Wildlife Problem Analysis and Study Proposal – Sterling Highway Milepost 45-60 Project

By

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Executive Summary

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 MP 45 and MP 60 to rural principal arterial standards. This is being done to address 3 interrelated needs: reduce highway congestion, upgrade the highway to meet current highway design standards, and improve highway function. The alternatives proposed to improve the Sterling Highway provide the opportunity to address issues associated with the effects of the highway on wildlife movements and with wildlife-vehicle collisions. Effects on wildlife include impediments to movements and road avoidance behaviors; direct wildlife mortality; and habitat loss, degradation, and fragmentation.

A wildlife study team, which included representative from the Alaska Department of Fish and Game, USDI Fish and Wildlife Service, and USDA Forest Service, oversaw development of this problem analysis and study proposal which was designed to specifically address analysis of movement patterns of wildlife in the vicinity of this project. Although managing the potential effects of the Sterling Highway Milepost 45-60 Project on wildlife using a species-by-species approach had intuitive ecological merit, the sheer number of species that would need to be considered made such an approach untenable. A focal species approach streamlined the assessment and potential mitigation process and was considered as a pragmatic response to dealing with ecosystem complexity. Generally, focal species are selected based on knowledge that factors limiting their populations are sensitive to characteristics associated with the management context of interest. We followed the lead of other investigators who based their analysis of placement of road crossings for wildlife on carnivores with large ranges and on ungulates. Using an objective evaluation process, we selected black bear, brown bear, wolverine, Canadian lynx, moose, and Dall sheep as the principal focus of these evaluations.

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 wildlife-vehicle collisions. These approaches have used information from expert knowledge, track surveys, remote cameras, radio-telemetry locations, genetic information, and landscape modeling. Our recommendation of a primary technique was responsive to the following criteria: the analysis should be completed in a timely fashion; data required to complete the analysis are currently available, can be generated from existing data sets, or can be estimated from the scientific literature; and the capacity exists to implement the technique and complete the analysis for each focal species.

Type 1 analysis for focal species with existing habitat and threat models developed for the Kenai Peninsula will use those models to generate resistance values for movement, and

incorporate them into analyses of movement corridors (i.e., brown bear). In Type 2 analysis models of habitat selection will be developed for focal species that do not have existing local models but do have adequate data on landscape use patterns collected on the Kenai Peninsula (i.e., black bear, moose, Canadian lynx). Those models will be incorporated into analyses of movement corridors. Type 3 analysis will be used for focal species without existing habitat models or adequate data on landscape use patterns from the Kenai Peninsula. These species will have habitat quality models developed for them using information available in the literature and expert knowledge (i.e., wolverine, Dall sheep). Those models will be incorporated into analyses of movement corridors.

An initial step in evaluating the effectiveness of the results of these analyses will be to convene a panel of experts to review the findings. The objective of the panel review will be to evaluate the outcomes of this work based on panel members' experience and knowledge of corridor analysis and transportation planning. A final step in the process will be implementation of a 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.

The objective of the final step will be to determine if focal species are more likely to occur within modeled movement corridors than in the landscape matrix. This analysis will allow us to determine if the modeled corridors are selected by focal species as movement/use areas more often than the landscape matrix and if associated locations of potential mitigation measures are 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. The individual analyses for the focal species and the evaluation are presented as components of the whole project. The component analyses may be implemented as a complete suite of studies or individual components may be selected for implementation depending on degree of concern for the resource, time constraints, and/or funding constraints.

Estimated total preliminary resources needed for development and evaluation of movement corridors for focal species in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days	Cost	Total
Personnel				
	Wildlife Ecologist	240	--	--
	Spatial Analyst	128	--	--
	Biostatistician	75	--	--
	Wildlife Technician	156	--	--
	Expert Reviewers	15	--	--

Estimated total preliminary resources needed for development and evaluation of movement corridors for focal species in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource	Days	Cost	Total
Equipment (assessment)	Number	Cost / item	
Remote field cameras	40	$650	$26,000
Miscellaneous materials	--	--	$1,000
Travel (assessment)	Miles	Cost / mi	
Vehicle costs	9,700	$0.565	$5,480
Services			
Access to professional literature	--	--	--
Software			
ArcGIS 10.x	--	--	--
Statistics package	--	--	--
Bayesian Network model shell	--	--	--
Use area (home range estimator)	--	--	--
MS Office	--	--	--

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Introduction

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 MP 45 and MP 60 to rural principal arterial standards. This is being done to efficiently and safely serve through-traffic, local community traffic, and traffic bound for recreation destinations in the area, so that the Sterling Highway may provide an acceptable level of service, now and in the future. In achieving this purpose, DOT&PF and FHWA recognize the desire to serve the traveling public, while doing their part to protect the Kenai River corridor.

Specifically, the proposed project alternatives would address, in varying degrees, the following 3 interrelated needs: reduce highway congestion, upgrade the highway to meet current highway design standards, and improve highway function. These improvements and reconstruction provide the opportunity to address issues associated with the effects of the highway on wildlife movements and with wildlife-vehicle collisions (WVCs) (Jeanne Lawson and Associates 2006). The project area lies within the Upper Kenai River watershed, paralleling a section of the Kenai River between Quartz Creek and Jim's Landing at the start of the Kenai River Canyon that flows into Skilak Lake.

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).

Effects of Highways on 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 is able to move to access habitat, other important resources, mates, or to disperse (Kramer-Schadt et al. 2004). A landscape has low permeability when there are barriers which impede movement, 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).

Potentially the most severe effect of roads on wildlife is that they possibly create barriers wherever they dissect habitat (Forman and Alexander 1998); this is a relatively understudied topic (Spellerberg 1998). Three main road characteristics affect behavioral responses of wildlife to crossing roads: (1) traffic volume, (2) road width, and (3) road surface (Fahrig and Rytwinski 2009, Forman and Alexander 1998, Yale Conrey and Mills 2001). 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, edge of the road, and fencing all constitute 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 (see Cumulative Effects section below). 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), speed limits (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. Hypothetically, at low traffic volumes, wildlife may cross a road corridor unimpeded. As traffic volumes increase, wildlife may shift their movement patterns to favor periods of the day when traffic is low. However, there is probably a theoretical 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 (*Ursus arctos*) 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.

Along much of the portion of the Sterling Highway that runs east-west through the Chugach National Forest and the Kenai National Wildlife Refuge, a species basically has to successfully cross the highway to move from conservation estate[1] to conservation estate. However, much of the area associated with the Sterling Highway Milepost 45-60 Project has an expanding urban interface that may include 2 highways, depending on which build alternative is considered. Consequently, a species may need a habitat corridor in addition to mitigation structure(s) to safely move from conservation estate to conservation estate in this area (Morton et al. 2010).

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 individuals 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 in areas considered important for species conservation are of concern for a wide range of species (Roger et al. 2012). The frequency of wildlife-vehicle collisions (WVCs) has been recognized as a public safety issue with economic consequences (Allen and McCullough 1976, Dussault et al. 2006a, Joyce and Mahoney 2001).

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

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[1] Those parts of the environment on the Kenai Peninsula that are formally reserved for conservation of native species, ecosystems, and recreation.

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 kilometer of highway construction, an estimated 644 hectares 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 has committed to "controlled access" along new portions of highway that may be constructed as part of the Sterling Highway Milepost 45-60 Project. This will limit or eliminate opportunities for additional development adjacent to the highway thus decreasing potential habitat loss.

However, the habitat fragmentation effect of roads can isolate certain wildlife populations 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 landscape composition, structure, and function across scales (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 can also 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 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).

Wildlife species within every taxonomic group have been reported to be negatively affected by the presence of road networks (Bennett et al. 2011). Therefore, it is reasonable to assume that where 1 or more species are affected by a road, there can be secondary or cascading effects on the other species within an ecosystem and on ecosystem dynamics. This aspect of road ecology has received limited attention in the scientific literature.

There will be cumulative effects within the Sterling Highway Milepost 45-60 Project area that will need to be identified and addressed as discussed above. However, it should also be recognized that the Sterling Highway Milepost 58-79 Project will have additional and cumulative effects on wildlife that moves north ↔ south on the Kenai Peninsula (USDI Fish and Wildlife Service 2009). The effects of both projects will need to be considered in this analysis.

Information Needs

By determining how wildlife may respond to features and circumstances associated with roads, we will be able to ascertain how sensitive wildlife species will be to the transportation corridor associated with the Sterling Highway Milepost 45-60 Project and what mitigation measures may be appropriate.

This includes describing:

- Focal species upon which to base management actions suitable to mitigate the effects of the Sterling Highway Milepost 45-60 Project on wildlife;
- How the focal species are likely to respond to the current presence of the Sterling Highway Milepost 45-60, to planned improvements, and to traffic on that road (e.g., Clark et al. 2001);
- What characteristics of the current Sterling Highway Milepost 45-60 and planned improvements, such as substrate, gap width, or traffic volume, are likely to result in a negative response in the focal species (e.g., van Langevelde and Jaarsma 2004);
- The form and magnitude of focal species response related to the current transportation corridor associated with the Sterling Highway Milepost 45-60 and with planned improvements (e.g., Jaeger et al. 2005);
- The implications of those responses to populations of the focal species on the Kenai Peninsula (e.g., Roger et al. 2011); and
- Management actions suitable to mitigate the effects of the Sterling Highway Milepost 45-60 Project on the focal species.

Evaluation and Selection of Focal Species

Although managing the potential effects of the Sterling Highway Milepost 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. 1997, Noon 2003). Generally, focal species are selected based on knowledge that factors limiting their populations are sensitive to characteristics associated with the management context of interest (Wiens et al. 2008). In this case, the focus is on landscape-scale characteristics, such as land cover composition or connectivity (Mikusiński et al. 2007). By addressing the needs of focal species, other species with which they are associated are expected to benefit.

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, very mobile species that move on the ground will be negatively affected by the potential effects of the Sterling Highway Milepost 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. 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 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. 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 endangered, the relative consequences are likely to be small. It is anticipated that even ecological functions associated with the species will be unaltered on both sides of the corridor (Hunter and Hunter 2008).

Many mammalian carnivores are sensitive to landscape change similar to the potential effects of the Sterling Highway Milepost 45-60 Project because of their low population density, low fecundity, limited dispersal ability across open or developed habitat, 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) provides 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 Milepost 45-60 Project on wildlife movement patterns (Table 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 occur 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).

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 ≥80% 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 Milepost 45-60 Project. This included black bear, brown bear, wolverine, Canadian 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, Canadian lynx, and Dall sheep were also identified as species of highest concern in relation to the Sterling Highway Milepost 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 a subsistence, game, and viewing resource; and the incidence of WVCs involving moose. Moose had an index value of 70% in our ranking system. ADOT&PF (2012) included an emphasis on the large number of collisions involving animals in their strategic traffic safety plan, mainly moose. Because of the size of a moose, a collision with one often results in major damage to vehicles and sometimes human and moose fatalities. 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). Consequently, the Sterling Highway was identified as one of the priority areas in the State for the implementation of mitigation measures to address WVCs involving moose (ADOT&PF 2007).

Table 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
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
Brown bear (*U. arctos*)[4]	6-9 years/2	0.4/2	2.24/1	33,000/4	S4/1	10

Table 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
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						
Canadian 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						
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

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

Order Family	Reproductive characteristics					
Species	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
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 zibethicus*)	6 months/0	2.4/0	6.55/0	0.34/0	S5/0	0
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

Table 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
Lagomorpha						
Leporidae						
Snowshoe hare (*Lepus americanus*) [4]	7 months/0	2.5/0	3.54/0	5/0	S5/0	0

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[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.

Black bear

The population of black bears on the Kenai Peninsula was estimated to be ≥4,000 (Selinger 2011a). Although black bears are long-lived, mature slowly, and have very low reproductive rates (Bunnell and Tait 1981) this population supports a sport harvest that exceeds all other big game species on the Kenai Peninsula (mean annual harvest of 573 black bears). 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, Selinger 2011a). 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 (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 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 and they are an important component of genetic diversity among black bears in Alaska (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 Manen et al. 2012).

Brown bear

Brown bears occur across most of the Kenai Peninsula with the exception of glaciated areas and they move 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). Although movement of brown bears between the Kenai Peninsula and the mainland is restricted by an isthmus approximately 18 km-wide, genetic characterization of brown bears on the Kenai Peninsula did not find evidence of significant inbreeding (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.

This population was estimated to be 624 (Morton et al. 2013) and supported harvests of 5–6 bears annually from 2008–2010 (Selinger 2011b). However, non-hunting mortalities totaled 34 in 2008–2009 and 25 in 2009–2010 including 3 resulting from WVCs (Selinger 2011b). 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 habitats in proximity to roads and human developments by female brown bears could result in adult females in poor condition and, consequently, increase 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 45-60 Project area indicated that past management activities appeared to have significantly reduced habitat effectiveness 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 quality and increases in mortality for brown bears (Suring and Del Frate 2002, Suring et al 2006).

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 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). Although road-crossing frequency for brown bears was negatively correlated with hourly traffic volume, they continued to cross roads when traffic volumes were high (Percy 2003).

Road crossings are 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 future of any population is in the subadult cohort. However, dispersal by young brown bears appears to be a gradual process over months or even years (McLellan and Hovey 2001) making these crossing zones potentially critical to the population.

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. Brown bears crossed the highway at least partially to reach salmon resources. 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. Their results indicate that the frequency of highway crossings by brown bears may already have decreased due to current traffic volumes and road configuration. They recommended maintaining or reducing current highway traffic volumes and developing and implementing measures to improve highway-crossing opportunities.

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).

Wolverine

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 2010a). 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 2010a). 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 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). Natal and maternal dens are often at high elevations, in cirque basins, with woody debris and large talus. 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). Juvenile dispersals of 185–378 km have also been reported.

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. 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.

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 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).

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). 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 WVCs (Krebs et al. 2004).

Most juvenile females 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).

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).

Canadian lynx

Canadian 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 2010a). A population estimate of 15.09±4.34 Canadian lynx was calculated for a 285-km^2 study area on the Kenai Peninsula in 1987 (i.e., 53±15/1,000 km^2) (Becker 1991). 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 2010a). Trapping seasons are closed on the Peninsula (but hunting seasons remain open) during local Canadian lynx population declines following the recommendations of Brand and Keith (1979). Recruitment into Canadian lynx populations is 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 Canadian 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 Canadian lynx across the Kenai Peninsula is often dependent on immigration from local refugia (Slough and Mowat 1996).

Mortality by WVC has been found to be significant for Canadian lynx in other parts of their range (Brocke et al. 1990, 1991; Aubry et al. 2000). Roads and highways are sometimes found to be a barrier to Canadian lynx movements (Alexander and Waters

2000, Apps 2000), and some researchers have found that Canadian lynx avoid roadways (Apps 2000). However, other investigations suggest that Canadian lynx may have a neutral relationship with roads, meaning that they are neither avoiding nor attracted to roadways (McKelvey et al. 2000, Carroll et al. 2001). Further, a recent study suggested that road density in a given area did not have a detectable effect on Canadian lynx land use (Hoving et al. 2005). However, modeling exercises have shown that Canadian lynx populations are very sensitive to potential road mortality (Kramer-Schadt 2004).

As specialized predators of snowshoe hares, Canadian 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, Canadian lynx may be distributed as several small subpopulations on the Kenai Peninsula. Canadian 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 Canadian lynx on the Kenai Peninsula may be low. This is reinforced by the fact that the population of Canadian 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 Canadian 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).

Moose

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 2010b). The high mortality rate for moose in this area has been linked to consistent severe winters with heavy snow fall. The average annual harvest of 30 (range 18–38) moose in GMU 7 from 2004–2009 contributes <10% of the annual moose harvest on the Kenai Peninsula (McDonough 2010b). 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 WVCs from 2004–2009 was 25 (range 19–30).

In 2008 the population of moose on the northwest portion of the Kenai Peninsula (GMU 15A) was estimated to be 1,670 (95% CI 1,405–1,934) (Selinger 2010). Decreasing area of early-succession forest in this area will limit the amount of browse available to moose and is anticipated to result in decreasing moose populations. The average annual harvest of moose in GMU 15A from 2004–2009 was 122 animals (range 111–131) (Selinger 2010). Hunters participating in the general moose season have had an average success rate of 11% (range 10–13). The average annual mortality of moose in GMU 15A as a result of WVCs from 2004–2009 was 73 (range 45–101).

The moose population in the west-central portion of the Kenai Peninsula (GMU 15B) was estimated to be approximately 1,680 in 2001 (Selinger 2010). The average annual harvest of moose in GMU 15B from 2004–2009 was 39 animals (range 33–47) (Selinger 2010). Hunters participating in the general moose season have had an average success rate of 15% (range 13–18). The average annual mortality of moose in GMU 15B as a result of WVCs from 2004–2009 was 50 (range 41–61).

The moose population in the southwest portion of the Kenai Peninsula (GMU 15C) increased approximately 30% from 1993 to 2002 and was estimated to number 2,981 (95% CI 2,508–3,454) (Selinger 2010). The average annual harvest of moose in GMU 15C from 2004–2009 was 235 animals (range 192–279) (Selinger 2010). Hunters participating in the general moose season have had an average success rate of 18% (range 14–22). The average annual mortality of moose in GMU 15C as a result of WVCs from 2004–2009 was 66 (range 40–86).

The largest impacts on the moose population on the Kenai Peninsula are considered to be declining habitat quality, predation, and mortality caused by WVCs (Selinger 2010). Up to 90% of the moose killed by WVCs on the Kenai Peninsula are cows and calves (Ernst et al. 2009). Bangs et al. (1989) reported that WVCs were the largest source of mortality for mature female moose on the Kenai National Wildlife Refuge. Mortality of mature female moose from WVCs is likely to be additive (Gasaway et al. 1983, Bangs et al. 1989, Loranger 1991). The spatial and temporal distributions of WVCs involving moose are not random (e.g., Seiler 2005; Dussault et al. 2006a, 2007). Primary factors in moose WVCs 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 moose WVCs in Maine included traffic volume and speed limit (Danks and Porter 2010). For each additional 500 vehicles/day, odds of a location with a moose WVC increased by 57%. For each 8-km/hr increase in speed limit, odds of a WVC increased by 35%. Evaluation of WVC 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 WVCs involving moose (Finder et al. 1999, Malo et al. 2004, Hurley et al. 2007).

While mortalities in the moose population on the Kenai Peninsula are of substantial concern to natural resource managers, the effects of the Sterling Highway on use of habitat and movement by moose is also an issue that needs to be assessed. Landscape-use patterns by moose are likely to be significantly modified by the presence of the Highway. 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). Evidence comes from Laurian's et al. (2008) analysis of 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 consider areas ≥500 m beyond the roadway, as low-quality habitat and therefore avoid these areas. 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 on 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 one 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 one side of the highway because of their reluctance to cross the highway, limiting dispersion and use of available habitats.

Dall sheep

Dall sheep in the Kenai Mountains on the Kenai Peninsula are at the southern extent of their range in Alaska (McDonough 2011). They occupy 3 adjacent but distinct ranges 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.

Mortality of Dall sheep resulting from WVCs was reported by Hoefs and McTaggart Cowan (1979) in Kluane National Park. Vehicle traffic impeded Dall sheep from crossing roads in some cases during migration (Singer and Beattie 1986). Proximity to, and degree of traffic on roads increases the degree of avoidance 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 a road crossing by an individual may depend on previous exposure to traffic, and there is the possibility of disruption of daily and perhaps even seasonal movement patterns (Demarchi and Hartwig 2004). Dalle-Molle and van Horn (1991) reported reluctance by Dall sheep to cross the road during migration in Denali National Park. 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).

Transportation corridors for highways have had negative effects on bighorn sheep in British Columbia 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 removed 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, Dall sheep may abandon use of the area, even if an immediate replacement for lost resources is not available (Papouchis et al. 2001).

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. 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.

Summary of Potential Methods to Evaluate Spatial Interaction of Focal Species with the Sterling Highway

Roads result in impediments to movements of wildlife and road avoidance behaviors; direct wildlife mortality; and habitat loss, degradation, and fragmentation (Alexander et al. 2005a, Forman et al. 2003). Jaeger and Fahrig (2004) demonstrated that although movement and dispersal behavior in wildlife is necessary for a population to survive in a habitat crossed by roads, its individuals had to disperse less to minimize the road-induced mortality. However, such behavior is likely to be detrimental since it induces population isolation (van der Grift et al. 2004) and potential consequent lack of genetic diversity (Epps et al. 2005)[2]. Limiting daily and seasonal movements also restrict a species ability to fully use habitat and other resources (Coffin 2007). All of these consequences potentially lead to reductions in opportunities to harvest animals through hunting and trapping and to reductions in associated economic and social benefits. To mitigate these potential effects, efforts may be needed to make roads more permeable and to reduce WVCs. One approach to mitigation would be to identify and maintain movement corridors. Gilbert-Norton et al. (2010) found that corridors increase movement between habitat patches by approximately 50% compared to patches that are not connected with corridors. Natural corridors (those existing in landscapes prior to the study) showed more movement than manipulated corridors (those created and maintained for the study). These results suggest that existing corridors increase species movement in fragmented landscapes and that efforts spent on maintaining and creating corridors are worthwhile.

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 (Clevenger et al. 2002a, Beier et al. 2009), track surveys (Scheick and Jones 1999, Alexander et al. 2005b), remote cameras (Scheick and Jones 1999, Roesch 2010), radio-telemetry locations (Waller and

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[2] Genetic considerations are just one of several factors that may influence conservation policies and strategies, but it is generally agreed that the maintenance of genetic variation is an important factor in managing wild populations (Allendorf and Luikart 2007, Frankham. et al. 2010).

Servheen 2005, Dodd et al. 2007), genetic information (Balkenhol and Waits 2009, Simmons et al. 2010), and landscape modeling (Kindall and van Manen 2007, Landguth et al. 2011).

Expert knowledge

Expert knowledge is used widely in the science and practice of conservation because of the complexity of problems, relative lack of data, and the imminent nature of many conservation decisions (Martin et al. 2012). Expert knowledge is defined as substantive information on a particular topic that is not widely known by others. An expert is someone who holds this knowledge and who is often deferred to in its interpretation. Use of expert knowledge to evaluate and assess management situations may be characterized as qualitative reasoning leading to qualitative (not quantitative), or fuzzy, models (McIntosh 2003, Adriaenssens et al. 2004). This approach may be very useful to capture and handle expert knowledge in order to develop hypotheses in data-poor situations and for qualitative impact assessments (e.g., Verboom et al. 1993). In an effort to improve mitigation strategies for WVCs, Hurley et al. (2009) used the most readily available source of knowledge of collision factors (i.e., expert opinion) to develop a series of models that explained and predicted location of WVCs involving moose. They developed expert-based models and used a structured survey approach where experts could assess criteria relevancy, weight criteria, and review weights for consistency.

There remains uncertainty regarding the reliability of expert knowledge (Maddock and Samways 2000). The results of Yamada et al. (2003) indicate that natural resource managers should act with caution when relying on expert knowledge from relatively small cohorts of experts. Pullinger and Johnson (2010) used an expert-based model and a resource selection function (RSF) to predict least-cost paths of woodland caribou. Using independent data for a rigorous model evaluation, they found that the expert-based model was a poor predictor of long-distance animal movements; in comparison, the RSF model was effective at predicting habitat selection by caribou. However, use of expert knowledge to respond to ecological questions is gaining momentum as a tool for conservation decision-making. Guidance in using expert knowledge in a transparent and credible manner to inform ecological models and ultimately natural resource and conservation decision-making is being developed (Kuhnert et al. 2010, Martin et al. 2012).

Track surveys

Mammal tracks can be used to document presence and movements relative to roads and mitigation measures, and, potentially, population trends (Beier and Cunningham 1996, Clevenger et al. 2002b, Hardy et al. 2003). Track data alone cannot identify absolute total numbers of different animals or distinguish between specific individuals, but they can be a measure of relative population density (Huijser and Bergers 2000, Hayward et al. 2002) and relative movement rates (Stephens et al. 2006). The method detects an animal at a fixed location by identifying tracks left after crossing a track bed or surface of soft media. Null movement models can also be developed, especially using snow-tracking data.

Species habitat relationships have been evaluated using the results of track surveys (Alexander 2008). Alexander et al. (2005b) showed that a landscape probability model developed using track data was highly consistent with telemetry data predictions. Powell (1994) used a simple univariate test of observed fisher (*Martes pennanti*) movements in snow against expected movements to determine fisher habitat selection. Species' relationship to roads, or species habitat selection at different scales, can be tested using Powell's method. Analysis of movement paths using track surveys can also be especially useful in determining how organisms respond to landscape boundaries, including roads (Wiens et al. 1985, Wiens et al. 1993, Turchin 1998).

Remote cameras

The simplest approach involves use of remote trail cameras that are available at retail stores. However, these systems are limited in capabilities compared to a continuous monitoring system using multiple cameras simultaneously (Scheibe et al. 2008, Huckschlag 2008). The most expensive equipment (about $12,000) is a real-time device which can transmit images via satellite to a website for download (Locke et al. 2005).

Motion and heat-activated cameras capture images of animals, providing presence and occurrence data, similar to tracking occurrences (Kucera and Barrett 1993). One potential advantage of cameras over tracking is that individuals may be identified if they have unique markings or tags that can be seen in the images (Hardy et al. 2003). Video monitoring also allows a person to evaluate animal behavior, including possible failed highway crossing attempts. Because animals are often more active during low-light periods, flashes are necessary for standard digital cameras; infra-red film may also work in low-light conditions. With typical triggering, ranges from about 10–20 m from the camera can be expected. Remotely triggered cameras can be set up to capture images of animals moving along a trail or can be set up in arrays to sample larger areas. However, camera systems along roads have not proven reliable for obtaining information on where animals cross roads (Clevenger et al. 2008). This is particularly related to their limited range of detection.

Radio-telemetry locations

Global Positioning System (GPS) telemetry has had increasing use in wildlife movement studies because it is becoming cost-effective and reliable (Rodgers et al. 1996, D'Eon et al. 2002). The availability of continuous automated tracking at set time intervals has reduced observer bias compared with very high frequency (VHF) telemetry and has provided the ability to collect large data sets. GPS telemetry has potential to facilitate highway permeability assessment. Applications of GPS telemetry to assess wildlife highway permeability have included brown bears (Waller and Servheen 2005), black bears (McCoy 2005), caribou (*Rangifer tarandus*; Dyer et al. 2002), and Rocky Mountain elk (*Cervus elaphus nelsoni*; Dodd et al. 2007).

Despite its advantages, presence points collected via GPS telemetry likely represent locations from a limited number of individuals, so the assumption that the samples represent a representative sample of the entire population is often hard to justify (Manly et al. 2010). Moreover, care must also be taken to either ensure independence of locations since they are intrinsically serially autocorrelated (Cushman 2010) or conduct analyses in a fashion that takes advantage of serially correlated data (e.g., Turchin 1998).

The use of GPS telemetry data for pathway analysis by having ≥2 sequential locations of the same individuals at sufficiently frequent intervals to treat each sequence as a movement pathway is the best approach to estimating resistance to movement through the landscape. In such an analysis, the focus is on the specific connections between subsequent locations rather than the ambiguous matrix between locations or the point locations themselves (Wiens et al. 1985, Wiens et al. 1993, Cushman and Lewis 2010, Richard and Armstrong 2010). The limited use of pathway analyses, to date, reflects the practical and economic tradeoffs associated with obtaining numerous relocations of numerous individuals at frequent intervals (Zellet et al. 2012).

Genetic information

Collection and analysis of genetic data has valuable applications for management of wildlife-road interactions (e.g. Hardy et al. 2003, Clevenger 2005, Shepard et al. 2008). Roads, acting as barriers, can lead to increased genetic structure and decreased genetic diversity in affected populations (Keyghobadi 2007). Numerous studies have used genetic data to demonstrate the effects of roads on wildlife (Balken and Waits 2009). These effects included relative importance of road characteristics (e.g., size, age, traffic volume) in gene flow and resulting genetic structures. Genetic sampling may only be able to provide information on the general location of potential wildlife crossing sites unless genetic data are used to parameterize landscape resistance surfaces (Garroway et al. 2011). However, gene flow will not always reflect animal movement behavior nor will movement behavior necessarily reflect realized gene flow. Furthermore, the high correlation between roads and other environmental features (e.g., rivers, topography) make it difficult to assign cause.

Direct observations of movement or dispersal and indirect measures of gene flow often differ (Fedy et al. 2008). Gene flow refers to the transfer of genes from one spatial location to another (i.e., an individual dispersing from one area to breed in the area to which it has dispersed, or genes moving from one population to another, via intermediate populations, over multiple generations) (Spear et al. 2010). Direct observations (e.g., based on telemetry or mark–recapture), however, can only document the physical presence of an individual in >1 location at ≥2 time periods. Such individual movements may have very little to do with dispersal or gene flow.

Corridor design requires actual delineation of connectivity areas on the landscape and must address questions regarding the relationship between movement and gene flow, how habitat suitability translates to movement, and what types of movement ultimately connect spatial localities (Spear et al. 2010). Both direct estimates of movements and gene flow are important parameters; the goals are to protect habitat that individuals can survive in, but also to ensure genetic connectivity for long-term viability (Crooks and Sanjayan 2006). Given the indirect link between individual movements and genetic patterns, application of genetic methods to study the consequences of highways is difficult.

Wildlife-vehicle collisions

WVCs do not occur randomly, either spatially or temporally (Puglisi et al. 1974, Bashore et al. 1985, Clevenger et al. 2001). However, locations with high numbers of WVCs may simply indicate a particularly dangerous crossing location, as opposed to a preferred place to cross (Barnum et al. 2007). Because WVC rates may be dependent on traffic volume as well as the number of animals crossing the roadway (Roof and Woodling 1996, Barnum 2003), this effect may not be apparent for low volume roads. Although WVC data can help identify conflict areas, it does not incorporate information about the surrounding habitat and landscape structure into identification of crossing locations.

The primary source of these data is usually State highway patrol accident reports, which often estimate collision location to the nearest road marker, and are rarely more precise then the nearest 0.2 km. More rigorous efforts to document location and number of WVCs are also subject to several factors that may affect the accuracy of road mortality estimates, including the rate at which the carcasses decompose, the time interval between the occurrence of mortality and road monitoring, the number of vehicles that pass over the carcass, the visibility of carcasses, the abundance and diversity of scavengers, the weather, and the accuracy and precision of the search method (Wobeser and Wobeser 1992, Slater 2002, Prosser et al. 2008, Santos et al. 2011). Many of the methodologies to identify crossing zones using WVCs also require accurate identification of sites where no collisions occurred (Malo et al. 2004, Ramp et al. 2005, Seiler, 2005) which may be difficult information to gather. Consequently, WVC data provide adequate precision to identify conflict zones, which are generally over 2 km in width, but not usually for crossing zones, which are generally 30–600 m in width. Further, understanding where mortality occurs may not address where animals prefer to cross roads or where they cross roads safely (Clevenger et al. 2002a, Alexander et al. 2005a).

However, there is a clear human safety connection to places where WVCs happen. If WVCs occur, drivers are in danger and such sites represent a critical location to provide mitigation to prevent collisions, but these locations are less likely to facilitate movements of animals.

Landscape modeling

To evaluate and manage consequences of roads on movement and mortality of wildlife, least-cost path (LCP) modeling is often used with geographic information systems (GIS) to predict the most likely movement routes of affected wildlife (Leoniak et al 2012). Least-cost analysis is based on graph theory (Bunn et al. 2000) and uses a simple raster-based algorithm that weighs the minimal distance between a source and a target cell, based upon species-specific resistance values of the intervening matrix (Adriaensen et al. 2003). The output is a raster map where every cell in the landscape is assigned a value that represents the lowest possible cumulative cost from the source to the target cell. The results of these analyses may be used to prioritize locations for mitigation actions such as placement of wildlife bridges, tunnels, or overpasses (Adriaensen et al. 2003, Clevenger et al. 2002a). However, results of evaluations of the ability of LCP modeling to predict movement corridors have been mixed (Pullinger and Johnson 2010, Leoniak et al 2012).

Despite the wide-spread use of LCP there is not a generally accepted method for translating habitat selection indices based on detections into resistance values for movement (Beier et al. 2008). Movement or dispersal habitat is generally assumed to be similar to breeding or foraging habitat (Chetkiewicz et al. 2006, LaRue and Nielsen 2008). Errors can arise from this inference because detections usually represent within-home range habitat use patterns and thus may not adequately reflect how environments affect animals during movements such as dispersal and migration (Cushman et al. 2013). Although in a recent study on mountain lion (*Puma concolor*) dispersal, it was shown that habitat preference of dispersers was similar to habitat preference of resident adults (Newby 2011).

LCP analysis is an attractive technique for analyzing and designing habitat corridors and crossing zones because it allows quantitative comparisons of potential movement routes over large study areas, can incorporate simple or complex models of habitat effects on movement, and models connectivity as it might be perceived by a species on a landscape (Sawyer et al. 2011).

Conclusions

Selection of a primary technique from those described above was responsive to the following criteria. The analysis should be completed in a timely fashion; data required to compete the analysis are currently available, can be generated from existing data sets, or can be estimated from the scientific literature; and the capacity exists to implement the technique and complete the analysis for each focal species. Through application of these criteria, LCP analysis is recommended for identifying locations in the road corridor for the Sterling Highway, mileposts 45-60, for mitigation measures to maintain movement patterns of the focal species.

Type 1 analysis for focal species with existing habitat and threat models developed for the Kenai Peninsula will use those models to generate resistance values for movement, and incorporate them into LCP analyses (i.e., brown bear; Table 2). In Type 2 analysis RSFs will be developed for focal species without existing local models but with adequate local data on landscape use patterns collected on the Kenai Peninsula (i.e., black bear, moose, Canadian lynx; Table 2). Those RSFs will be used to generate resistance values for movement and will be incorporated into LCP analyses. Type 3 analysis will be used for focal species without existing habitat models or adequate data on landscape use patterns from the Kenai Peninsula. These species will have habitat quality models developed for them using information available in the literature and expert knowledge (i.e., wolverine, Dall sheep; Table 2). Those models will be used to generate resistance values for movement which will then be incorporated into LCP analyses.

Table 2. Data and modeling resources available for focal species on the Kenai Peninsula, Alaska, USA.

	Telemetry data		Kenai Peninsula models		Other models	
Focal species	Date	Source	Landscape use	Threats	Landscape use	Threats
American black bear	1982-1987	Schwartz and Franzmann 1991	Model development initiated[1]	None known	Rogers and Allen 1987, Clark et al. 1993, Clevenger et al. 2002a, Lyons et al. 2003, Gaines et al. 2005, Carter et al. 2010, Sadeghpour and Ginnett 2011	None known
Brown bear	1995-2010	IBBST 2001, Morton et al. 2013	Suring et al. 2006	Suring et al. 1998, Suring and Del Frate 2002	NA	NA
Wolverine	2005 (limited)	A. Poe, personal communication	None known	None known	Carroll et al. 2001, Copeland et al. 2007, Krebs et al 2007, Suring et al. 2011, Johnson et al. 2012, Inman 2013	None known

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Canadian lynx	1985-1995	T. Bailey, personal communication	None known	None known	Carroll et al. 2001, Hoving et al. 2004, Hoving et al. 2005, Squires et al. 2010, Linden et al. 2011, Squires et al. 2013	None known
Moose	2005-2008; 2006-2008	Ernst et al. 2009; T. Lohuis, personal communication	None known	None known	Puttock et al. 1996, Snaith et al. 2003, Dussault et al. 2006b, Serrouya et al. 2011	Hurley et al. 2007
Dall sheep	2011 or 2012 (potential)	McDonough 2011	None known	None known	Rachlow and Bowyer 1998, Walker 2005, Walker et al. 2006, Parker and Walker 2007, Walker et al. 2007, Barker 2012	None known

[1] In 2000 Lowell Suring and Chuck Schwartz began development of a landscape use model for black bears on the Kenai Peninsula.

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Methods for Analysis of Focal Species Movement Patterns

Resource selection functions

Identifying the kind and location of potential mitigation measures associated with wildlife and the Sterling Highway Milepost 45-60 Project requires an understanding of factors that govern the distribution, abundance, and movement of focal species. Numerous methods are available that would allow us to characterize and predict how focal species use space and resources on the Kenai Peninsula. These include relatively simple comparisons between expectations of used and available resources (e.g. foraging or selection indices; Manly et al. 2002), to more complex techniques such as compositional analysis (Aebischer et al. 1993), K-select analysis (Calenge et al. 2005), species distribution models (Phillips et al. 2006), mechanistic home range models (Moorcroft and Barnett 2008), habitat suitability models (Hirzel et al. 2006, Hirzel and Le Lay 2008), and related resource selection and resource selection probability functions (Manly et al. 2002). RSFs have been shown to be good predictors of animal distribution (e.g., Johnson et al. 2004) and have become the most widely used and generally accepted procedure to quantify relative use of habitat resources (McLoughlin et al. 2010). Further, they are considered a powerful and useful tool for wildlife management and the examination of ecological relationships (Johnson et al. 2006).

A RSF is essentially any function that is used to measure selection by an individual proportional to available resources, including habitat (Manly et al. 2002). With this approach it is common to compute a RSF using logistic regression by assuming an exponential function. RSFs provide the ability to link spatial locations and frequency of use to resources that may be of particular importance for a focal species (Boyce and McDonald 1999, Manly et al. 2002). The ability of RSFs to inform conservation efforts has been shown for various organisms and spatial scales (Edwards et al. 1996, Meyer et al. 1998, Johnson et al. 2004).

It is often assumed that animals will select resources in space and time in a way that will maximize their probability of survival and the survival of their offspring (Buskirk and Millspaugh 2004). A corollary to this is that high quality resources will be selected by animals more than low quality resources. Results of RSF analyses are proportional to the probability of the occurrence by a species of interest across land areas. They may be used to characterize factors influencing habitat use by a species and, with GIS applications, may be made spatially explicit. Research efforts have found RSFs to be reliable in predicting animal distribution and habitat use and useful in cumulative effects analysis, land-management planning, and population viability analyses (e.g., Boyce et al. 1994, Boyce and McDonald 1999, Boyce and Waller 2003).

The basis of RSFs is that the values of features measured or described within a unit of the landscape (e.g., forest stand, map pixel) are proportional to the probability of that unit being used by a focal species (Manly et al. 2002). The features of interest are those presumed to influence habitat use patterns of the focal species. They may be categorical (e.g., land cover class) or continuous (e.g., elevation, slope, distance to road). Our design for developing RSFs is based on sampling resource units that are used relative to a sample of those that are available (i.e. use/availability design). Not all resource units in the study area will have been sampled for occupancy or use. Furthermore, there is a vast literature exploring the difficult choices involved in identifying available habitat (Alldredge and Ratti 1986, 1992; Aebischer et al. 1993).

It should also be noted that patterns of landscape use by a focal species are influenced by more than the availability of resources and include other ecological processes such as competition, predation, mutualism, and parasitism (Hobbs and Hanley 1990, Garshelis 2000, Hirzel and Le Lay 2008). However, our analysis is intended to be habitat-based and those factors are beyond the scope of this proposed work.

Least cost path analyses

LCP analysis, as modified by Beier et al. (2008) to describe corridors, is a GIS-based approach that estimates movement costs between 2 points based on the suitability of habitat for movement between the 2 points. This technique models the relative cost for an animal to move between 2 areas of suitable habitat (Penrod et al. 2006). LCP analysis is based on how the movement path of an animal may be affected by characteristics of the landscape, such as land cover, human density, roads, or slope (Singleton et al. 2002, Penrod et al. 2006). Within a GIS, each cell in a raster dataset is assigned a value for cost of movement. The model creates the most likely travel route by selecting a combination of cells that accrue the least resistance with the shortest distance between two areas (Larkin et al. 2004). Least-cost paths contain the most suitable habitat and fewest movement barriers (Larkin et al., 2004), and therefore, the best theoretical route for an animal.

Incorporating results of a RSF analysis into a LCP analysis typically relies on analysis of point locations of the focal species to describe habitat use. An alternative approach may use analysis of movement pathways of animals to describe movement responses to landscape characteristics. Kernohan et al. (2001) described 3 nonexclusive categories of quantitative approaches for characterizing movement: (a) summarizing movement pathways with turning angles, fractal dimensions, and step lengths; (b) modeling movement with random walks or their variations (Turchin 1998); and, (c) identifying patterns in movement data retrospectively to distinguish different movement types (e.g., Morales et al. 2004). However, these approaches tend to require extensive data to calculate. Given the tradeoff between information content and data requirements, LCP approaches may possess the greatest benefit to effort ratio for conservation problems that require characterization of connectivity at relatively large scales (Calabrese and Fagen 2004).

LCP represents an intermediate approach to corridor planning, in terms of data requirements and model complexity (Adriaensen et al. 2003). These models evaluate potential animal routes across the landscape based on the ‘cost’ of animal movement between locations (Beier et al. 2008) and have been applied to a number of species (Theobald 2006). Parameters are based on descriptions of habitat quality derived either from empirical data (e.g., RSFs) or from the literature or expert knowledge (e.g., habitat quality models). Clevenger et al. (2002a) tested the frequency of black bear crossings of a major road with crossing points predicted with GIS-based models. They found that empirical (e.g., RSFs) and expert literature-based models both predicted linkage zones reasonably well. Combining RSF models with least-cost modeling for corridor planning can integrate the functional connectivity of landscapes (Taylor et al. 2006) while maintaining the visual advantage of structural connectivity-based approaches (Chetkiewicz et al. 2006).

A fundamental assumption in LCP analyses is that habitat quality and permeability are synonymous, and that both are the inverse of the ecological cost of travel. Essentially all the relevant literature describes habitat use, not animal movement, so it is less difficult to estimate habitat quality rather than habitat permeability to movement (Chetkiewicz et al. 2006). Translating how animals use landscapes to the data necessary to implement a LCP analysis requires that the landscape be described as a gradient along a continuum of selection (Fischer et al. 2004). Large values for a resource unit indicate good habitat quality and high permeability, while low values indicate poor suitability for movement. Resistance or travel cost is the inverse of quality or permeability and indicates the ecological cost of travel through a resource unit. This reflects the assumption that animals choose travel routes on the basis of the same factors they use to choose habitat (Chetkiewicz et al. 2006).

These digital databases are expressed as raster maps that divide landscapes into many cells with unique values that depict a range of values representing habitat quality. Cells are given weights or ‘resistance values’ reflecting the presumed influence of habitat quality on movement of the focal species. LCP routines are then used to:

- calculate the relative cost of all possible routes among conservation estates;
- determine the least costly route for animal movement between pairs of conservation estates; and
- plot these most probable routes on maps for use in conservation planning.

‘Cost’ is related to probability of transit and is not defined explicitly; energetic costs, increased risk of predation, or costs associated with reduced forage availability are among the reasons why focal species might avoid or be less able to traverse a landscape feature.

Beier et al. (2007, 2008) have thoroughly considered and examined the choices, biases, and assumptions associated with approaches to modeling movement corridors using habitat quality as a basis for identification of corridors. They have worked to reduce uncertainty where possible, and describe the impact of remaining uncertainty on corridor design. As a result, we believe that their approach improves the science of corridor design and ultimately will lead to the maintenance of wildlife movement patterns on the Kenai Peninsula.

Habitat quality modeling

Wildlife habitats are areas of land that provide resources such as food, cover, and water and environmental conditions such as precipitation and soil types that affect occupancy of individuals or populations of species, allowing those species to survive and reproduce (Morrison et al. 2006). Habitat selection is the behavioral process used by individuals when choosing resources and habitats (Johnson 1980). The motivation for habitat selection is presumably to maximize individual fitness (Garshelis 2000) with consequences for distribution and density across different habitats (Morris 2003). The behavioral mechanisms that play a role in habitat selection at a local scale logically apply to the selection of habitats for movement (i.e., corridors) as well (Chetkiewicz et al. 2006).

It is difficult to identify the motivation of focal species for moving across the landscape (Lima and Zollner 1996). Instead of assuming this motivation, we will identify habitats that are associated statistically with short-range movements versus longer-distance movements and incorporate them into habitat quality models (e.g., Johnson et al. 2002). Even if focal species use corridors only to travel between suitable patches, they are unlikely to do so if they perceive that habitats within the corridor are unsuitable. Focal species use a wide variety of mechanisms to select suitable habitats (Clobert et al. 2001) and incorporating the details of habitats they select is important to corridor design and placement.

Models are formal frameworks for organizing and synthesizing existing knowledge of an ecological system (in this case, habitat quality for focal species on the Kenai Peninsula). Models describing habitat quality provide an estimate of the area within which resources for a modeled species can be found, or rank an area based on the capability of that area to support a species based on important environmental variables (Morrison et al. 2006:337). Habitat effectiveness is often incorporated into these models to reflect the degree that maximum use or carrying capacity can be met (Morrison et al. 2006:337). Effectiveness is often moderated to indicate the constraints that human activities have on an area that is usable by animals (Lyon and Christensen 1992, Merrill et al. 1999). Because maps of these proximate habitat factors are rarely available for any species, habitat quality models generally rely on available GIS data as proxies for these factors.

Beck and Suring (2009) identified and described the structure, uses, output, and operation of 40 habitat-relationships modeling frameworks to provide conceptual information useful for evaluation of how well specific frameworks achieve modeling objectives. Their assessment and the decision tree in Roloff et al. (2001) for selecting a wildlife habitat modeling approach lead to a recommendation for using Bayesian Networks (BNs) as a framework for developing and applying habitat quality models for focal species on the Kenai Peninsula. Bayesian Network (BN) models using the Netica® (Norsys Software Corporation, Vancouver, British Columbia, Canada) modeling shell provide a structured tool for integrating information on habitat associations for focal species (Raphael et al. 2001). 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) and clearly display how habitat conditions influence wildlife populations (Marcot et al. 2001).

BNs are increasingly being used to model the response of wildlife species to a variety of environmental and ecological variables (Uusitalo 2007, Vilizzi et al. 2012). BNs provide a transparent tool in which complex relationships among variables can be clearly articulated, knowledge gaps identified, alternate scenarios compared, and the most important drivers for ecological responses determined (Marcot et al. 2006, McCann et al., 2006). The flexibility of BNs; their ability to cope with little and/or missing data; and the ease of incorporation of empirical data, expert opinion, or a combination of both make them well suited to a management assessment framework (Nyberg et al. 2006). BNs have thus become an integral part of probability-based decision support tools (Marcot et al., 2006), which represent an effective means of synthesizing and applying ecological knowledge to management decisions (Beck and Suring 2009), including modeling movement corridors (McNay et al. 2006, Beier et al. 2007).

Focal Species Analyses

Black bear

Significant variables explaining the distribution of black bears include forest cover, patch size, road density, land use intensity and distance from intensive land uses (Gaines et al. 2005). Both habitat models (Lyons et al. 2003, Larkin et al. 2004) and empirical studies including genetic analysis (Dixon et al. 2006) have demonstrated the value of regional-scale habitat corridors for this species.

Schwartz and Franzmann (1991) collected data on black bears north of the Sterling Highway on the Kenai lowlands, a glaciated plain encompassing the western third of the Kenai Peninsula. These data may be available for analysis and development of RSFs that may be useful in describing habitat corridors for black bears in association with the Sterling Highway Milepost 45-60 Project[3]. The data were collected from 1978 through 1987 so any associated data that may have changed since then (e.g., land cover, human developments) would need to come from legacy sources that approximate that time period. Legacy datasets developed for the analysis of landscape use of female brown bears on the Kenai Peninsula (Suring et al. 2006) are available for this analysis. The primary study area for the RSF analysis will be the northwest Kenai Peninsula north of the Sterling Highway and west of the Kenai Mountains.

RSF data sources

Animal locations.–Schwartz and Franzmann (1991) captured 167 individual black bears a total of 308 times in snares (1.6%), in barrel traps (41.6%), darted from a helicopter (27.3%), or immobilized in winter dens (29.5%). All female (72), resident male (62) and subadult (77) black bears were fitted with radio-transmitter collars. Resulting location data (5,258 locations) included aerial fixes (92.5%), capture locations (6.2%), locations at deaths (1.2%), and observations from the ground (0.1%).

Land cover classes.–Land cover was described on the Kenai Peninsula through a modified supervised/unsupervised classification technique (Chuvieco and Congalton 1988) applied to Landsat Thematic Mapper I satellite imagery acquired in July 1989 (Ducks Unlimited, Inc. and Spatial Solutions, Inc. 1999). The classification scheme for this earth cover inventory was based on Viereck et al. (1992). The overall classification accuracy of the final map was 80.8%. Detailed descriptions of these land cover classes on the Kenai Peninsula were provided in Ducks Unlimited, Inc. and Spatial Solutions, Inc. (1999). The major land cover classes used in the analysis of landscape use patterns of black bears may include barren, conifer forest, deciduous forest, mixed forest, shrubs, and herbaceous. Land cover data were developed, stored, and manipulated using GIS functions with a 28.5 m cell size.

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[3] The Alaska Department of Fish and Game should be consulted regarding the availability of these data for this analysis.

After the RSFs are developed using this land cover data the RSFs will be run on a more recent land cover data set that can be cross walked to these data (DeVelice 2012). This will be done to approximate current land cover conditions.

Distance to cover.–A "distance to cover" variable will be calculated by determining the distance from relocation and random points to the nearest pixel with a land cover class characterized as cover (i.e., either forest or shrub). This process will be repeated on a more recent land cover data set that can be cross walked to the land cover data used to develop the RSFs (DeVelice 2012). This will be done to approximate current land cover conditions.

Streams.–Potential salmon spawning habitat on the study area may be derived from the anadromous waters catalog developed and maintained by the Alaska Department of Fish and Game (ADF&G) and available at: http://www.adfg.alaska.gov/index.cfm?adfg=maps.data. Distances from relocation points and random points to the nearest salmon stream and lake will be calculated to develop a "distance to stream" variable. Also, a 1-km^2 moving-window GIS routine will be used to calculate the density of high potential salmon streams, low potential salmon streams, and all salmon streams in m per km^2 for each pixel in the study area. The density values at relocation and random points will then be determined.

Topography.–A 1:250,000 digital elevation model was acquired from the U.S. Geological Survey (http://agdc.usgs.gov/data/usgs/erosafo/dem/dem.html) and was used to describe aspect and elevation on the Kenai Peninsula.

Human development.–A point coverage of buildings was developed by extracting information on locations of structures from tax assessment records for 1998 from the Kenai Peninsula Borough. A 1-km^2 moving-window GIS routine was used to calculate the density of buildings in number per km^2 for each pixel in the study area. These values will be associated with relocation points and random points.

After the RSFs are developed using these human development data the RSFs will be run on a more recent data set available from the Kenai Peninsula Borough (http://www2.borough.kenai.ak.us/GISDept/Downloads.html. This will be done to approximate current development conditions.

Roads.—Roads for the Kenai quadrangle on the western Kenai Peninsula were extracted from digital maps developed for the Alaska Department of Natural Resources (DNR) along with associated information on use type, class, capacity, and surface type (Environmental Systems Research Institute 1983). Roads with a medium duty capacity were considered "high use" and roads with light duty or unimproved dirt capacity were considered "low use." A 1-km^2 moving-window GIS routine was used to calculate the density of high use, low use, and all roads in m per square kilometer for each pixel in the study area. These values will be associated with relocation and random points.

After the RSFs are developed using this roads data set the RSFs will be run on a more recent data set available from the Kenai Peninsula Borough (http://www2.borough.kenai.ak.us/GISDept/Downloads.html. This will be done to approximate the current road network.

RSF data analysis

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

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

Sampling 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 will be 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) and to differ in home range size (Powell et al. 1997). Consequently, all analyses will be 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. Black bears with ≥20 relocations by stratum will be included in the analysis.

Land cover preference.—Use of the 6 land cover designations by black bears will be estimated by calculating selection ratios at the 2 spatial scales: within each of the sampling strata across the study area and within black bear use areas. The percentage of each land cover used by each black bear will be determined by noting the land cover associated with each relocation. These percentages will be averaged across all black bears in each stratum. The percentage of each land cover available will be determined by noting the land cover associated with each of ~6,000 random points across the study area and each of 500 random points within each black bear's use area. Points that fall on ice, snow, or lakes will be excluded from the analysis. The ratio will be calculated as the observed proportion of use over the available proportion in each cover class. The confidence intervals will be calculated from a boot strap distribution of the ratios.

Univariate analysis.—Fourteen physical habitat and human development variables (Table 3) will be reviewed for potential inclusion in multiple regression models of landscape use by black bears. Landscape use by black bears and availability of habitat characteristics, as described by the physical habitat and human development variables, will be evaluated at 2 spatial scales (i.e., study area-wide and within use areas) and at the 4 strata. Comparisons will be 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 will be compared over all relocation points for an individual black bear to averages of the same variables at ~6,000 points randomly selected across the study area and 500 additional points randomly selected across each use area for individual black bears. Paired t-tests (paired by black bear) between used and available averages will be applied at each spatial scale and for each stratum. One-sample t-tests will also be conducted, by strata, to compare the mean of each variable used by black bears to the mean of each variable available across the study area. These comparisons will enable 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 are large, and they will be selected across each stratum, the available averages will be considered constants.

For each physical habitat and human development variable, a univariate logistic regression model for resource selection across the study area and within use areas will be estimated for black bears in each stratum, with used or available as the binary response. The estimated linear coefficients from each model will be averaged over all black bears by stratum, and the standard error of this mean will be used to form a t-test for the significance of the variable.

Table 3. Variables available for modeling resource selection by black bear and for developing habitat quality models on the Kenai Peninsula, Alaska. Distances will be in 100s of meters and densities will be in m per km^2.

Variable	Description
Human activity	
DEV_KM	Density of human developments
KROAD_KM	Density of all roads
HROAD_KM	Density of high use roads
LROAD_KM[a]	Density of low use roads
Topography	
ELEV	Elevation
ASPECT	Aspect
Vegetation	
COVER_C	Distance to forest or shrub cover
LCOVCAT	Land cover category
Salmon	
KESTM_C	Distance to all salmon spawning stream
KESTM_KM	Density of all salmon spawning streams
SSTMH_C	Distance to high potential salmon spawning stream
SSTMH_KM	Density of high potential salmon spawning streams
SSTML_C	Distance to low potential salmon spawning stream
SSTML_KM	Density of low potential salmon spawning streams

Additionally, a 1-sample t-test for each variable will be used to test for differences in average availability of resources across the Kenai Peninsula study area and within use areas. Two sample t-tests will also be conducted to compare used resources within use areas. Four comparisons will be made: 1) female black bears versus male black bears in the spring, 2) female black bears versus male black bears in the summer, 3) summer versus spring for female black bears, and 4) summer versus spring for male black bears.

Multivariate analysis.—The results from the above t-tests and univariate regressions will be used to determine if a variable is to be included in the multiple regression modeling of resource selection at each spatial scale. Variables with a significant difference in the t-tests or with a regression coefficient different from 0 with alpha = 0.10 will be candidates for modeling, subject to elimination of redundant variables through a correlation analysis. We will calculate correlations among the variables and keep 1 variable for multivariate modeling among correlations that were >0.7. After reducing the variable set with the correlation analyses, we will use backward model selection procedures to obtain a final multivariate linear model for each stratum at each spatial scale. Final models of landscape use across the study area and within use areas will then be determined using these selected variables with and without land cover effects included.

For analysis of resource selection at the use-area level, we will fit logistic regression models using each black bear's relocations as the used data and the 500 random observations from within each use area as the available data. Each black bear will be fit separately to a logistic regression model with the same covariates, and the coefficients will be averaged across black bears. The standard error of this average will be used to form a t-test to determine if each coefficient is significantly different from 0. We will remove the variable with the highest p-value from the model and refit the new model as above, until each variable left in the model is significant at the 0.05 level.

For analysis of resource selection at the study-area level, we will fit logistic regression models using each black bear's location points as the used data and the random selection of points from the entire study area as the available data. Again, we will use backward selection, and incorporate a jackknife procedure to test the significance of the coefficients in the model. The model will be fit with every black bear in the data set, and the same model will be fit with each black bear sequentially removed from the data set. Jackknife pseudo-values (X_j) will be obtained for each covariate in the model by

$$X_j = n\overline{X} - (n-1)\overline{X}_{-j}$$

where n is the number of black bears, $\overline{X}$ is the regression coefficient calculated with each black bear in the model, and $\overline{X}_{-j}$ is the regression coefficient calculated without black bear j in the model. The jackknife parameter estimate will be found by averaging the pseudo-values. The standard error of this average will be used to form a t-test to determine if the regression coefficient for a covariate is significantly different from 0. We will remove the variable with the highest p-value from the model and refit the model as above. This process will continue until each variable left in the model is significant at the 0.05 level.

LCP corridor analysis

LCP corridor analysis as described by Beier et al. (2007) is a GIS-based method of estimating the optimal location of a landscape linkage between areas of interest based on estimates or assumptions about how a focal species responds to various landscape features that can be reflected in digital map layers (Singleton et al. 2002, Theobald 2006). Because LCP corridor analysis identifies all pixels with low travel costs, it produces a swath that can include >1 alternative path, and is thus superior to LCP analysis, which yields a single path 1 pixel in width for its entire length (Theobald 2006).

We will follow the steps outlined by Beier et al. (2007) to move from maps of habitat quality for each analysis strata generated by the RSF calculations for black bears to the development of LCP corridors:

- Step 1 – Use the inverse of the habitat quality maps as a resistance map.

We will use the inverse of the gender-specific seasonal RSF models to generate a cost surface for LCP analyses. Through this subjective translation (Beier et al. 2008), we assume that pixels with higher RSF values afford lower costs to movement than those with low RSF values. We define resistance or travel cost as the inverse of quality or permeability, such that:

Resistance (cost of travel through a pixel) = Maximum quality - pixel quality

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.

- Step 2 – Select start and end points for modeling corridors.

We will identify the largest patch of high-quality habitat for black bears (as defined by the RSF analyses) in each 5th-level watershed in proximity to the Sterling Highway (see http://databasin.org/datasets/fa6f0a4210b14b239fc4ea0d5c165886 for 5th-level watersheds in Alaska). The habitat patch in each of paired watersheds on either side of the highway would become source and end termini for the LCP algorithm to generate pathways. The LCP algorithm may not form a continuous path of low resistance pixels. To identify well-connected, low-resistance pixels, each pixel's *accumulative cost-distance* will be calculated to determine the lowest possible cumulative resistance from that pixel to terminuses in each watershed. These cost-distance values do form continuous paths.

- Step 3 – Determine an appropriate width for the modeled corridor.

As the path created by the LCP algorithm may be a single pixel width wide (~30 m), we will buffer each path at least 350 m following guidelines recommended for carnivores (BCEAG 2011). However, as the length of the corridor increases, so should the width (Bentrup 2008).

Corridors developed for each of the analysis strata will be compared and evaluated. Evaluation will begin with a frequency distribution of habitat quality (e.g., percentage low, percentage medium, percentage high) within each corridor. Consideration will be given to merging the separate corridors when appropriate.

Estimate of resources needed

In addition to personnel (Table 4), resources needed for developing movement corridors for black bears will include access to professional literature via the internet, GIS software (i.e., ArcGIS 10.x), a biostatistics software package, a Bayesian Network model shell, and the MS Office software package.

Table 4. Estimate of resources need for developing movement corridors for black bears in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days
Personnel		
	Wildlife Ecologist	30
	Spatial Analyst	15
	Biostatistician	20

Brown bear

Brown bears on the Kenai Peninsula have been the subject of study by the Interagency Brown Bear Study Team (IBBST) for approximately 30 years, resulting in publication of A Conservation Assessment of the Kenai Peninsula Brown Bear (IBBST 2001) and several other publications (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, Suring et al. 2006, Graves et al. 2006, Graves et al. 2007, Goldstein et al. 2010). Initial applications of a cumulative effects model developed by the IBBST indicated that large reductions in habitat effectiveness resulted from past land management activities (Suring et al. 1998).

Brown bears on the Kenai Peninsula 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.

RSF analyses

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 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 selections by brown bears. From 3 to 5 variables were selected for each model (i.e., for each stratum).

We used landscape characteristics associated with telemetry locations from female brown bears during 1999 and 2000 to evaluate the resulting models by strata (following the process described by Howlin et al. 2004).

Analysis of defense of life or property (DLP) kills

Methods similar to those used in the RSF analysis for brown bears were used to identify landscape attributes associated with locations of brown bears killed in DLP and subsequently the threat to brown bears (Suring and Del Frate 2002). Characteristics of a DLP site and landscape variables were compared statistically using discrete choice variables measuring the likelihood of a DLP event occurring in the presence (or absence) of landscape characteristics (Manly et al. 2002). Predictive threat models were developed at 4 scales (i.e., within 400 m, 3,000 m, and 8,000 m radius of kill locations, and within watersheds) to estimate the relative probability that a DLP kill will occur in association with certain landscape attributes. The analysis at each scale incorporated DLP kill records with accuracy known to be within the distance named in the scale (e.g., analysis of kill locations at the 3,000 m scale included locations used in the 400 m scale analysis).

LCP corridor analysis

We will follow the steps outlined by Beier et al. (2007) to move from maps of habitat quality for each analysis strata generated by the RSF calculations for brown bears and for the degree of threat for the analysis strata generated by the DLP calculations to the development of LCP corridors:

- Step 1 – Use the inverse of the habitat quality maps and the threat maps as resistance maps.

We will use the inverse of the offspring-specific seasonal RSF models for brown bears to generate a cost surface for LCP analyses. Through this subjective translation (Beier et al. 2008), we assume that pixels with higher RSF values afford lower costs to movement than those with low RSF values. We define resistance or travel cost as the inverse of quality or permeability, such that:

Resistance (cost of travel through a pixel) = Maximum quality - pixel quality

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 decreases as the quality of habitat increases in a pixel; it is not necessarily related to the speed of travel through the pixel.

We will also use the inverse of the DLP threat models for brown bears to generate a cost surface for LCP analyses. Through this subjective translation (Beier et al. 2008), we assume that pixels with higher values afford higher costs to movement than those with lower values. We define resistance or travel cost as the inverse of threat, such that:

Resistance (cost of travel through a pixel) = Minimum threat + pixel threat

Resistance reflects the threat of brown bears traveling through a pixel. In general, resistance increases as threat increases and affects travel through the pixel. Resistance decreases as the level of threat decreases in a pixel; it is not necessarily related to the speed of travel through the pixel.

- Step 2 – Select start and end points for modeling corridors.

We will identify the largest patch of high-quality habitat for brown bears (as defined by the RSF analyses) in each 5th-level watershed in proximity to the Sterling Highway (see http://databasin.org/datasets/fa6f0a4210b14b239fc4ea0d5c165886 for 5th-level watersheds in Alaska). The habitat patch in each of paired watersheds on either side of the highway would become source and end termini for the LCP algorithm to generate pathways. The LCP algorithm may not form a continuous path of low resistance pixels. To identify well-connected, low-resistance pixels, each pixel's *accumulative cost-distance* should be calculated to determine the lowest possible cumulative resistance from that pixel to terminuses in each watershed. These cost-distance values do form continuous paths.

- Step 3 – Determine an appropriate width for the modeled corridor.

As the path created by the LCP algorithm may be a single pixel width wide (~30 m), we will buffer each path at least 350 m following guidelines recommended for carnivores (BCEAG 2011). However, as the length of the corridor increases, so should the width (Bentrup, 2008).

Corridors developed for each of the analysis strata (i.e., 4 RSF strata and 4 threat strata) will be compared and evaluated. Evaluation will begin with a frequency distribution of habitat quality (e.g., percentage low, percentage medium, percentage high) within each corridor. Consideration will be given to merging the separate corridors when appropriate.

Estimate of resources needed

In addition to personnel (Table 5), resources needed for developing movement corridors for brown bears will include access to professional literature via the internet, GIS software (i.e., ArcGIS 10.x), and the MS Office software package.

Table 5. Estimate of resources needed for developing movement corridors for brown bears in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days
Personnel		
	Wildlife Ecologist	20
	Spatial Analyst	10
	Biostatistician	0

Wolverine

Habitat quality model

We have selected Bayesian Networks (BN) as the framework for development and application of habitat quality models for focal species that lack sufficient data to develop RSFs. A BN is simply a way of showing how variables interact and cause specific outcomes relative to habitat quality. BNs are commonly used in wildlife and natural resource management and land use planning. Creating BNs for wildlife and natural resource management involves several stages:

- Listing the variables that most influence outcomes of interest;
- Specifying the states or values that each variable can take;
- Linking the variables; and
- Specifying probabilities of the linkages.

We briefly describe the process to develop a BN here but more detailed guidance is available from Marcot (2006), Marcot et al. (2006), and from the website of the provider of the model framework (e.g., http://www.norsys.com/). The best approach for building BNs may be to use information from the scientific literature to initially structure the model; then use a combination of expert judgment and empirical data, when available, to specify the probability distributions of each node. Because knowledge in wildlife and natural resource management comes as much from personal expertise as from statistical data and field research, BNs are viewed as tools that can effectively combine prior knowledge, expert judgment, and field data, and that can provide useful results even in the face of missing or incomplete data.

Influence diagrams, which can be a simple figure of boxes and arrows showing relations and causes among variables, will be used to initially depict how habitat and environmental conditions influence habitat quality of wolverines (e.g., Figure 1).

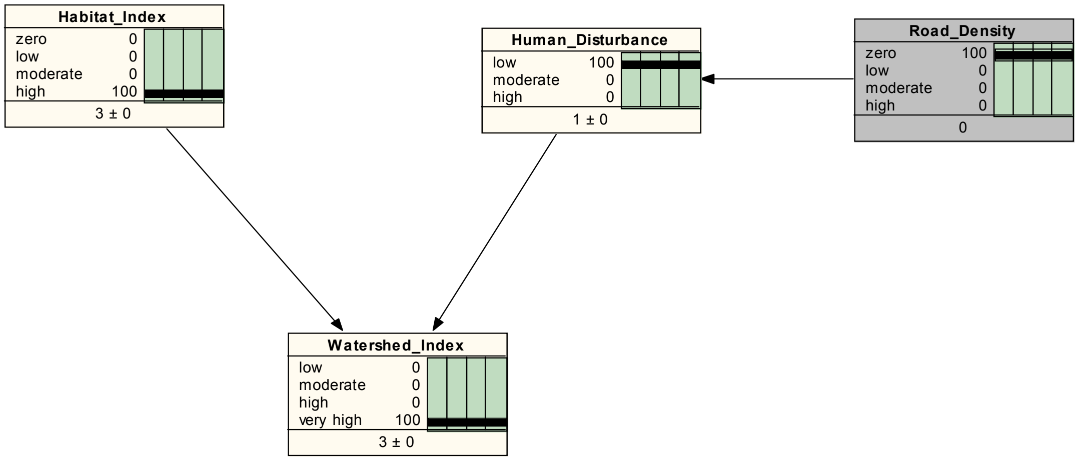


Figure 1. Example of an influence diagram that will be used in the BN for wolverines on the Kenai Peninsula, Alaska, USA.

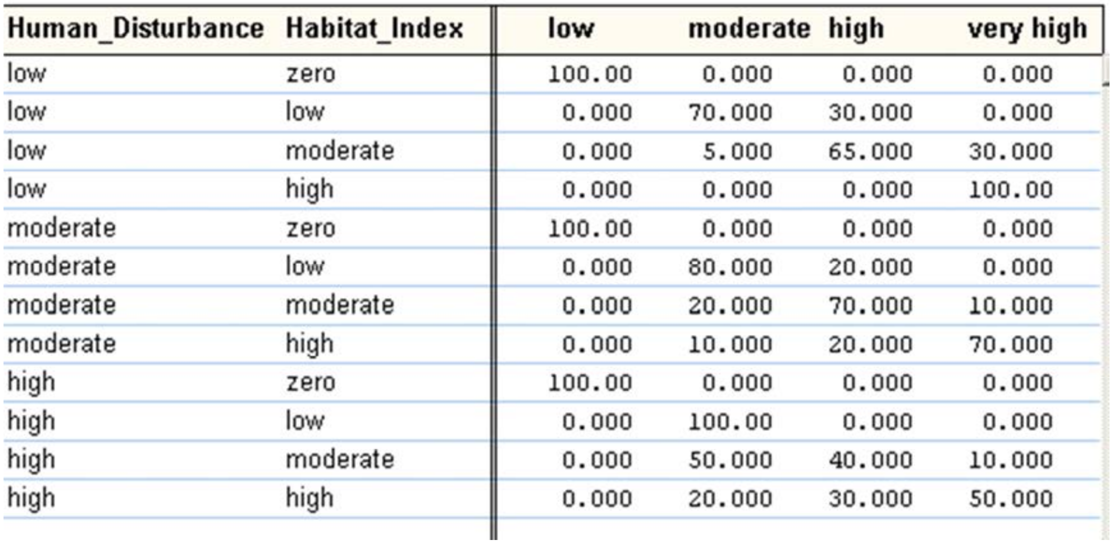
The basic pattern we will use for developing the BN for wolverine is depicted here. We anticipate evaluating the effects of habitat and the effects of threat factors on movement patterns of wolverines. Based on published habitat quality models for wolverines, variables that are likely to be incorporated into our model include land cover, topography, land form, road density, human population density, ungulate winter range (Carroll et al. 2001, Rowland et al. 2003, Copeland et al. 2007, Krebs et al. 2007, Lofroth and Krebs 2007).

The states for each variable will be developed from information in the literature concerning the influence that variable has on habitat quality. Combinations of the states from each of the variables lead to a determination of an index of the quality of the habitat for wolverines. This will be accomplished through the development of conditional probability tables, an integral part of a BN (e.g., Figure 2).

LCP corridor analysis

Schwartz et al. (2009) mapped landscape resistance for wolverine across the full extent of their study area using LCP analysis and molecular genetics. Their analysis confirmed that areas with habitats suitable for wolverines provided low resistance to wolverine dispersal, and areas without suitable habitats provided high resistance.

Variables **Habitat Quality Index**



Human_Disturbance	Habitat_Index	low	moderate	high	very high
low	zero	100.00	0.000	0.000	0.000
low	low	0.000	70.000	30.000	0.000
low	moderate	0.000	5.000	65.000	30.000
low	high	0.000	0.000	0.000	100.00
moderate	zero	100.00	0.000	0.000	0.000
moderate	low	0.000	80.000	20.000	0.000
moderate	moderate	0.000	20.000	70.000	10.000
moderate	high	0.000	10.000	20.000	70.000
high	zero	100.00	0.000	0.000	0.000
high	low	0.000	100.00	0.000	0.000
high	moderate	0.000	50.000	40.000	10.000
high	high	0.000	20.000	30.000	50.000

Figure 2. Example of conditional probability table that will be used in the BN for wolverines on the Kenai Peninsula, Alaska, USA.

We will follow the steps outlined by Beier et al. (2007) to move from the map of habitat quality generated for wolverines through the BN process to the development of LCP corridors:

- Step 1 – Use the inverse of the habitat quality map as a resistance map.

We will use the inverse of the values in the habitat quality model for wolverines to generate a cost surface for LCP analyses. Through this subjective translation (Beier et al. 2008), we assume that pixels with higher values afford lower costs to movement than those with low values. We define resistance or travel cost as the inverse of quality or permeability, such that:

Resistance (cost of travel through a pixel) = Maximum quality - pixel quality

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.

- Step 2 – Select start and end points for modeling corridors.

We will identify the largest patch of high-quality habitat for wolverines (as defined by the BN-based analysis) in each 5th-level watershed in proximity to the Sterling Highway (see http://databasin.org/datasets/fa6f0a4210b14b239fc4ea0d5c165886 for 5th-level watersheds in Alaska). The habitat patch in each of paired watersheds on either side of the highway would become source and end termini for the LCP algorithm to generate pathways. The LCP algorithm may not form a continuous path of low resistance pixels. To identify well-connected, low-resistance pixels, each pixel's *accumulative cost-distance* should be calculated to determine the lowest possible cumulative resistance from that pixel to terminuses in each watershed. These cost-distance values do form continuous paths.

- Step 3 – Determine an appropriate width for the modeled corridor.

As the path created by the LCP algorithm may be a single pixel width wide (~30 m), we will buffer each path at least 350 m following guidelines recommended for carnivores (BCEAG 2011). However, as the length of the corridor increases, so should the width (Bentrup, 2008).

Evaluation of corridors will begin with a frequency distribution of habitat quality (e.g., percentage low, percentage medium, percentage high) within each corridor. Consideration will be given to merging the separate corridors when appropriate.

Estimate of resources needed

In addition to personnel (Table 6), resources needed for developing movement corridors for wolverine will include access to professional literature via the internet, GIS software (i.e., ArcGIS 10.x), a Bayesian Network model shell, and the MS Office software package.

Table 6. Estimate of resources needed for developing movement corridors for wolverines in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource	Days
Personnel	
Wildlife Ecologist	25
Spatial Analyst	20
Biostatistician	0

Canadian lynx

Bailey et al. (1986) collected data on Canadian lynx in a study area primarily north of the Sterling Highway on the Kenai lowlands, a glaciated plain encompassing the western third of the Kenai Peninsula. Data collection continued via radio telemetry for about 12 years (T. Bailey personal communication). These data are available for analysis and development of RSFs that may be useful in describing habitat corridors for Canadian lynx in association with the Sterling Highway Milepost 45-60 Project. The data were collected from 1982 through the mid-1990s so any associated data that may have changed since then (e.g., land cover, human developments) would need to come from legacy sources that approximate that time period. Legacy datasets developed for the analysis of landscape use of female brown bears on the Kenai Peninsula (Suring et al. 2006) are available for this analysis. The primary study area for the RSF analysis will be the northwest Kenai Peninsula north of the Sterling Highway and west of the Kenai Mountains.

RSF data sources

Animal locations.–Bailey et al. (1986) captured 159 Canadian lynx from 1982 through 2000. These animals were examined, weighed, and fitted with a 300-g radio collar, released, and aerially located 1-10 times/month until the Canadian lynx died or radio contact was lost.

Land cover classes.–Land cover was described on the Kenai Peninsula through a modified supervised/unsupervised classification technique (Chuvieco and Congalton 1988) applied to Landsat Thematic Mapper I satellite imagery acquired in July 1989 (Ducks Unlimited, Inc. and Spatial Solutions, Inc. 1999). The classification scheme for this earth cover inventory was based on Viereck et al. (1992). The overall classification accuracy of the final map was 80.8%. Detailed descriptions of these land cover classes on the Kenai Peninsula were provided in Ducks Unlimited, Inc. and Spatial Solutions, Inc. (1999). The major land cover classes used in the analysis of landscape use patterns of Canadian lynx may include barren, conifer forest, deciduous forest, mixed forest, shrubs, and herbaceous. Land cover data were developed, stored, and manipulated using GIS functions with a 28.5 m cell size.

After the RSFs are developed using this land cover data, the RSFs will be run on a more recent land cover data set that can be cross walked to these data (DeVelice 2012). This will be done to approximate current land cover conditions.

Distance to cover.–A “distance to cover” variable will be calculated by determining the distance from relocation and random points to the nearest pixel with a land cover class characterized as cover (i.e., either forest or shrub). This process will be repeated on a more recent land cover data set that can be cross walked to the land cover data used to develop the RSFs (DeVelice 2012). This will be done to approximate current land cover conditions.

Topography.–A 1:250,000 digital elevation model was acquired from the U.S. Geological Survey (http://agdc.usgs.gov/data/usgs/erosafo/dem/dem.html) and was used to describe aspect and elevation on the Kenai Peninsula.

Human development.–A point coverage of buildings was developed by extracting information on locations of structures from tax assessment records for 1998 from the Kenai Peninsula Borough. A 1-km^2 moving-window GIS routine was used to calculate the density of buildings in number per km^2 for each pixel in the study area. These values will be associated with relocation points and random points.

After the RSFs are developed using these human development data the RSFs will be run on a more recent data set available from the Kenai Peninsula Borough (http://www2.borough.kenai.ak.us/GISDept/Downloads.html. This will be done to approximate current development conditions.

Roads.—Roads for the Kenai quadrangle on the western Kenai Peninsula were extracted from digital maps developed for the Alaska Department of Natural Resources (DNR) along with associated information on use type, class, capacity, and surface type (Environmental Systems Research Institute 1983). Roads with a medium duty capacity were considered “high use” and roads with light duty or unimproved dirt capacity were considered “low use.” A 1-km^2 moving-window GIS routine was used to calculate the density of high use, low use, and all roads in m per square kilometer for each pixel in the study area. These values will be associated with relocation and random points.

After the RSFs are developed using this roads data set the RSFs will be run on a more recent data set available from the Kenai Peninsula Borough (http://www2.borough.kenai.ak.us/GISDept/Downloads.html. This will be done to approximate the current road network.

RSF data analysis

This analysis will focus on two spatial scales of habitat selection as described by Johnson (1980):

- 2nd Order selection of a multi-year, annual use area within the study area, and
- 3rd Order selection of habitats within the multi-year, annual use areas of the black bears.

Description of use areas.—Use areas of Canadian lynx may be calculated from the relocation data using HRT: Home Range Tools for ArcGIS®[4] (Rodgers et al. 2007), Home Range Estimation in R: the adehabitatHR Package (Calenge 2011), or Geospatial Modelling Environment (http://www.spatialecology.com/gme/).

Land cover preference.—Use of the 6 land cover designations by Canadian lynx will be estimated by calculating selection ratios at the 2 spatial scales: within each of the sampling strata across the study area and within Canadian lynx use areas. The percentage of each land cover used by each Canadian lynx will be determined by noting the land cover associated with each relocation. These percentages will be averaged across all Canadian lynx. The percentage of each land cover available will be determined by noting the land cover associated with each of ~6,000 random points across the study area and each of 500 random points within each Canadian lynx’s use area. Points that fall on ice, snow, or lakes will be excluded from the analysis. The ratio will be calculated as the

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[4] HRT: Home Range Tools for ArcGIS® may have been upgraded to function with ArcGIS 10.x as well as ArcGIS 9.x. This will need to be confirmed.

observed proportion of use over the available proportion in each cover class. The confidence intervals will be calculated from a boot strap distribution of the ratios.

Univariate analysis.—Eight physical habitat and human development variables (Table 7) will be reviewed for potential inclusion in multiple regression models of landscape use by Canadian lynx. Landscape use by Canadian lynx and availability of habitat characteristics, as described by the physical habitat and human development variables, will be evaluated at 2 spatial scales (i.e., study area-wide and within use areas). Comparisons will be 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 will be compared over all relocation points for an individual Canadian lynx to averages of the same variables at ~6,000 points randomly selected across the study area and 500 additional points randomly selected across each use area for individual Canadian lynx. Paired t-tests (paired by Canadian lynx) between used and available averages will be applied at each spatial scale and for each stratum. One-sample t-tests will also be conducted to compare the mean of each variable used by Canadian lynx to the mean of each variable available across the study area. These comparisons will enable 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 Canadian lynx are large, the available averages will be considered constants.

Table 7. Variables available for modeling resource selection by Canadian lynx on the Kenai Peninsula, Alaska. Distances will be in 100s of meters and densities will be in m per km^2.

Variable	Description
Human activity	
DEV_KM	Density of human developments
KROAD_KM	Density of all roads
HROAD_KM	Density of high use roads
LROAD_KM[a]	Density of low use roads
Topography	
ELEV	Elevation
ASPECT	Aspect
Vegetation	
COVER_C	Distance to forest or shrub cover
LCOVCAT	Land cover category

For each physical habitat and human development variable, a univariate logistic regression model for resource selection across the study area and within use areas will be estimated for Canadian lynx, with used or available as the binary response. The estimated linear coefficients from each model will be averaged over all Canadian lynx, and the standard error of this mean will be used to form a t-test for the significance of the variable.

Additionally, a 1-sample t-test for each variable will be used to test for differences in average availability of resources across the Kenai Peninsula study area and within use areas. Two sample t-tests will also be conducted to compare used resources within use areas.

Multivariate analysis.—The results from the above t-tests and univariate regressions will be used to determine if a variable is to be included in the multiple regression modeling of resource selection at each spatial scale. Variables with a significant difference in the t-tests or with a regression coefficient different from 0 with alpha = 0.10 will be candidates for modeling, subject to elimination of redundant variables through a correlation analysis. We will calculate correlations among the variables and keep 1 variable for multivariate modeling among correlations that were > 0.7. After reducing the variable set with the correlation analyses, we will use backward model selection procedures to obtain a final multivariate linear model for each stratum at each spatial scale. Final models of landscape use across the study area and within use areas will then be determined using these selected variables with and without land cover effects included.

For analysis of resource selection at the use-area level, we will fit logistic regression models using each Canadian lynx's relocations as the used data and the 500 random observations from within each use area as the available data. Each Canadian lynx will be fit separately to a logistic regression model with the same covariates, and the coefficients will be averaged across Canadian lynx. The standard error of this average will be used to form a t-test to determine if each coefficient is significantly different from 0. We will remove the variable with the highest p-value from the model and refit the new model as above, until each variable left in the model is significant at the 0.05 level.

For analysis of resource selection at the study-area level, we will fit logistic regression models using each Canadian lynx's location points as the used data and the random selection of points from the entire study area as the available data. Again, we will use backward selection, and incorporate a jackknife procedure to test the significance of the coefficients in the model. The model will be fit with every Canadian lynx in the data set, and the same model will be fit with each Canadian lynx sequentially removed from the data set. Jackknife pseudo-values (X_j) will be obtained for each covariate in the model by

$$X_j = n\overline{X} - (n-1)\overline{X}_{-j}$$

where n is the number of Canadian lynx, $\overline{X}$ is the regression coefficient calculated with each Canadian lynx in the model, and $\overline{X}_{-j}$ is the regression coefficient calculated without Canadian lynx j in the model. The jackknife parameter estimate will be found by averaging the pseudo-values. The standard error of this average will be used to form a t-test to determine if the regression coefficient for a covariate is significantly different from

0. We will remove the variable with the highest p-value from the model and refit the model as above. This process will continue until each variable left in the model is significant at the 0.05 level.

LCP corridor analysis

Squires et al (2013) combined resource selection and least-cost path models to define empirically movement corridors for Canadian lynx in the Northern Rocky Mountains. Their analysis demonstrated that connectivity between lynx habitat in Canada and that in the conterminous US is facilitated by only a few putative corridors.

We will follow the steps outlined by Beier et al. (2007) to move from maps of habitat quality generated by the RSF calculations for lynx to the development of LCP corridors:

- Step 1 – Use the inverse of the habitat quality maps as a resistance map.

We will use the inverse of the RSF models to generate a cost surface for LCP analyses. Through this subjective translation (Beier et al. 2008), we assume that pixels with higher RSF values afford lower costs to movement than those with low RSF values. We define resistance or travel cost as the inverse of quality or permeability, such that:

Resistance (cost of travel through a pixel) = Maximum quality - pixel quality

Resistance reflects the ecological cost of Canadian lynx 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.

- Step 2 – Select start and end points for modeling corridors.

We will identify the largest patch of high-quality habitat for Canadian lynx (as defined by the RSF analyses) in each 5th-level watershed in proximity to the Sterling Highway (see http://databasin.org/datasets/fa6f0a4210b14b239fc4ea0d5c165886 for 5th-level watersheds in Alaska). The habitat patch in each of paired watersheds on either side of the highway would become source and end termini for the LCP algorithm to generate pathways. The LCP algorithm may not form a continuous path of low resistance pixels. To identify well-connected, low-resistance pixels, each pixel's *accumulative cost-distance* should be calculated to determine the lowest possible cumulative resistance from that pixel to terminuses in each watershed. These cost-distance values do form continuous paths.

- Step 3 – Determine an appropriate width for the modeled corridor.

As the path created by the LCP algorithm may be a single pixel width wide (~30 m), we will buffer each path at least 350 m following guidelines recommended for carnivores (BCEAG 2011). However, as the length of the corridor increases, so should the width (Bentrup 2008).

Corridors developed will be compared and evaluated. Evaluation will begin with a frequency distribution of habitat quality (e.g., percentage low, percentage medium, percentage high) within each corridor. Consideration will be given to merging the separate corridors when appropriate.

Estimate of resources needed

In addition to personnel (Table 8), resources needed for developing movement corridors for Canadian lynx will include access to professional literature via the internet, GIS software (i.e., ArcGIS 10.x), a biostatistics software package, a program to estimate use areas (home ranges), and the MS Office software package.

Table 8. Estimate of resources needed for developing movement corridors for Canadian lynx in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days
Personnel		
	Wildlife Ecologist	50
	Spatial Analyst	25
	Biostatistician	20

Moose

Ernst et al. (2009) collected data on moose in proximity to the Sterling Highway in the northwestern portion of the Kenai Peninsula between MP 58 in the east and 79 in the west. Moose were captured primarily in the western portion of the study area on the Kenai lowlands, a glaciated plain encompassing the western third of the Kenai Peninsula. From 2006–2008 investigators with the ADF&G and the Chugach National Forest captured and collared moose with GPS units in the vicinity of Cooper Landing on the Kenai Peninsula.

The primary study area for the RSF analysis will be the northern Kenai Peninsula from south of the Sterling Highway north to Cook Inlet and Turnagain Arm. Previously developed habitat models for moose provide insight to what variables may be considered in the RSF analysis: land cover (Puttock et al. 1996, Snaith et al. 2002, Dussault et al. 2006b, Serrouya et al. 2011), landscape structure (e.g., edge density, distance to cover) (Dussault et al. 2006b, Serrouya et al. 2011), topography (Hurley et al. 2007, Serrouya et al. 2011, Laurian et al. 2012), snow depth (Puttock et al. 1996), and roads (Laurian et al. 2008, Laurian et al. 2012).

RSF data sources

Animal locations.–Thirty adult cow moose were successfully captured and collared with GPS units in late October and early November, 2005 by Ernst et al. (2009)[5]. GPS units were programed to record locations of moose every 30 minutes from October through March, then every 2 hours 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

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[5] The Kenai National Wildlife Refuge will need to be contacted to request use of these data.

were programed to record locations of moose every 30 minutes from October through March, then every 2 hours until collar release in summer. Thirty units were recovered with their data in July and August 2007; 1 unit was not recovered. These investigators recorded over 558,239 locations from 59 moose with GPS units from 2005 through 2007. Additional locations of radio-collared moose will be available for this analysis from a cooperative study conducted by the Chugach National Forest and ADF&G in the Cooper Landing area[6].

Description of use areas.—Use areas of moose may be calculated from the relocation data using HRT: Home Range Tools for ArcGIS®[7] (Rodgers et al. 2007), Home Range Estimation in R: the adehabitatHR Package (Calenge 2011), or Geospatial Modelling Environment (http://www.spatialecology.com/gme/).

Land cover classes.–Land cover has been described on the Kenai Peninsula through a number of mapping efforts (DeVelice 2012). These include the National Land Cover Database (NLCD) which is based on satellite imagery representing 2001 conditions (Selkowitz and Stehman 2011); LANDFIRE EVT which describes existing vegetation cover based on satellite imagery from around 2000 (http://www.landfire.gov/notifications23.php); KP 2006 which is based on satellite imagery from 2002 (O'Brien 2006); Borough Veg which is based on interpretation of aerial photographs taken from 1996 through 2001 (Kenai Peninsula Borough Spruce Bark Beetle Task Force 2003); and KP 1999 which is based on satellite imagery from 1989 (Ducks Unlimited and Spatial Solutions 1999). DeVelice's (2012) evaluation of these land cover databases indicated while the LANDFIRE EVT land cover product provided the most classes (97) it was also the least accurate. NLCD had fewer classes (19) but was considered the most accurate product available for the Kenai Peninsula.

Landscape structure.–A "distance to cover" variable will be calculated by determining the distance from relocation and random points to the nearest pixel with a land cover class characterized as cover (depending on the land cover map used). FRAGSTATS (McGarigal et al. 2012) will be used to describe patterns of landscape structure that may influence habitat use by moose (e.g., edge density).

Topography.–A 1:250,000 digital elevation model will be acquired from the U.S. Geological Survey (http://agdc.usgs.gov/data/usgs/erosafo/dem/dem.html) and will be used to describe aspect and elevation on the Kenai Peninsula.

Roads.–A digital database describing roads on the Kenai Peninsula is available from the Kenai Peninsula Borough (http://www2.borough.kenai.ak.us/GISDept/Downloads.html). A 1-km^2 moving-window GIS routine will be used to calculate the density of high use, low use, and all roads in m per square kilometer for each pixel in the study area. These values will be associated with relocation and random points.

RSF data analysis

This analysis will focus on two spatial scales of habitat selection as described by Johnson (1980):

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[6] ADF&G and the Chugach National Forest will need to be contacted to request use of these data.

[7] HRT: Home Range Tools for ArcGIS® may have been upgraded to function with ArcGIS 10.x as well as ArcGIS 9.x. This will need to be confirmed.

- 2nd Order selection of a multi-year, annual use area within the study area, and
- 3rd Order selection of habitats within the multi-year, annual use areas of the moose.

Land cover preference.—Use of land cover designations by moose will be estimated by calculating selection ratios at the 2 spatial scales. The percentage of each land cover used by each moose will be determined by noting the land cover associated with each relocation. These percentages will be averaged across all moose. The percentage of each land cover available will be determined by noting the land cover associated with each of ~12,000 random points across the study area and each of 500 random points within each moose's use area. Points that fall on ice, snow, or lakes will be excluded from the analysis. The ratio will be calculated as the observed proportion of use over the available proportion in each cover class. The confidence intervals will be calculated from a boot strap distribution of the ratios.

Univariate analysis.—Nine physical habitat and human development variables (Table 9) will be reviewed for potential inclusion in multiple regression models of landscape use by moose. Landscape use by moose and availability of habitat characteristics, as described by the physical habitat and human development variables, will be evaluated at 2 spatial scales (i.e., study area-wide and within use areas). Comparisons will be 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 will be compared over all relocation points for an individual moose to averages of the same variables at ~12,000 points randomly

Table 9. Variables available for modeling resource selection by moose on the Kenai Peninsula, Alaska. Distances will be in 100s of meters and densities will be in m per km^2.

Variable	Description
Human activity	
KROAD_KM	Density of all roads
HROAD_KM	Density of high use roads
LROAD_KM[a]	Density of low use roads
Topography	
ELEV	Elevation
ASPECT	Aspect
Vegetation	

Table 9. Variables available for modeling resource selection by moose on the Kenai Peninsula, Alaska. Distances will be in 100s of meters and densities will be in m per km^2.

Variable	Description
COVER_C	Distance to forest or shrub cover
LCOVCAT	Land cover category
EDGE_D	Edge density

selected across the study area and 500 additional points randomly selected across each use area for individual moose. Paired t-tests (paired by moose) between used and available averages will be applied at each spatial scale and for each stratum. One-sample t-tests will also be conducted to compare the mean of each variable used by moose to the mean of each variable available across the study area. These comparisons will enable 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 moose are large, the available averages will be considered constants.

For each physical habitat and human development variable, a univariate logistic regression model for resource selection across the study area and within use areas will be estimated for moose, with used or available as the binary response. The estimated linear coefficients from each model will be averaged over all moose, and the standard error of this mean will be used to form a t-test for the significance of the variable.

Additionally, a 1-sample t-test for each variable will be used to test for differences in average availability of resources across the Kenai Peninsula study area and within use areas. Two sample t-tests will also be conducted to compare used resources within use areas.

Multivariate analysis.—The results from the above t-tests and univariate regressions will be used to determine if a variable is to be included in the multiple regression modeling of resource selection at each spatial scale. Variables with a significant difference in the t-tests or with a regression coefficient different from 0 with alpha = 0.10 will be candidates for modeling, subject to elimination of redundant variables through a correlation analysis. We will calculate correlations among the variables and keep 1 variable for multivariate modeling among correlations that were >0.7. After reducing the variable set with the correlation analyses, we will use backward model selection procedures to obtain a final multivariate linear model for each stratum at each spatial scale. Final models of landscape use across the study area and within use areas will then be determined using these selected variables with and without land cover effects included.

For analysis of resource selection at the use-area level, we will fit logistic regression models using each moose's relocations as the used data and the 500 random observations from within each use area as the available data. Each moose will be fit separately to a logistic regression model with the same covariates, and the coefficients will be averaged across all moose. The standard error of this average will be used to form a t-test to determine if each coefficient is significantly different from 0. We will remove the variable with the highest p-value from the model and refit the new model as above, until each variable left in the model is significant at the 0.05 level.

For analysis of resource selection at the study-area level, we will fit logistic regression models using each moose's location points as the used data and the random selection of points from the entire study area as the available data. Again, we will use backward selection, and incorporate a jackknife procedure to test the significance of the coefficients in the model. The model will be fit with every moose in the data set, and the same model will be fit with each moose sequentially removed from the data set. Jackknife pseudo-values (X_j) will be obtained for each covariate in the model by

$$X_j = n\overline{X} - (n-1)\overline{X}_{-j}$$

where n is the number of moose, $\overline{X}$ is the regression coefficient calculated with each moose in the model, and $\overline{X}_{-j}$ is the regression coefficient calculated without moose j in the model. The jackknife parameter estimate will be found by averaging the pseudo-values. The standard error of this average will be used to form a t-test to determine if the regression coefficient for a covariate is significantly different from 0. We will remove the variable with the highest p-value from the model and refit the model as above. This process will continue until each variable left in the model is significant at the 0.05 level.

LCP corridor analysis

Schmidt (2007) inferred that that incorporation of ecological and social landscape features such as vegetation and roads would improve the description of dispersal by moose through LCP analyses. The analysis also tested whether high-quality or low-quality habitat would be a likely dispersal corridor for moose. She found that even at large spatial scales, the inclusion of habitat and landscape features in LCP analyses provided a good understanding of gene flow and population structure of moose in Alaska.

We will follow the steps outlined by Beier et al. (2007) to move from maps of habitat quality generated by the RSF calculations for moose to the development of LCP corridors:

- Step 1 – Use the inverse of the habitat quality maps as a resistance map.

We will use the inverse of the RSF models to generate a cost surface for LCP analyses. Through this subjective translation (Beier et al. 2008), we assume that pixels with higher RSF values afford lower costs to movement than those with low RSF values. We define resistance or travel cost as the inverse of quality or permeability, such that:

Resistance (cost of travel through a pixel) = Maximum quality - pixel quality

Resistance reflects the ecological cost of moose 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.

- Step 2 – Select start and end points for modeling corridors.

We will identify the largest patch of high-quality habitat for moose (as defined by the RSF analyses) in each 5th-level watershed in proximity to the Sterling Highway (see http://databasin.org/datasets/fa6f0a4210b14b239fc4ea0d5c165886 for 5th-level watersheds in Alaska). The habitat patch in each of paired watersheds on either side of the highway would become source and end termini for the LCP algorithm to generate pathways. The LCP algorithm may not form a continuous path of low resistance pixels. To identify well-connected, low-resistance pixels, each pixel's *accumulative cost-distance* will be calculated to determine the lowest possible cumulative resistance from that pixel to terminuses in each watershed. These cost-distance values do form continuous paths.

- Step 3 – Determine an appropriate width for the modeled corridor.

As the path created by the LCP algorithm may be a single pixel width wide (~30 m), we will buffer each path at least 350 m following recommended guidelines (BCEAG 2011). However, as the length of the corridor increases, so should the width (Bentrup 2008).

Corridors developed will be compared and evaluated. Evaluation will begin with a frequency distribution of habitat quality (e.g., percentage low, percentage medium, percentage high) within each corridor. Consideration will be given to merging separate corridors when appropriate.

Estimate of resources needed

In addition to personnel (Table 10), resources needed for developing movement corridors for moose will include access to professional literature via the internet, GIS software (i.e., ArcGIS 10.x), a biostatistics software package, a program to estimate use areas (home ranges), and the MS Office software package.

Table 10. Estimate of resources needed for developing movement corridors for moose in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days
Personnel		
	Wildlife Ecologist	55
	Spatial Analyst	30
	Biostatistician	25

Dall sheep

Habitat quality model

We have selected Bayesian Networks (BN) as the framework for development and application of habitat quality models for focal species that lack sufficient data to develop

RSFs. A BN is simply a way of showing how variables interact and cause specific outcomes relative to habitat quality. BNs are commonly used in wildlife and natural resource management and land use planning. Creating BNs for wildlife and natural resource management involves several stages:

- Listing the variables that most influence outcomes of interest;
- Specifying the states or values that each variable can take;
- Linking the variables; and
- Specifying probabilities of the linkages.

We briefly describe the process to develop a BN here but more detailed guidance is available from Marcot (2006), Marcot et al. (2006), and from the website of the provider of the model framework (e.g., http://www.norsys.com/). The best approach for building BNs may be to use information from the scientific literature to initially structure the model; then use a combination of expert knowledge and empirical data to specify the probability distributions of each node. Because knowledge in wildlife and natural resource management comes as much from personal expertise as from statistical data and field research, BNs are viewed as tools that can effectively combine prior knowledge, expert knowledge, and field data, and that can provide useful results even in the face of missing or incomplete data.

Influence diagrams, which can be a simple figure of boxes and arrows showing relations and causes among variables, will be used to initially depict how habitat and environmental conditions influence habitat quality of Dall sheep (Figure 3).

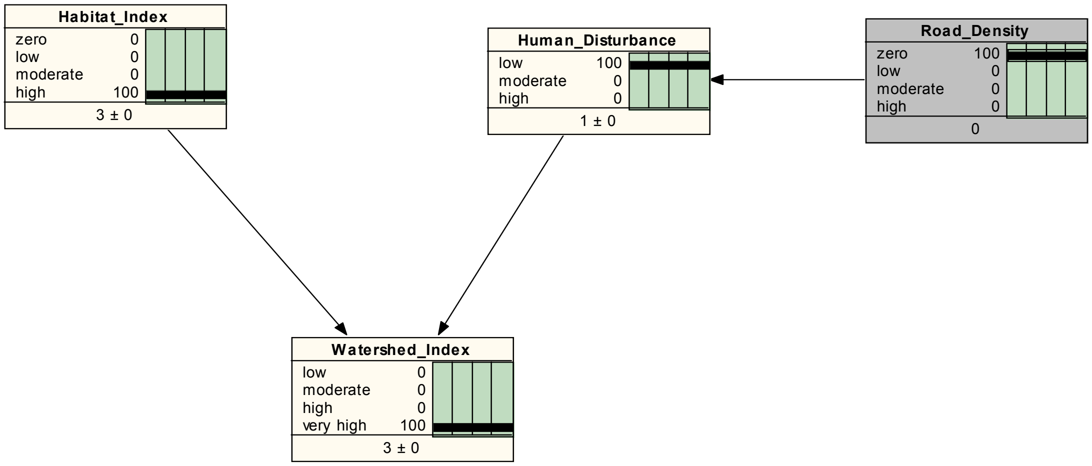


Figure 3. Example of an influence diagram that will be used in the BN for Dall sheep on the Kenai Peninsula, Alaska, USA.

The basic pattern we will use for developing the BN for Dall sheep is depicted here. We anticipate evaluating the effects of habitat and the effects of threat factors on movement patterns of Dall sheep. Based on published habitat quality models for Dall sheep, variables that are likely to be incorporated into our model include land cover (Walker et al. 2006, Parker and Walker 2007, Walker et al. 2007), topography (Parker and Walker 2007, Walker et al. 2007, Barker 2012), land form (Parker and Walker 2007), and distance to escape terrain (Rachlow and Bowyer 1998, Walker et al. 2006, Walker et al. 2007).

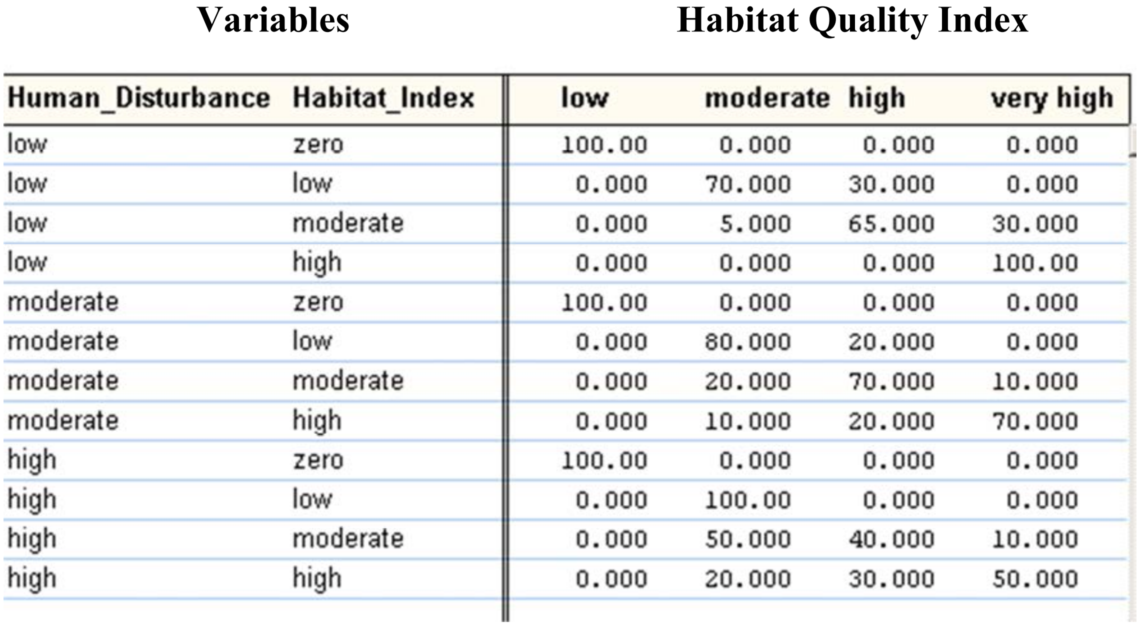
The states for each variable will be developed from information in the literature on the influence that variable has on habitat quality. Combinations of the states from each of the variables lead to a determination of an index of the quality of the habitat for Dall sheep. This will be accomplished through the development of conditional probability tables, an integral part of a BN (Figure 4).

LCP corridor analysis

Shafer et al (2012) found that RSF-based habitat models for alpine ungulates produced such realistic resistance surfaces that the LCP analyses were reflective of movements actually undertaken by the animals. The LCP resistance values were based on RSF coefficients; as a result, they had meaningful biological interpretations and showed that habitat selection (or the inverse resistance score) was a good predictor of gene flow.

We will follow the steps outlined by Beier et al. (2007) to move from the map of habitat quality generated for Dall sheep through the BN process to the development of LCP corridors:

- Step 1 – Use the inverse of the habitat quality map as a resistance map.



Variables **Habitat Quality Index**

Human_Disturbance	Habitat_Index	low	moderate	high	very high
low	zero	100.00	0.000	0.000	0.000
low	low	0.000	70.000	30.000	0.000
low	moderate	0.000	5.000	65.000	30.000
low	high	0.000	0.000	0.000	100.00
moderate	zero	100.00	0.000	0.000	0.000
moderate	low	0.000	80.000	20.000	0.000
moderate	moderate	0.000	20.000	70.000	10.000
moderate	high	0.000	10.000	20.000	70.000
high	zero	100.00	0.000	0.000	0.000
high	low	0.000	100.00	0.000	0.000
high	moderate	0.000	50.000	40.000	10.000
high	high	0.000	20.000	30.000	50.000

Figure 4. Example of conditional probability table that will be used in the BN for Dall sheep on the Kenai Peninsula, Alaska, USA.

We will use the inverse of the values in the habitat quality model for Dall sheep to generate a cost surface for LCP analyses. Through this subjective translation (Beier et al. 2008), we assume that pixels with higher values afford lower costs to movement than those with low values. We define resistance or travel cost as the inverse of quality or permeability, such that:

Resistance (cost of travel through a pixel) = Maximum quality - pixel quality

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.

- Step 2 – Select start and end points for modeling corridors.

We will identify the largest patch of high-quality habitat for Dall sheep (as defined by the BN-based analysis) in each 5th-level watershed in proximity to the Sterling Highway (see http://databasin.org/datasets/fa6f0a4210b14b239fc4ea0d5c165886 for 5th-level watersheds in Alaska). The habitat patch in each of paired watersheds on either side of the highway would become source and end termini for the LCP algorithm to generate pathways. The LCP algorithm may not form a continuous path of low resistance pixels. To identify well-connected, low-resistance pixels, each pixel's *accumulative cost-distance* should be calculated to determine the lowest possible cumulative resistance from that pixel to terminuses in each watershed. These cost-distance values do form continuous paths.

- Step 3 – Determine an appropriate width for the modeled corridor.

As the path created by the LCP algorithm may be a single pixel width wide (~30 m), we will buffer each path at least 350 m following recommended guidelines (BCEAG 2011). However, as the length of the corridor increases, so should the width (Bentrup, 2008).

Evaluation of corridors will begin with a frequency distribution of habitat quality (e.g., percentage low, percentage medium, percentage high) within each corridor. Consideration will be given to merging the separate corridors when appropriate.

Estimate of resources needed

In addition to personnel (Table 11), resources needed for developing movement corridors for Dall sheep will include access to professional literature via the internet, GIS software (i.e., ArcGIS 10.x), a Bayesian Network model shell, and the MS Office software package.

Table 11. Estimate of resources needed for developing movement corridors for Dall sheep in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days
Personnel		
	Wildlife Ecologist	25
	Spatial Analyst	20
	Biostatistician	0

Multispecies movement corridors

Once the movement corridors have been defined for each species, the species-specific corridors will be overlaid to evaluate a multi-species network following the process of

Alexander (2001). However, it may be a challenge to identify multi-species corridors given the variations in resource selection within and between species and variations in species behavior (Chetkiewicz and Boyce 2009). As a result it is likely that options for planning will could include multiple corridors within the Sterling Highway Milepost 45-60 Project area.

Estimate of resources needed

Table 12. Estimate of resources needed for developing and evaluating multispecies movement corridors for focal species in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days
Personnel		
	Wildlife Ecologist	10
	Spatial Analyst	5
	Biostatistician	0

Review of movement corridor analyses

This analysis and description of movement corridors for focal species on the Kenai Peninsula described above was responsive to the potential need to mitigate the effects on movement patterns of wildlife by the Sterling Highway Milepost 45-60 Project. Successful highway mitigation projects may be defined by maintaining existing animal movement patterns from one side of a newly constructed road to the other (Ford et al. 2009). As an initial step in evaluating the effectiveness of the results of these analyses will be to convene a panel of experts to review the findings. The objective of the panel will be to evaluate the outcomes of this work based on their experience and knowledge of corridor analysis and transportation planning.

Estimate of resources needed

Table 13. Estimate of resources needed for review of the suitability of movement corridors for focal species in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource		Days
Personnel		
	Wildlife Ecologist	10
	Expert Reviewers (≤5)	3 each

Evaluation of movement corridor analyses

We are proposing implementation of a monitoring program to evaluate the movement corridors we identify prior to using them to locate and plan construction of wildlife crossing-structures or other mitigation efforts. Reviews of studies designed to monitor the effectiveness of wildlife crossing-structures after their construction found that 62% of studies used sand-traps, sooted track-plates, or some other type of tracking material to identify species use and frequencies and that 50% of studies in another review used remotely triggered devices such as infrared-triggered cameras, counters, video cameras, or still cameras (Ford et al. 2009). The analysis of Ford et al (2009) indicated that camera-based monitoring is more cost-effective in the long term and more efficiently detects crossing events for most large mammal species than other monitoring methods.

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 (O'Connell et al. 2011). 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.

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.

We propose to use RECONYX™ PC900 HyperFire™ Professional High Output Covert IR cameras (http://www.reconyx.com/hyperfire_detail.php?model=PC900) based on the recommendation of Kelly and Holub (2008). We will establish 10 cameras on the north side of the proposed realignment of the Sterling Highway and 10 cameras on the south side of the proposed realignment at random locations within the modeled movement corridors within 500 m of the new alignment. We will also establish 10 cameras on the north side of the proposed realignment of the Sterling Highway and 10 cameras on the south side of the proposed realignment at random locations outside of the modeled movement corridors within 500 m of the new alignment. We will position cameras approximately 0.75 m off the ground, in a randomly selected direction. Motion within an infrared beam will trigger the cameras to take 5 photographs at roughly 0.2-second intervals. Cameras will be equipped with the No-Glow™ High Output Covert infrared flash array that will allow continuous operation throughout day and night. We will download photographs from each camera onto a handheld computer once a week during a 12-month study period. We will then classify photographs using a database form to record the number of individuals by date, species, and direction of travel for each camera.

We will calculate the capture frequency of each focal species as the number of photographs/1,000 camera days, and will use a 1-sample t-test for comparisons between the corridor and non-corridor locations. Other studies have indicated that an effort of approximately 1,000 trap nights is needed to be certain that a species is truly absent from a site (Carbone et al. 2001). The objective of this work will be to determine if focal species are more likely to occur within modeled movement corridors than in the landscape matrix. This analysis will allow us to determine if the modeled corridors are selected by focal species as movement/use areas more often than the landscape matrix and if associated locations of mitigation measures are appropriate.

Estimate of resources needed

In addition to personnel, equipment, materials, and travel (Table 14), resources needed for evaluation of the effectiveness of movement corridors will include access to professional literature via the internet, GIS software (i.e., ArcGIS 10.x), a biostatistics software package, and the MS Office software package.

Table 14. Estimate of resources needed for evaluation of the effectiveness of movement corridors for focal species in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource	Days	Cost	Total
Personnel			
Wildlife Ecologist	15	--	--
Spatial Analyst	3	--	--
Biostatistician	10	--	--
Wildlife Technician	156	--	--
Equipment and materials	Number	Cost / item	
Remote field cameras	40	$650	$26,000
Miscellaneous materials	--	--	$1,000
Travel	Miles	Cost / mi	
Vehicle costs	9,700	$0.565	$5,480

Summary

A synthesis of information available in the literature indicated that implementation of alternatives under consideration for the Sterling Highway Milepost 45-60 Project may have effects on wildlife habitat, frequency of WVCs, and movement patterns. The objective of this document was to suggest means and methods to identify potential locations of management practices designed to mitigate effects on movement patterns. We developed 3 alternative approaches to identifying movement corridors for 6 focal species. Those approaches include using existing models to facilitate the corridor analysis (i.e., brown bear), using existing data to develop RSFs to facilitate the corridor analyses (i.e., black bear, Canadian lynx, and moose), and developing models of habitat quality from information in the literature to facilitate the corridor analyses (i.e., wolverine and Dall sheep) (Table 15). Following completion of these analyses we recommend that the results be reviewed by a panel of species and transportation ecology experts to ensure that the findings have scientific merit.

We have also suggested that limited field work be done to evaluate the modeled corridors to ensure they provide movement paths for the focal species. The resulting information will be useful in planning and implementing practices and structures that may mitigate the effects of highway construction and operation on wildlife movement patterns. The individual analyses for the focal species and the evaluation are presented as components of the whole wildlife study. The component analyses may be implemented as a complete suite of studies or individual components may be selected for implementation depending on degree of concern for the resource, time constraints, and/or funding constraints.

Table 15. Estimated total preliminary resources needed for development and evaluation of movement corridors for focal species in response to the Sterling Highway Milepost 45-60 Project on the Kenai Peninsula, Alaska, USA.

Resource	Days	Cost	Total
Personnel			
Wildlife Ecologist	240	--	--
Spatial Analyst	128	--	--
Biostatistician	75	--	--
Wildlife Technician	156	--	--
Expert Reviewers	~15	--	--
Equipment (assessment)	Number	Cost / item	
Remote field cameras	40	$650	$26,000
Miscellaneous materials	--	--	$1,000
Travel (assessment)	Miles	Cost / mi	
Vehicle costs	9,700	$0.565	$5,480
Services			
Access to professional literature	--	--	--
Software			
ArcGIS 10.x	--	--	--
Statistics package	--	--	--
MS Office	--	--	--
Use area (home range estimator)	--	--	--
Bayesian Network model shell	--	--	--

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