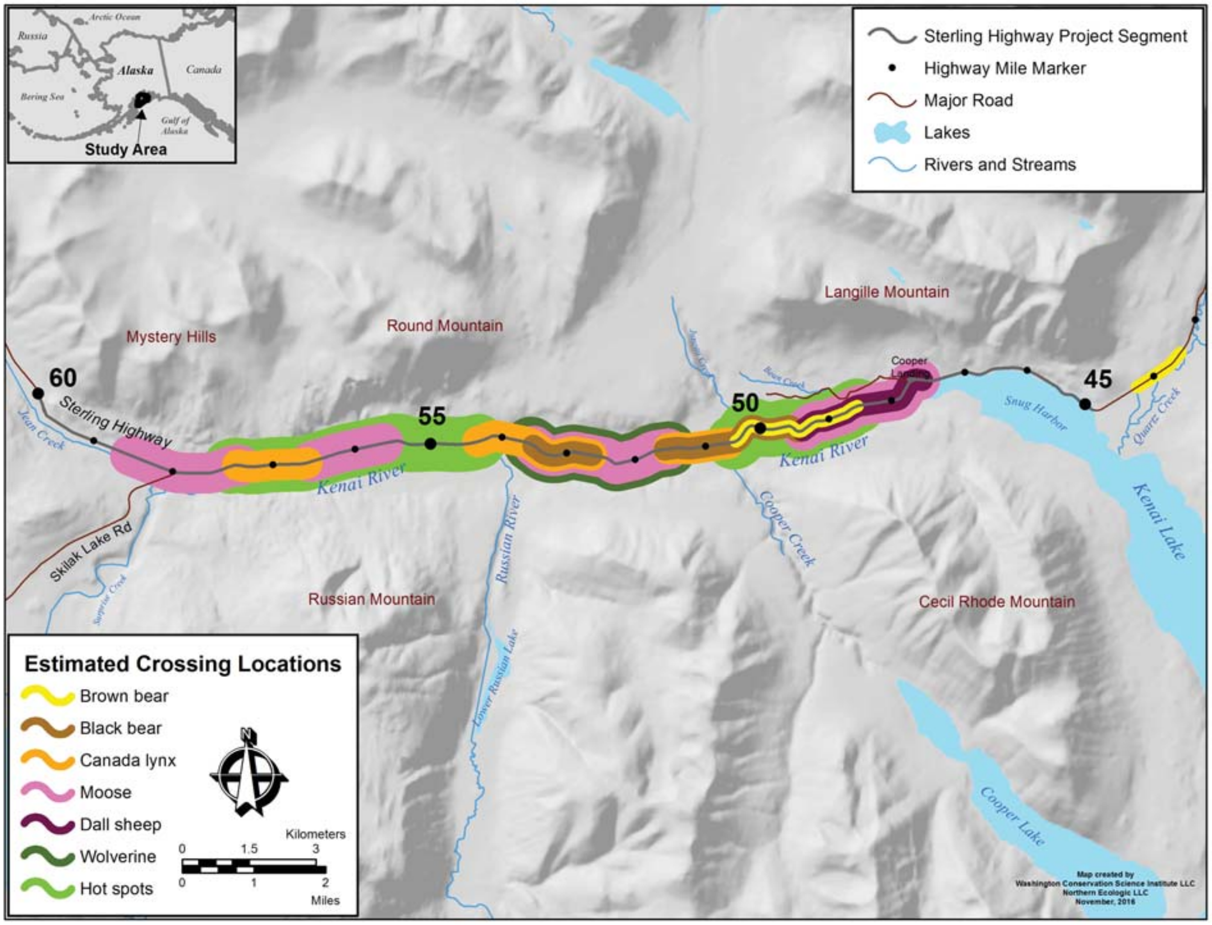


Figure 13-1. Primary estimated crossing locations of the Sterling Highway within the project area for individual focal species and for multispecies hot spots by milepost on the Kenai Peninsula, Alaska, USA.

Black Bear

Suring et al. (Chapter 6; 2017b) developed RSFs for black bears on the Kenai Peninsula and then used those RSFs in combination with LCC and circuit theory analyses to estimate movement paths for black bears (Chapter 7; Suring et al. 2017c). Based on those analyses, potential north-south movements of black bears across the Sterling Highway in the vicinity of Cooper Landing revealed 2 primary pinch points where animals were most likely to concentrate their crossings (MP 50–51 in the vicinity of Juneau and Cooper creeks and MP 53 where the Sterling Highway currently crosses the Kenai River) (Figure 13-1).

Wolverine

Suring et al. (Chapter 10; 2017d) developed a Bayesian Network for wolverines on the Kenai Peninsula and then used that Network in combination with LCC and circuit theory analyses to estimate movement paths for wolverines. Based on that analysis, potential north-south movements of wolverines across the Sterling Highway in the vicinity of Cooper Landing revealed 1 primary pinch point where animals were most likely to concentrate their crossings (MP 52–53) (Figure 13-1).

Canada Lynx

Gaines et al. (Chapter 8; 2017a) developed RSFs for Canada lynx on the Kenai Peninsula and then used those RSFs in combination with LCC and circuit theory analyses to estimate movement paths for Canada lynx (Chapter 9; Gaines et al. 2017b). Based on those analyses, they identified 3 primary north-south habitat linkages across the Sterling Highway between MP 45–60. The first linkage was near MP 51, west of where Cooper Creek and Juneau Creek join the Kenai River. The second linkage occurred near the confluence of the Russian and Kenai rivers near MP 53-54. The third linkage extended east-west across the Sterling highway near MP 57 (Figure 13-1).

Moose

Gaines et al. (Chapter 4; 2017c) developed RSFs for moose on the Kenai Peninsula and then used those RSFs in combination with LCC and circuit theory analyses to estimate movement paths for moose (Chapter 5; Gaines et al. 2017d). Based on those analyses, they identified 4 primary north-south habitat linkages within the project area for female moose. There was a linkage near MP 48-49 west of Kenai Lake near Cooper Landing and another near MP 52-53. West of the confluence with the Russian River and east of the intersection with the Skilak Lake Road there was a third (MP 56) and a fourth linkage (MP 58) (Figure 13-1).

Dall Sheep

Suring et al. (Chapter 11; 2017e) developed a Bayesian Network for Dall sheep on the Kenai Peninsula and then used that Network in combination with LCC and circuit theory analyses to estimate movement paths for Dall sheep. Based on that analysis, potential north-south movements of Dall sheep across the Sterling Highway in the vicinity of Cooper Landing revealed 1 primary pinch point where animals were most likely to concentrate their crossings (MP 48–49 near the outlet of Kenai Lake) (Figure 13-1).

Methods

In an effort to identify hot spots for movement corridors in the project area we first combined individual species models to create general models for brown bear, Canada lynx, and moose. We then overlayed the results of those models with the results from models for black bear, wolverine, and Dall sheep, as follows.

General Brown Bear LCC

Habitat and LCC's for female brown bear were modeled using 4 separate seasonal models: (1) spring with cubs (SPWC), (2) spring no cubs (SPNC), (3) summer with cubs (SUWC), and (4) summer no cubs (SUNC). The development of a general brown bear LCC model (BRBE_LCC) was performed by averaging the summation of each seasonal LCC model (Equation 1).

Equation 1: (SPWC_LCC + SPNC_LCC + SUWC_LCC + SUNC_LCC) / 4 = BRBE_LCC

General Canada Lynx LCC

Habitat and LCC's for Canada lynx were modeled using 2 separate seasonal models for both females and males: (1) female, snow free season (FSF), (2) female, snow season (FS), (3) male, snow free season (MSF), and (4) male, snow season (MS). The development of a general Canada lynx LCC model (LYNC_LCC) was performed by averaging the summation of each seasonal LCC model (Equation 2).

Equation 2: (FSF_LCC + FS_LCC + MSF_LCC + MS_LCC) / 4 = LYNX_LCC

General Moose LCC

Habitat and LCC's for female moose were modeled using 4 separate seasonal models: (1) autumn (AU), (2) winter (WI), (3) spring (SP), and (4) summer (SU). The development of a general moose LCC model (MOOSE_LCC) was performed by averaging the summation of each seasonal LCC model (Equation 3).

Equation 3 (AU_LCC + WI_LCC + SP_LCC + SU_LCC) / 4 = MOOSE_LCC

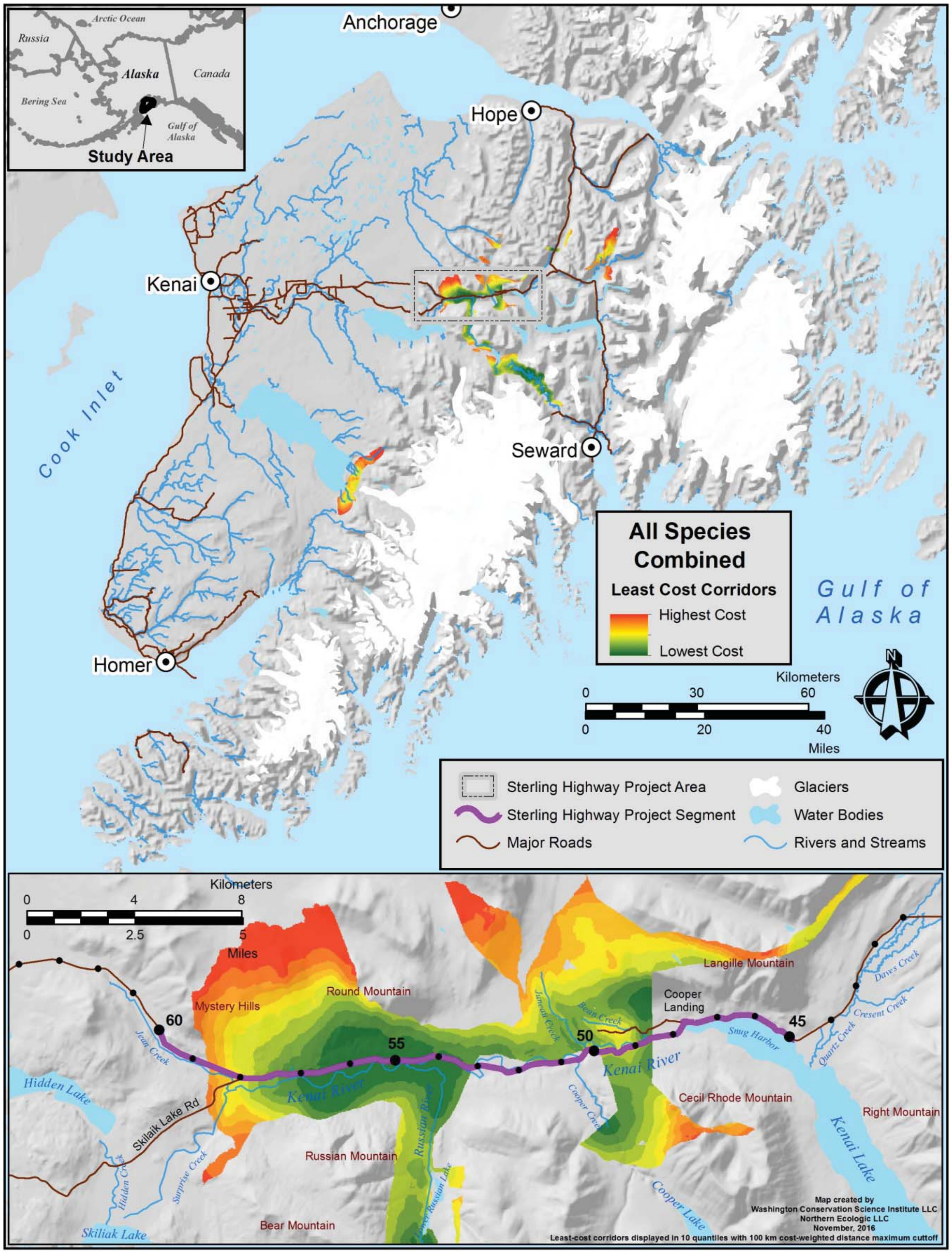
LCC Hot Spots

The development of a LCC model representing hot spots for all 6 focal species (ALL_SPECIES_LCC) was accomplished by averaging the summation of each individual species LCC model (Equation 4). For the species which had several LCC models by season or sex (i.e., brown bear, Canada lynx, and moose), a similar model averaging process was performed to generate a single "general" LCC model representing that species prior to combining with the other species.

Equation 4: (BRBE_LCC + LYNX_LCC + MOOSE_LCC + BLBE_LCC + WOLVERINE_LCC + DALL_LCC) / 6 = ALL_SPECIES_LCC

Results

The hot spot analysis showed a primary corridor running south to north along the Russian River to its confluence with the Kenai River near MP 54 (Figure 13-2). At that point the corridor turned west along the Kenai River to MP 58. Two other corridors crossed the Kenai River at the confluence of Juneau Creek (MP 50) and at the confluence of Bean Creek (MP 49).



Map created by
Washington Conservation Science Institute LLC
Northern Ecologic LLC
November, 2016

Least-cost corridors displayed in 10 quantiles with 100 km cost-weighted distance maximum cuttoff

Figure 13-2. Movement corridor hot spots for 6 focal species on the Kenai Peninsula, Alaska, USA.

Discussion

Movement paths estimated for individual focal species and the hot spot analysis indicated that the section of the existing Sterling Highway between MP 48–54 contained crossing sites for all focal species (Figure 13-1, 13-2). Other crossing sites for brown bear, moose, and Canada lynx occurred outside of this section (i.e., MP 44 for brown bear, MP 56 and 58 for moose, MP 57 for Canada lynx). However, Dilkina et al. (2017) showed that designing corridors and associated mitigation measures for single species on a landscape scale based on purely ecological criteria led to extremely expensive linkages that are often suboptimal for multispecies connectivity objectives. They also reported that acquiring the least-expensive linkages leads to ecologically poor solutions. Concentrating mitigation measures within the MP 48–54 area potentially provides an opportunity to optimize mitigation practices associated with the existing highway for all focal species while containing the potential costs of crossing structures. This section of highway coincided with, or was in proximity to, the confluences of Bean Creek, Juneau Creek, Cooper Creek, and Russian River with the Kenai River.

Wildlife crossing structures combined with fencing has long been considered the most effective means of mitigating road impacts on wildlife populations (Dodd et al. 2007, Huijser et al. 2007, McCollister and van Mannen 2010, Huijser et al. 2016). Sites where riparian areas approach or cross highways may be preferred sites for mitigation structures for many species (Dickson et al. 2005, Litvaitis and Tash 2008). The use of crossing structures by wildlife also appears to be affected by several factors such as locations in relation to estimated movement paths, size, design, visual appearance, proximity of human use, and vegetation in proximity to the entrances (Clevenger and Waltho 2000, Ng et al. 2008). Habitat quality in proximity to location and placement of crossing structures has been reported as an important factor affecting their use by wildlife (Ng et al. 2004, Grilo et al. 2008, Gagnon et al. 2011). Others have reported that the dimensions of the structure or type of structure provide the best explanation for willingness to use crossings (Cain et al. 2003, Clevenger and Waltho 2005, Gagnon et al. 2011).

Larger mitigation structures are generally more costly to build (Huijser et al. 2009) compared to the smaller structures. However, Clevenger and Barrueto (2014) reported that large mammal species preferred overpasses or large underpasses to smaller crossing structures. Also, previous multivariate analyses showed a preference of overpasses for brown bears (Clevenger and Waltho 2000, 2005). In pairwise comparisons of underpasses and overpasses <200 m (656 ft) apart Clevenger et al. (2009) found that brown bears, wolves (*Canis lupus*), moose, and other ungulates preferred overpass structures when there was an underpass nearby (<300 m distance [984 ft]). While brown bears in Clevenger and Barrueto's (2014) study area, especially males, appeared to have adapted to and eventually used all types of crossing structures, the smallest crossing structures remained virtually underutilized 17 years after construction. Sawaya et al. (2014) reported that female brown bears had a strong preference for overpasses and large underpasses. Structures similar to 4 by 7 m (13.1 by 16.7 ft) corrugated steel culverts and smaller were underutilized and appeared to be of little conservation value to brown bears (Clevenger and Barrueto 2014).

Conversely, while black bears did not prefer underpasses to overpasses, they did prefer narrow underpasses to more open underpasses. Clevenger and Barrueto (2014) speculated that the longer, more constricted crossing structures black bears tend to use most for safe passage might be explained by this species' requirements for cover and avoidance of exposed, sparsely wooded habitats (Kansas and Raine 1990, Lyons et al. 2003). Also, brown bears showed far more willingness to cross roads and far less tolerance to humans than black bears (Sawaya et al. 2014).

Baigas et al. (2017) documented Canada lynx crossing roads at sites with small distances to vegetative cover and higher tree basal area at a fine scale; at the landscape scale, lynx crossed highways in areas with high forest canopy cover in drainages on primarily north-facing aspects. Huijser and Paul (2008) noted in their literature review that lynx and wolverine have been observed using underpasses and lynx have been observed using an overpass in Banff National Park; however, the number of observations was considered too low to conclude that these species will readily use crossing structures. While there are uncertainties about the appropriate type and dimensions of crossing structures for lynx, wildlife overpasses or overspan bridges are likely safer choices than large mammal underpasses (Clevenger et al. 2012, Huijser and Begley 2012). Clevenger et al. (2011) and Clevenger (2013) also reported consistent use of underpasses and single use of overpasses by wolverines. Highway crossing structures have been identified as 1 of 3 recommended conservation strategies for the future conservation of the wolverine metapopulation in the northern U.S. Rocky Mountains (Inman 2013).

Moose tended to prefer overpasses to underpasses, although there was an indication of a decrease in overpass preference over time (Clevenger and Waltho 2000, Clevenger and Barrueto 2014). Olsson et al. (2008) and Olsson and Widen (2008) reported consistent but limited use of overpasses by moose. Information is not available on the potential use of road crossing structures by Dall sheep. Until recently there was limited interest in use of wildlife crossings by bighorn sheep (*Ovis canadensis*). Limited information from the Banff National Park studies indicated that bighorn sheep used underpasses exclusively (Clevenger and Barrueto 2014).

In summary, brown bears and moose tended to prefer large, open structures with good visibility, while black bears tended to prefer smaller structures that provide more cover (Clevenger 2012). Further, considering the high use of individual brown bears of more open, less constricted crossings, Sawaya et al. (2013) recommended that transportation planners and engineers consider overpasses and open span underpasses when constructing crossings for brown bears. It appeared to them that black bears are more adaptable and use a wider variety of crossing types than brown bears, so mitigation targeted for black bears could involve a broader array of smaller crossing types (Sawaya et al. 2013, M. Huijser, personal communication).

Management Implications

The work described here (Suring et al. 2017f) provided a thorough analysis for 6 focal species of their movement patterns and movement paths associated with the current condition (i.e., prior to construction of an alternative route for the Sterling Highway between MP 45–60.). Included in the objectives of this study was a description of management actions suitable to mitigate the potential effects of the Sterling Highway MP 45–60 Project on movement corridors used by the focal species. The goal of the mitigation will be to maintain existing movement patterns to the extent feasible through the use of wildlife crossing structures, fencing, and other means.

Compromise and trade-offs are inherent in the placement, design, and construction of all road projects (Roberts and Sjolund 2015, Rytwinski et al. 2015). During planning, multiple route options are often evaluated for their social, environmental and economic costs and benefits. The final route and road-design typically minimizes as many costs as possible. Construction of an alternative route for the Sterling Highway between MP 45–60 may result in an increase in the density of roads within the primary study area. Movement patterns of focal species that are sensitive to the presence of roads may be altered from those identified under the current condition when the new highway alignment is constructed.

The analysis techniques and models developed and implemented during this project will be of value in assessing the effects of a variety of management practices on the movement patterns of the focal species throughout the Kenai Peninsula. Analysis of the effects associated with other projects (e.g., other transportation corridors, energy development, pipeline construction, transmission line construction) would benefit from the application of these models.

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