Title
Bozeman Pass wildlife linkage and highway safety study

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BOZEMAN PASS WILDLIFE LINKAGE AND HIGHWAY SAFETY STUDY

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Abstract: Large-scale conservation efforts seek to maintain habitat connections so that native wildlife (and plant) species may move across the landscape as necessary to meet their needs to survive and reproduce. Barriers caused by roads and railways pose a significant impediment to wildlife movement at all scales throughout the U.S. Northern Rockies area, and a risk of injury or death to animals whose needs require crossing when traffic is present. In turn, animals on highways pose a risk of injury or death to motorists and property damage to vehicles. As traffic volumes increase, these risks also increase. Bozeman Pass is just beginning to experience significant conflicts with wildlife. In addition to a four-lane freeway (Interstate 90) there are parallel frontage roads and a railway. As traffic volumes continue to increase the problems will only get worse. To plan for inevitable growth in human populations and traffic volumes, and to fulfill the mandates of the Transportation Equity Act for the 21st Century (TEA-21) regarding wildlife needs and public safety, it is imperative that options for wildlife conflict mitigation be started as soon as possible on Bozeman Pass. This study attempts to identify the problem areas for wildlife and human safety at Bozeman Pass and make recommendations about how and where to mitigate wildlife mortality and human safety issues in the connectivity zone. Several moose, mountain lions, black bear, deer, elk, small mammals, and one wolf have been killed by traffic within the past two years. GIS models and maps have been developed for this project to summarize location data for wildlife-vehicle collisions, wildlife movement corridors, wildlife habitat, and potential sites for wildlife crossing structures. GIS models using least-cost-path analysis were compared with the known locations of road-kills and model predictions were close to actual crossing points. Differences between the field data and the model data suggest that the models can be improved by incorporating additional data layers and perhaps by adjusting the weights of model variables.

The Study Area

Bozeman Pass on Interstate 90 is located in south central Montana about 40 miles north of Yellowstone National Park (figure 1). The study area in and around Bozeman Pass encompasses approximately 908 km2 and includes the cities of Bozeman on the western edge and Livingston on the eastern edge of the study site. Interstate 90 bisects the area between Bozeman to Livingston and the Montana Rail Link runs parallel to the freeway. The distance between Bozeman and Livingston is approximately 33.6 km (21 miles).

The area comprises a mosaic of residential, agricultural, and public lands. The landscape varies from shrub-grassland communities near Bozeman and Livingston to coniferous forests in the middle section of Bozeman pass. Elevation varies from 1,398 meters at its low point near Livingston to 1,733 meters at the top of the pass. This area represents wildlife habitat that is fragmented by human development and transportation routes between the Gallatin and Absorka mountain ranges in the south to the Bridger and Bangtail Mountains in the north. Bozeman Pass has been identified as an important wildlife corridor or linkage, which connects important wildlife habitat in the Northern Rockies wildland matrix (Walker and Craighead 1997, Reudiger et. al. 1999).

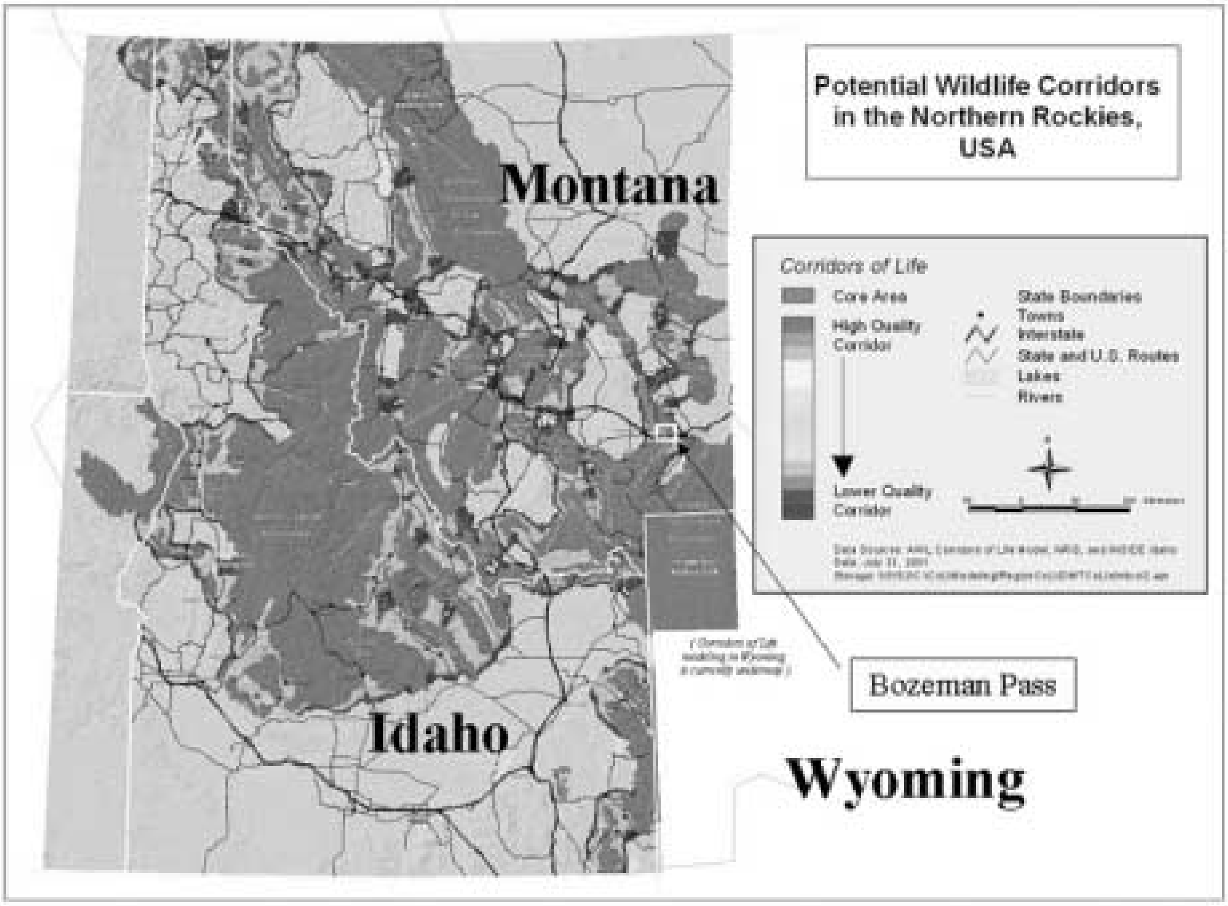

Fig. 1. The study area

Background

Large-scale conservation efforts seek to maintain habitat connections so that native wildlife (and plant) species may move across the landscape as necessary to meet their needs to survive and reproduce. Barriers caused by roads and railways pose a significant impediment to wildlife movement at all scales throughout the U.S. Northern Rockies area, and a risk of injury or death to animals whose needs require crossing when traffic is present (Joslin and Youmans 1999, Munro et. al. *in press*, Rauer and Zedrosser *in press*). In turn, animals on highways pose a risk of injury or death to motorists and property damage to vehicles. As traffic volumes increase, these risks also increase.

Different species of wildlife have specific habitat needs at various times of the day, season, year, and lifetime, in order to survive and reproduce. In order to meet those needs they must move from one type of habitat to another. Daily movements include travel from resting areas to foraging areas and to sources of water. Seasonal and yearly movements include travel from winter range to calving areas to summer range. Lifetime movements include dispersal of young animals from their areas of birth to establish new territories or home ranges. Highways and railways are sources of animal-vehicle collisions that kill individual animals and may threaten local wildlife populations through direct mortality, habitat loss, and habitat fragmentation: high volumes of traffic along transportation corridors can block, deflect, or delay wildlife movements and pose a risk of mortality to both wildlife and vehicle occupants (Maehr et. al. 1991, Forman and Hersperger 1996, Kohn et. al. 1999, Maxell and Hokit 1999, Claar et. al. 1999, Irby and Podruzny 2000). There is also growing evidence that highways with high traffic volumes such as Highway 3 in Canada are affecting genetic diversity of populations by acting as barriers to gene flow (Proctor et. al., in press).

Animal-vehicle collisions also threaten human safety. Each year, more than 200 motorists are killed and thousands more are injured. The insurance industry estimates that the annual cost to society for these fatalities and injuries is $200 million. Individual motorists usually pay at least $2,000 in vehicle repair every time they hit a large animal (U.S. Dept. of Transportation 2000).

Bozeman Pass is experiencing an increase in significant conflicts with wildlife. In addition to a four-lane freeway (Interstate 90), there are parallel frontage roads and a railway. As traffic volumes continue to increase the problems will only get worse. To anticipate these conflicts and plan for mitigation at this point will be much more cost effective if wildlife crossing options can be included in scheduled construction and maintenance projects rather than instituted at a later date, perhaps as emergency measures. To plan for inevitable growth in human populations and traffic volumes, and to fulfill the mandates of the Transportation Equity Act for the 21st Century (TEA-21) regarding wildlife needs and public safety, it is also imperative that options for wildlife conflict mitigation be started as soon as possible on Bozeman Pass.

To reduce the risk of collisions and increase the permeability of the highway barrier for wildlife, highway design modifications have traditionally been used, such as underpasses, overpasses, elevated spans, and fences. Data to evaluate crossing structures are available from Florida and other areas (Langton 1989, Yates et. al. 1995, Foster and Humphrey 1995, Land and Lotz 1996, Evink et. al. 1996 and 1999, Boarman and Sazake 1996, Roof and Wooding 1996, Forman and Hersperger 1996, Jackson 1996 and 1999, Simonyi et. al. 1999, MacDonald and Smith 1999, Veenbaas and Brandjes 1999, Jones 2000) and more regionally relevant studies in Banff National Park, Alberta (Clevenger 1998, Clevenger and Waltho 1999 and 2000, Gibeau and Heuer 1996, Leeson 1996, Paquet and Callaghan 1996, Paquet et. al. 1996), which demonstrate that underpasses and extended bridge spans are effective means to increase permeability for some species of wildlife. This study was designed to provide new data for additional species such as mountain lion, elk, black bear, and moose in a region with different topography and habitat than found in Banff, and to develop GIS tools to accurately predict movement routes and highway crossing sites for wildlife species. To provide input into highway construction planning and to allow for the construction of underpasses, overpasses, elevated spans or fences, if necessary, it is necessary to provide accurate, systematically collected data on the locations of animal vehicle collisions and to determine as accurately as possible the routes that animals use as they attempt to traverse the highway. Models developed by this project will identify probable movement routes for groups of species such as forest carnivores and ungulates, and will hopefully be applicable to many other areas throughout western Montana where they can be applied even in the absence of road-kill data to help locate sites for the construction of crossing structures. The identification of wildlife movement habitat is also critical for conservation planning; in order to allow wildlife species to move across landscapes, habitat on both sides of highways must be identified and prioritized for conservation management.

The Rocky Mountains run north to south. Landscape features, such as mountain passes, are natural conduits for wildlife movement but these are often bisected by highways and other human developments. Several studies have addressed aspects of wildlife movement habitat and the barriers to movement posed by highways; many of these have focused on grizzly bears. Models of grizzly bear movement to date have generally followed the logic of the grizzly bear cumulative effects model or CEM (Weaver et. al. 1986, USDA Forest Service 1990, ICE6 1994), which ranked habitat effectiveness for grizzly bears. Habitat effectiveness in the CEM was calculated by multiplying indices of habitat quality and habitat heterogeneity, and subtracting the summed indices of human disturbance and mortality risk.

One approach to modeling movement habitat uses a least-cost-path approach. Three studies have modeled movement habitat for grizzly bears in the Northern Rockies (Primm and Underwood 1996, Walker and Craighead 1997, Craighead et. al. *in press*). The central approach taken in these models is the generation of a least-cost path across a value, or cost, surface. Least-cost paths are travel routes between two given points that incur the lowest cost of transit. Originally, least-cost-paths were computed for vehicles, primarily delivery or freight vehicles, and cost was determined by distance traveled and the economics of individual vehicles (miles per gallon and maintenance costs).

Because of the wide applicability of computer algorithms that could compute least-cost-paths, several of these functions were incorporated into Geographic Information System (GIS) software, such as Arc Info™ GRID. The concept behind the least-cost-path is that within a grid of cells, each cell has a cost value associated with it.

The impedance, or cost of travel across the cell equals the value of the cell times one (if travel occurs parallel to a side) or times 1.414214 (if travel occurs diagonally across the cell). The cost of an entire route is the accumulated cost of all cells along the route. Most applications involve costs measured in dollars, time, or energy expended, e.g.: for emergency vehicles time is the overriding cost factor. However, these GRID functions have been useful for other analyses in which cost can be determined by other metrics. Cost can be calculated in any terms that can be quantified. For wildlife movement modeling, cost has been generally calculated as an index of risk to the animal, or its converse; security and food availability using the general approach of the CEM. Least-cost-path models for grizzly bear movement have focused on habitat quality and human disturbance; lower costs for grizzly bears are associated with high quality habitat and low human disturbance. Higher costs for grizzly bears are associated with poor habitat and high levels of human disturbance.

Similar least-cost-path approaches have also been used at a finer scale to model probable highway crossing points for grizzly bears in Slovenia using the IDRISI™ functions COSTGROW AND PATHWAY (Kobler and Adamic 1999), and in the North Cascades of Washington State using Arc Info™ GRID (Singleton and Lehmkuhl 1999). In Slovenia, a habitat suitability model was developed based upon resource selection functions derived from observed bear locations of females with cubs. Least-cost-paths from one side of the highway to the other all crossed at one of three points, which were then further evaluated as locations for wildlife bridges or underpasses to be constructed. In Washington, broad-scale linkage models for wolf, lynx, wolverine, and grizzly bear were developed using least-cost-path analysis on a cost surface derived from human disturbance (roads, buildings), forest canopy closure and tree size, slope and distance to water.

In a related approach that does not use least-cost-paths, the US Fish and Wildlife Service has analyzed grizzly bear habitat through “linkage zones” between some of the large blocks of public land in the Northern Rockies using four GIS layers: road density, human developed sites, vegetative cover, and riparian zones, to score the habitat in terms of its relative value (Servheen and Sandstrom 1993, Servheen et. al. 2001. A similar approach was used to determine linkage zones across Canada’s Highway 3 in Southeast British Columbia and Southwest Alberta (Apps 1997).

Traffic volumes on Interstate 90 between Bozeman and Livingston can be expected to increase in the near future as the populations of those cities increase, and as visitation, commercial transportation, and other highway use grows. At current levels, the Interstate, frontage roads, and the Burlington Northern Railroad pose a significant risk to many species of wildlife. Elk, deer, mountain lions, and bears are occasionally killed on the freeway. In 1998, thirty-nine carcasses were recorded between East Bozeman and Bozeman Pass by local residents. At least 15 black bears have been killed in the past two decades near the Bear Canyon exit according to the records of local residents. Such animal-vehicle collisions are a traffic hazard, a cause of significant property damage, and a public safety issue, as well as a detriment to wildlife populations. Currently, elk have been inferred by local residents to use the Montana Rail Link overpass at the west end of Bozeman Pass near milepost 314 as a crossing corridor for local movement, and it is possible that they also use it for seasonal movement. Elk are rarely killed on I-90 at this site. However, other species, including moose, black bear, mountain lion, and deer, have avoided the use of this bridge and have been killed on the interstate during either local or seasonal movements. Black bear in particular disperse in the fall and move from their natal areas after weaning. Some of them are funneled by the highway barriers and end up in the city or in subdivisions. Others attempt to cross the highway and are often killed. In anticipation of increasing traffic, serious accidents, and blockage of wildlife movement, it is wise to begin planning methods to allow wild animals to more easily traverse this transportation corridor safely.

Objectives

The overall objective of this project is to develop GIS and field biology tools that can accurately predict the areas along highways in the Rocky Mountains where wildlife are most likely to attempt to cross. These tools can then be used throughout the region to provide input into highway construction planning in order to improve the ability of animals to cross the highway safely and reduce the risk of collisions to both wildlife and motorists. These tools will hopefully be used to help highway departments site the construction of additional underpasses, overpasses, elevated spans, and fences. They can also be used by regional land conservancies and government agencies in identifying priority areas for wildlife habitat protection.

Specific objectives include:

1. Determine the location of most wildlife-vehicle collisions in the Bozeman Pass area.
2. Identify the best habitat for movement using available data in a GIS: the initial model includes two habitat layers (habitat value and forest edge) and two disturbance layers (road density and building density).
3. Refine the movement habitat model to best fit it to the road-kill data by incorporating additional data layers and by conducting sensitivity analysis on the habitat and disturbance value coefficients.
4. Determine the best site for wildlife crossing mitigation projects.
5. Collaborate in design of the type of mitigation structure most appropriate for its location on the landscape and most effective for wildlife passage.
6. Protect adequate habitat on either side of crossing structures on private and public lands so that animals can approach and leave with security.
7. Apply the refined movement habitat models to other areas in the Northern Rocky Mountains.

To implement the results of this study it will be necessary to provide accurate, systematically collected data on animal movements, and to provide it during the highway department systems planning stage for projects that are scheduled to occur three to four years later.

Methods

Methods employed in this project consist of field methods and GIS methods. Field methods were used to collect data on the locations of animal-vehicle collisions and to determine as accurately as possible the routes that animals use as they attempt to traverse the highway. GIS methods focused on an analysis of habitat conditions bordering the highway to identify probable habitat for movement of various species and develop GIS tools to accurately predict movement routes and highway crossing sites for wildlife species. GIS models, coupled with data on animal collision locations, remote camera photos, and animal signs, such as tracks, can pinpoint the most important highway crossing sites. Models identify probable movement routes for groups of species such as forest carnivores and ungulates, and will hopefully be applicable to many other areas. Models will be refined to best fit the field data as the project proceeds.

Field methods

Road-kill data

Biologists and volunteers recorded the date, location to the closest mile marker and tenths, and species of road-kills as they traveled between Bozeman and Livingston. Interesting or unusual species were further investigated by CERI personnel. All data were entered into a GIS database. Searches of agency records provided additional wildlife collision data. Road-kill data were obtained from Montana Department of Transportation and from Montana Fish, Wildlife, and Parks. Records from Montana Fish, Wildlife, and Parks date as far back as 1977. Accurate records contain the date, location and any other pertinent information such as sex of the animal. These data were entered into the GIS database. Ten records of road-killed black bears were not included in the data due to the lack of accurate locations. A mountain lion was killed in May of this year and brought in to Montana Fish, Wildlife, and Parks. However, an accurate location was not given from the Montana highway patrolman, and that record could not be used.

Track surveys

Snow tracking surveys will be implemented in October or November of 2001 as soon as snowfall begins and will continue as long as snow remains along the freeway. Track observations are made on surfaces prepared at potential crossing sites such as underpasses. Track plates consisting of a sticky paper surface on which an animal steps after collecting a layer of soot or other material on its feet will also placed. All data points will be entered into a GIS database.

Remote cameras

Remote cameras will used to photograph animals crossing in front of the camera at key sites. These will be employed as the study progresses and crossing sites are identified. Other probable crossing sites, such as culverts and bridges, will also be examined.

GIS Methods

Least cost path analysis

We constructed a least-cost path corridor model to identify quality habitat areas for wildlife movement. Modeling methods were based on a model developed for American Wildlands (Walker and Craighead 1997, Craighead et. al. *in press*) with a building density variable added. Four variables were used: two habitat variables (habitat suitability and habitat complexity), and two disturbance variables (weighted road density and building density). Using these variables, probable movement habitat for two wildlife species groups -- forest carnivores and ungulate species -- were evaluated.

Unlike the original regional scale (1 km by 1 km) American Wildlands model, this Bozeman Pass analysis was done at a finer scale of resolution (30m by 30 m) to approximate a localized view of wildlife movement. All spatial analysis was done using Environmental Systems Research Institute (ESRI) ArcInfo™ software.

The model was designed to assess the potential movement habitat for wildlife through Bozeman Pass and the surrounding area. Wildlife species were split into two groups: forest carnivore species and ungulate species. The forest carnivore group included black bear, grizzly bear, mountain lion, and wolf species. Ungulate species group included moose, elk, mule deer, and whitetail deer. Habitat suitability was assigned for each land cover type for each species group; in general the forest carnivore group was assigned higher values for forest cover types and the ungulate group was assigned higher values for open cover types. However, there is broad overlap between the models since many of the forest carnivores travel across open habitat types, particularly at night, and since ungulate species often rely on forest cover for security.

Habitat suitability was thus assigned by an "expert opinion" ranking of land cover types. Suitability values ranged between 0 (unsuitable) to 3 (highly suitable). Land cover was ranked to match habitat requirements of the two species groups. Land cover was acquired from the U.S. Forest Service Northern Region 30-meter Land Cover data set. Land cover classification was conducted at the University of Montana Wildlife Spatial Analysis Laboratory for the Montana Gap Analysis Project (Redmond et. al. 1998) and derived from Landsat Thematic Mapper images.

Habitat complexity was defined as the forest to shrub-grassland interface density (edge density). This variable was determined by the amount of cell lengths where forest and either shrub or grassland land cover types were adjacent. Density was calculated by summing the lengths in 1km^2 windows using the FOCALSUM GRID function.

Weighted road density was determined using two roads data sources. For the western half of the study area, a GPS roads data layer was obtained from the Gallatin County GIS Lab. Roads were updated in January 1999. Roads outside Gallatin County, in the eastern portion of the study area, were based on USFS 1992 Cartographic Feature File (CFF) data. Since no road attributes existed for the eastern portion of the study area, values were based on pre-existing knowledge of the area and USGS topographic and orthophoto maps. Road weights ranged from 1 - 4. A weight of 1 indicated either Forest Service or low-use county roads, 2 represented state and moderate-use county roads, 3 were in-use railroad tracks and Highway 89, and Interstate 90 was given a weight of 4. Road length was calculated for each cell and multiplied by road weight. These weighted road lengths were then summed per km^2 in order to calculate total weighted road density.

Building density was determined using a "structures" coverage provided by Gallatin County and derived from USGS orthophotos. For the western half of the study area, structures were identified from Gallatin County GIS Lab data. For the eastern half of the study area (Park County), structures were on-screen digitized from 1997 - 1998 digital orthophotos. The AGGREGATE command was used to identify the number of buildings per cell and then FOCALSUM was used to calculate number of buildings per km2.

Before application to the model, all variable were normalized:

Variable	Normalized Values
Habitat Suitability	0 -1
Habitat Complexity	0 - 2
Weighted Road Density	0 - 4.4
Building Density	0 - 4.7

To develop the travel cost surface necessary for the cost distance and corridor analysis, the four variables were combined into a single GRID layer. This was done in three steps. For the forest carnivore model, the equations used were as follows:

Forest Carnivore Species:
1. 1. Habquality = Habitat Suitability * Habitat Complexity
2. 2. Habcost = -1.0 (Habquality) + maximum value of Habquality
3. 3. Costsurface = (Habcost * 2) + Road Density + Building Density

To calculate habitat quality (habquality), habitat suitability and habitat complexity were multiplied (this calculation is based on the CEM model (CEM 1990). Habcost was calculated multiplying –1 with habquality and adding it to the maximum habquality value. This equation set the highest quality habitat (areas with no cost for movement) equal to 0. To calculate costsurface, habcost was doubled in order to balance habitat influence with the human disturbance variables (road density and building density), and added to the values for those variables.

For the ungulate species model we varied the equation slightly in order to determine whether multiplying or adding the habitat variables would give more realistic results. Rather than multiply habitat suitability and habitat complexity, they were added. All other of the equations were the same. This is a preliminary model; both models will be run using multiplication and both will be run using addition of habitat variables. Only one run of each was done at this time because of time constraints; it takes several days to develop a new cost grid and run all the necessary pairwise comparisons. Using addition instead of multiplication to calculate the habitat quality (Habquality) enabled areas with high suitability and 0 habitat complexity values, to retain an influence in reducing the cost surface, instead of being reduced to zero.

The final costsurface grids for the two wildlife groups were evaluated to identify core habitat and suitable habitat areas for movement. Core areas were identified as areas with the lowest costsurface and at sizes suitable for home range. Movement areas were defined as having the lowest costsurface values with areas too small to be home ranges, but sufficient enough to support wildlife movement. The movement areas were conceptualized as "stepping stones" for wildlife movement between the larger core areas. Both core areas and movement areas were considered to be source areas for animal movement; or Nodes. Thirty-seven nodes were identified from the forest carnivore cost surface results and 44 were identified from the ungulate species cost surface results.

Least-cost path analysis was applied to both the forest carnivore and ungulate species nodes using each group's respective overall cost surface grid. The COSTDISTANCE function develops these by calculating a value for each cell in the grid, which is the cumulative value of all the cells in the least-cost-path to that cell from the nearest point of a Node area (or source grid). The inputs for this function are a cost grid of the Node, or source area, and the overall Cost Grid. Thus, as you move further from the source grid, cells increase in value or cost depending upon the least cost route to that individual cell.

Pairs of COSTDISTANCE grids were then used as inputs for the CORRIDOR function to define least cost corridors between pairs of Core areas, or source grids. The inputs for each comparison are the COSTDISTANCE grid for one source (i.e., a habitat node north of the freeway) and the COSTDISTANCE grid for the other source (I,e., a habitat node south of the freeway). This function combines these into a single grid with cell values representing the relative cost of that cell along a route between the nearest point of each source grid. The CORRIDOR function was thus used to determine the least-cost corridors between node pairs. The final step in the model was to determine the least-cost corridors between all nodes. This was done by combining inter-node corridor results using LPOS and PICK functions, resulting in a single grid containing the lowest values for each internode corridor.

GIS Analysis

The model results are currently being refined by comparing the results of alternate GIS methods (ie. multiplying habitat variables versus adding them) and by conducting a sensitivity analysis on the relative weighting of the values assigned to cover types, road impacts, and building impacts. As maps are developed using different techniques and weightings, they are evaluated first by subjectively deciding which results seem most realistic in terms of what is known about the habitat and wildlife distribution. Secondly, the results of field surveys and road-kill data will be correlated with the most realistic least cost path corridor results to determine the degree to which the lcp models predict the areas at which animals are attempting to cross. Additional sensitivity analysis and the incorporation of additional data layers, such as slope or topographic severity, can be used to further refine the models and better fit them to the field data. These models can then be used to predict sites for crossing structures both locally and throughout the region.

Implementation of Results

Researchers will evaluate wildlife crossing and collision information to determine potential sites for wildlife crossing structures. Landscape and highway features, such as high cliffs, broad valleys, streams, fencing, and existing culverts, will help determine the options for mitigation. These options will be discussed with MDT personnel during site visits and at various stages in the project. An expert panel will be convened to include respected scientific authorities on the species in question and highway design engineers to determine the best feasible design for crossing structures at each crossing site.

In collaboration with the Gallatin Valley Land Trust, American Wildlands, the Trust For Public Lands, Yellowstone to Yukon Conservation Initiative, the Western Transportation Institute, and other governmental and non-governmental organizations in Bozeman and Livingston, researchers are investigating lands adjacent to I-90. A critical part of mitigation will be the status of land ownership and wildlife habitat adjacent to the freeway right-of-way at potential crossing sites. The study is evaluating current habitat conditions, conservation easements, and land status on adjacent public and/or private lands as well as opportunities for cooperation with landowners or managers.

Results

Road-kill Results

Currently we have 108 known locations of road-killed animals dating back to 1989. These data come from a variety of sources including the Montana Department of Transportation (MDT), Montana Fish Wildlife and Parks (MDFWP), biologists working for CERI who search for road-kills on a weekly basis, and volunteers that drive Bozeman Pass daily. Since MDT and MDFWP have not kept systematic records in the past, and since only records of bears, mountain lions, and wolves, were usually kept, the totals cannot be considered completely representative of relative numbers of species killed.

Carnivores hit along Interstate 90 or the frontage road include black bear (*Ursus americanus*), mountain lion (*Felis concolor*), wolf (*Canis lupus*), and red fox (*Vulpes vulpes*). Ungulates include elk (*Cervus elaphus*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*). A variety of smaller mammals including striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), and porcupine (*Erethizon dorsatum*), as well as several species of raptors have been killed by vehicle collisions.

By far the most commonly hit species are deer, either mule deer or white-tailed deer, which represent 62.0 percent (67 individuals) of the total road-kills accurately recorded. Black bears (8 individuals) and raccoons (8 individuals) were the next most commonly hit species each representing 7.4 percent of these data. Smaller mammals, such as skunks, represent 6.4 percent(7 individuals) of the current data.

Moose (4 individuals) and elk (4 individuals) each represent 3.7 percent of the total road-kill data. Carnivores, including coyote, represent (3 individuals); mountain lion (2 individuals); wolf (1 individual); and red fox (1 individual), were all represented in the accurately recorded road-kill data. These carnivores represent 6.5 percent of these data. Raptors and porcupines represent less than 3 percent of these data (table 1).

Table 1
Number of Road-kills (108) and Percentages with Known Locations on Bozeman Pass (1989 through Sept. 13, 2001)

Carnivores					
	Black bear	Wolf	Mountain lion	Coyote	Red fox
Number of Road Kills	8	1	2	3	1
Percentage	7.4%	<1%	1.9%	2.8%	<1%
Ungulates					
	Moose	Elk	Mule deer	White-tailed deer	Unknown deer species
Number of Road Kills	4	4	22	26	19
Percentage	3.7%	3.7%	20.4%	24.1%	17.6%
Other Species					
	Porcupine	Raccoon	Striped skunk	Raptor	
Number of Road Kills	1	8	7	2	
Percentage	<1%	7.4%	6.4%	1.9%	

2001 Road-kill totals

All species of large- and medium-sized mammals were recorded from January 1 through Sept 13, 2001, by volunteers and CERI staff. Not all volunteers recorded accurate locations, and many records were duplicates. CERI staff verified the species and locations and reconciled duplicate records. By January 1, 2002, these data should be representative of the relative proportion of each species being killed by vehicles over the course of a year. A total of 88 road-kills were recorded; of these 69 road-kills were considered to have accurate locations and species identification. Of this subtotal, deer species currently represent 63.7 percent (44 individuals) of the accurate 2001 data. The smaller mammals, including raccoons and skunks, accounted for 21.8 percent of this year's data. Carnivores, including coyote, red fox, and wolves, accounted for 7.2 percent of the data. Elk represent 2.9 percent of the 2001 data. Raptors and porcupines combined represent 4.3 percent of the data (table 2).

Table 2
Numbers and Percentages of Road-killed Animals with Accurate Locations on Bozeman Pass (2001 Jan 1 through Sept. 13)

Carnivores					
	Black bear	Wolf	Mountain lion	Coyote	Red fox
Number of Road Kills	0	1	0	3	1
Percentage	0	1.4%	0	4.3%	1.4%
Ungulates					
	Moose	Elk	Mule deer	White-tailed deer	Unknown deer species
Number of Road Kills	0	2	12	16	16
Percentage	0	2.9%	17.4%	23.2%	23.2%

Other Species				
	Porcupine	Raccoon	Striped skunk	Raptor
Number of Road Kills	1	8	7	2
Percentage	1.4%	11.6%	10.2%	2.9%

GIS Results

The original model for both forest carnivores and ungulates was run using four data layers: habitat value, forest edge, road density, and building density. In the forest carnivore model, habitat value and forest edge values were multiplied together; these values were negative in sign (low cost). The values for road density and building density were added; these values were positive in sign (high cost). The sum of the density values was then added to the product of the habitat values. Areas with a low cost were chosen as core or movement habitat in areas where wildlife species were known to reside. In the ungulate species model, the two habitat values were added together rather than multiplied. Least cost corridors were then identified between these habitat areas using the techniques described. The differences between the forest carnivore model and the ungulate model were due primarily to differences in habitat values assigned to each group, and secondarily to using an additive rather than multiplicative algorithm.

Forest Carnivore Species Model

Results of the Forest Carnivore Species Model indicate that there are three areas where animals moving from one patch of secure habitat to another are likely to approach Interstate 90 (figure 2). These are termed the West Bozeman Pass Corridor, the Bozeman Pass Summit Corridor, and the East Bozeman Pass Corridor. Relative habitat values indicate that the West Bozeman Pass corridor offers the best route for connectivity between secure habitat on either side of the freeway, and that the Bozeman Pass Summit Corridor offers the least connectivity for forest carnivores.

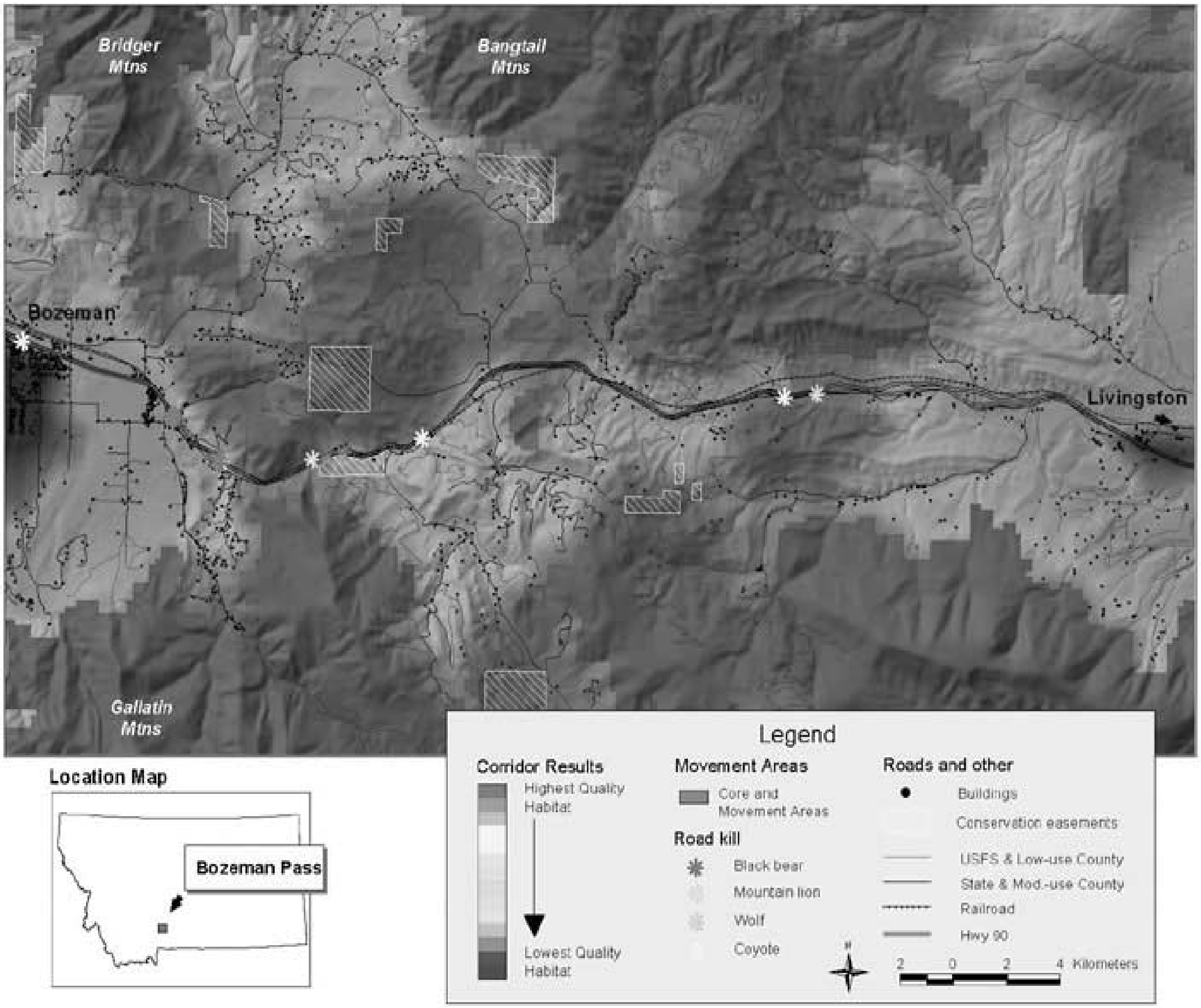

Fig. 2. Forest carnivore species habitat model

Ungulate Species Model

Results of the Ungulate Species Model indicate that there are also three areas where animals moving from one patch of secure habitat to another are likely to approach Interstate 90 (figures 3 and 4). These are similar to the forest carnivore corridors: the West Bozeman Pass Corridor, the Bozeman Pass Summit Corridor, and the East Bozeman Pass Corridor, with differences in the extent of the movement habitat. The greatest difference is in the patches of secure habitat, or nodes, that are identified for ungulates in comparison to the nodes identified for carnivores. Knowledge of local distributions confirms the fact that the smaller nodes are frequently utilized by both deer and elk. Because there is more secure movement habitat on both sides of the freeway, the movement corridors identified are generally larger. In particular, the West Bozeman Pass Corridor for ungulates extends further east and includes the area near the Trail Creek exit. Similarly, the Bozeman Pass Summit Corridor is slightly wider and may extend as far west as the Jackson Creek exit. The East Bozeman Pass Corridor remains about the same as it does for carnivores.

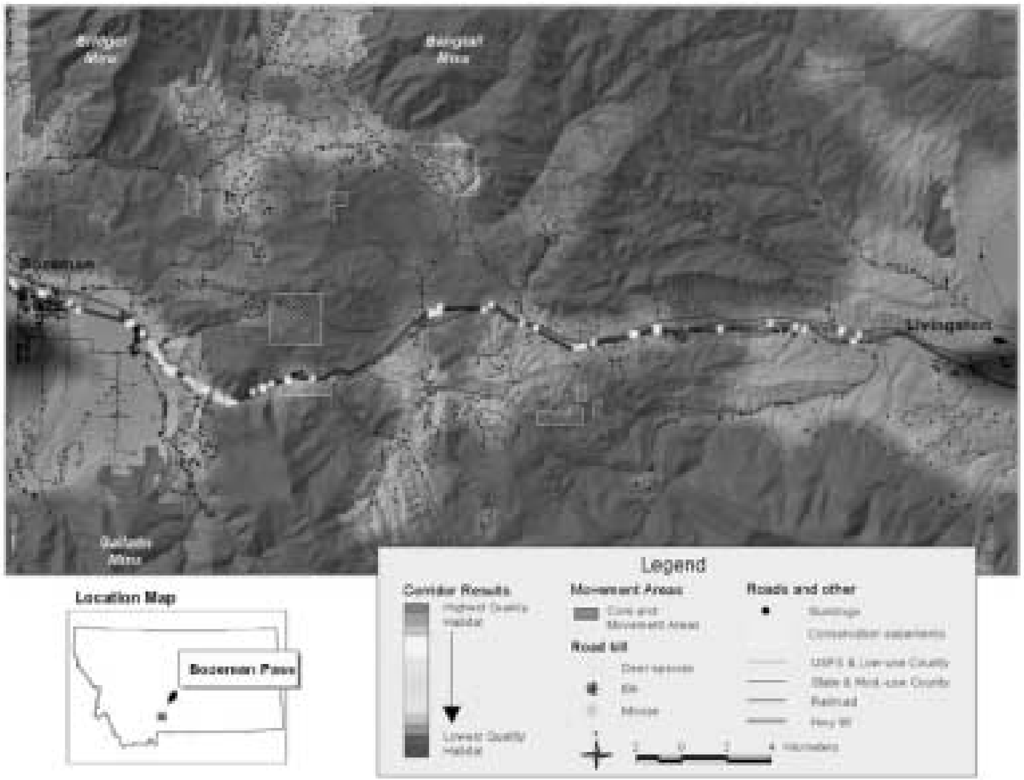

Fig. 3. Ungulate species habitat model

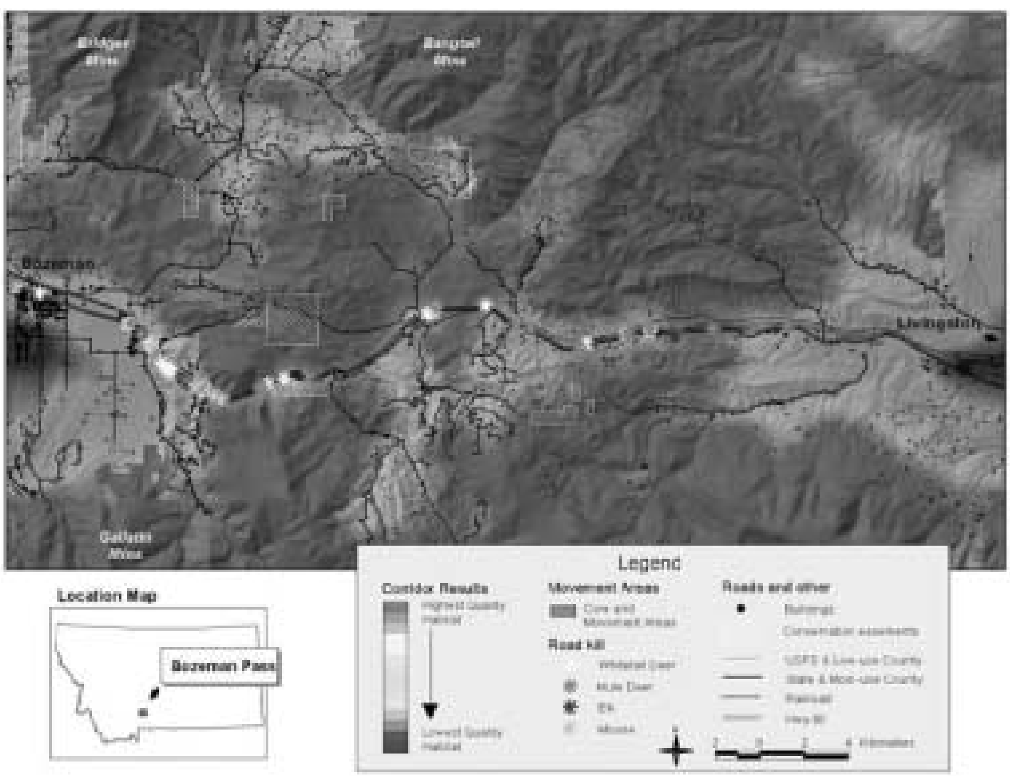

Fig. 4. Deer road-kill separated by species

Discussion

A majority of the carnivore road-kills occurred on or near the routes identified as potential corridors by the GIS analysis. These initial models incorporated only two habitat variables and two disturbance variables. Examination of the results indicates that at the western end of Bozeman Pass, the main corridor habitat includes several areas of cliff on either side of the freeway, which may reduce use of the center of the identified corridor for movement. Access to the freeway itself is difficult from the north due to steep cliffs and a fence. It is likely that most animals moving through this corridor stay on gentler terrain on either side of the cliff areas; those that do approach the freeway in the center of this area are probably deflected east or west to the areas where road-kills have been recorded. In future refinements of the model, the addition of slope and topography should fit the model better to the road-kill data.

Road-killed black bears occurred in the western part of the study area near Bozeman. Eight black bears have been killed within a 3.2 km (two miles) stretch of Interstate 90. The bears probably wander through coniferous forests and streams along Moffit gulch, Bear Canyon, and Trail Creek until they come upon the interstate and try to cross. The mountain lion road-kills also occurred on the western edge of the study area near Bozeman. Both mountain lions were killed within a 3.2 km stretch of Interstate 90 near steep and rocky terrain.

Road-killed coyotes were found throughout the study area. Their generalist ecology requires them to travel and utilize a variety of habitats. Two of the coyotes were killed near corridors. A single wolf was killed on the frontage road adjacent to Interstate 90 on the Livingston side of Bozeman Pass. It was killed in an area considered to be quality corridor habitat for both forest carnivores and ungulates. Wolves probably fit the ungulate model better than the forest carnivore model since they are cursorial hunters using open habitat to run down their prey. They are generally found in habitat that contains their prey: primarily deer and elk.

Ungulates were killed throughout the study area from Bozeman to Livingston. High concentrations of ungulates were road-killed in the vicinity from Bozeman to Trail Creek. When mule deer and white-tailed deer are separated out (figure 3) there is considerable overlap between road-kill locations. In general, more white-tailed deer than mule deer are killed in the open habitat near agricultural lands and residential areas east of Bozeman, and more mule deer than white-tailed deer are killed in the open rangeland near the East Corridor.

The model in general seems to be a better fit for mule deer than for white-tailed deer, which use more open habitats closer to human developments. The addition of the habitat variables in this model did not change the results greatly from multiplication of the habitat variables as done in the carnivore model. At this preliminary stage it appears that addition of variables gives more realistic results since it enabled areas with high suitability and 0 habitat complexity values, to retain an influence in reducing the cost surface, instead of being reduced to zero. At this scale, areas of suitable monotypic vegetation with no complexity are undoubtedly used by both carnivores and ungulates.

Both carnivores and ungulates (black bears, moose, and deer) were killed at the western end of the study area near the mouth of Moffitt Gulch where no corridor habitat was indicated. This points up one of the limitations of the model approach, which can only delineate movement habitat between two end points of known habitat. These are not models of animal movement, but rather models of habitat conditions. In some cases, animals can see the habitat across the freeway that they are trying to reach; in other cases, they move through areas of good habitat, such as Moffitt Gulch, and encounter a freeway at the end. Even though they have no immediate habitat goal in site, it is likely that they continue to move in the same direction compelled by whatever drive is operating (i.e., hunger, search for a mate, avoidance of predators, dispersal) and move out onto the freeway. In the case of Moffitt Gulch they encounter a sort of trap because the riparian habitat empties out at a freeway interchange where there are no fences to impede movement. It is likely that animals move out across the frontage roads and encounter a bridge over the local road; if they are uncomfortable crossing under this small bridge, with loud traffic passing overhead, they are likely to travel up the entrance or exit ramps and eventually onto the freeway.

A possible refinement to the models that may address this issue is to identify areas where relatively undisturbed riparian habitat leads up to the freeway; especially where it intersects at any area where there is an interchange and a gap in the fence. A possible design modification to address this problem is to install cattle guards across the entrance and exit ramps. A better solution might be to install cattle guards and to raise and extend the bridge leaving space and perhaps vegetative cover alongside the local road beneath the freeway. Site-specific examples such as this illustrate the importance of obtaining field data, the possibilities of adjusting the models to fit the data, and the possibilities of using both models and field data to develop site-specific solutions that may keep animals off the freeway, and allow them to cross the barrier safely.

Conclusions

To successfully implement highway design modifications, we feel that the solution lies in providing enough distance from traffic and enough cover so that sensitive species such as elk, bears, wolverine, etc., can pass across the highway without being frightened. Design modifications that are possible include underpasses, overpasses, elevated spans, and fences. The appropriate solution needs to be determined on a site-specific basis to accommodate topography, habitat, and the needs of the animals for which it is designed. Biologists need to work with highway engineers to determine how closely we can approach the best biological solution given the constraints of budgets, engineering features, and local topography. The convening of expert panels of biologists and engineers on a site-specific basis will be extremely important in determining and validating the types of structures that will be most effective in allowing wildlife crossing of highways. As this project continues, the process will in essence be a conceptual model for cooperation with a wide range of involved parties that will be developed and tested: these include federal and state agencies, local governments, private landowners, land trusts, conservation groups, and other non-governmental organizations.

This project has the potential to provide increased security for wildlife moving locally between the Story Hills and Wineglass Mountains, which is part of longer migration routes between the Bridger and Absaroka or Gallatin Mountains. The transportation corridor, which bisects the north-south ridges contains an interstate freeway, frontage road and railroad and is likely one of the major barriers for animal movement in the region. Forest Service biologists have identified Bozeman Pass as a high-priority, key linkage area in the Northern Rockies due to the cumulative impact of these transportation systems (Ruediger et. al. 1999).

In addition to I-90 this project has the potential to provide increased security for wildlife moving locally across Highway 86 between the Story Hills, Bangtail Mountains, and Bridger Mountains, also as a part of longer migration routes. Highway 86 is also experiencing increased traffic flows as residential and ski area developments increase along the Bridger Creek drainage. White-tailed and mule deer particularly use this area both for local movements between water and forage, and for seasonal movements between winter and summer range. Many animals are killed between Story Mill Road and the entrance to Bridger Canyon near the "M." It is not within the scope of the present project to collect equivalent road-kill data for Highway 86, but the GIS models predict movement habitat across this highway. In the future, the collection of road-kill data along other highways and roads could be used to further validate the GIS models.

The CERI study will help inform decision-makers where animals cross between the Bridger and Absaroka Mountains and where wildlife mortality poses the greatest threat to human safety. Baseline field data will continue to be collected throughout the year in 2001, and 2002. GIS models of movement habitat for groups of affected wildlife species such as forest carnivores and ungulates will be refined to better fit road-kill, track survey, and remote camera data. To maintain and improve conditions for wildlife movement, design modifications in bridge length and landscaping features can be incorporated into bridge reconstruction if crossing sites are identified at current bridge locations. Alternatively, if crossing sites occur in other areas, new crossing structures such as underpasses, overpasses, or elevated spans can be considered.

The decision to spend millions of taxpayer's dollars on highway improvements to protect wildlife habitat and populations is largely a political issue. Although highway departments, such as the Montana Department of Transportation, may not feel compelled to act soon on such planning and construction, the history of human population growth throughout the world and in the United States, particularly in areas like the Front Range of Colorado, which is similar in many ways to the Bozeman Pass area, teaches us that eventually decisions will have to be made. The sooner such decisions are made, the lower the environmental, social, and economic costs. Tools such as those being developed by this study will provide highway departments with the data necessary to make those decisions when the time comes. More importantly, perhaps, these tools will provide regional land trusts, land management agencies, and state and local governments with the data needed to pursue effective conservation planning in order to maintain wildlife habitat and movement options: so that the habitat will still be intact by the time the highway department is ready to act.

Biographical Sketch: April Hudoff Craighead is a wildlife biologist with Craighead Environmental Research Institute. April received her master's degree in biology from Montana State University in 2000. Her primary focus is avian ecology, particularly raptor ecology. She is also interested in paleoecology, and part of her master's research was focused on relating paleontological data from cave deposits (pack-rat middens of raptor pellets) to habitat and climate change. She is working on the Bozeman Pass/I-90 project and is collaborating with Wayne McCrory on a review and analysis of bear poaching in North America.

References

Apps, C. D. 1997. Identification of grizzly bear linkage zone along the highway 3 corridor of Southeast British Columbia and Southwest Alberta. Prepared for B.C. MELP and WWF-Canada.

Aspen Wildlife Research, Calgary, AB. 45pp.

Beier, P., and R. J. Barrett. 1993. The cougar in the Santa Ana Mountain Range, California. Final Rep., Orange City Coop. Mt. Lion Study. University of California, Berkeley. 104pp.

Boarman, W. and M. Sazaki. 1996. Highway mortality in desert tortoises and small vertebrates: Success of barrier fences and culverts. Pages 169-173 in Evink G., D. Ziegler, P. Garrett, and J. Berry, editors. Highways and movement of wildlife: Improving habitat connections and wildlife passageways across highway corridors. Proceedings of the Florida Department of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.]

Claar, J. J., N. Anderson, D. Boyd, M. Cherry, B. Conard, R. Hompesch, S. Miller, G. Olson, H. Ihsle Pac, J. Waller, T. Wittinger, and H. Youmans. 1999. Carnivores. Pages 7.1-7.63 in Joslin, G. and H. Youmans, coordinators. 1999. Effects of recreation on Rocky Mountain wildlife: A Review for Montana. Committee on Effects of Recreation on Wildlife, Montana Chapter of the Wildlife Society. 307 pp.

Clevenger, A.P. 1998. Permeability of the Trans-Canada Highway to Wildlife in Banff National Park: the importance of crossing structures and factors influencing their effectiveness. Proceedings of the International Conference on Wildlife Ecology and Transportation. February 10-12, Ft. Myers, FL. FL-ER-69-98: pp. 109-119.

Clevinger, A.P., and N. Waltho. 1999. Dry drainage culvert use and design considerations for small and medium-sized mammal movement across a major transportation corridor. Pages 263-277 in Evink G.L., P. Garrett, D. Zeigler, eds. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

Clevinger, A.P., and N. Waltho. 2000. Factors influence the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14: 47-56.

Craighead, F.L., T. Merrill, R. Walker, E. Underwood-Russell, and S.A. Primm. *In press*. Least-cost grizzly bear habitat models: a comparison. Ursus.

Evink G.L., P. Garrett, D. Zeigler, eds. 1999. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds. 1996. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors. Proceedings of the Florida Department of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

Forman, R.T.T., and A.M. Hersperger. 1996. Road ecology and road density in different landscapes, with international planning and mitigation solutions. Pages 1-23 in Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors. Proceedings of the Florida Department of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

Foster, M.L. and S.R. Humphrey. 1995. Use of highway underpasses by Florida Panthers and other wildlife. Wildlife Society Bulletin 23(1) 92-94.

Gibeau, M.L., and K. Heuer. 1996. Effects of transportation corridors on large carnivores in the Bow River Valley, Alberta. Pages 67-79 in Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors.

Proceedings of the Florida Dept. of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

ICE6. 1994. ICE6 Tool Kit for Cumulative Effects Analysis. Systems for Environmental Management, Missoula MT.

Irby, L., and K. Podruzny. 2000. Literature Availability Assessment for Relevant Interactions between Highways, Wildlife and Fisheries in Montana.

Jackson, S. 1996. Underpass systems for amphibians. Pages 224-227 in Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors. Proceedings of the Florida Department of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

_________. 1999. Overview of Transportation Related Wildlife Problems. In: Evink, G.L., P. Garrett and David Zeigler, eds. 1999. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida. 330 pp.

Jones. M.D. 2000. Highway underpasses for bears and other wildlife. International Bear News Vol. 9, No. 2.

Joslin, G. and H. Youmans, coordinators. 1999. Effects of recreation on Rocky Mountain wildlife: A Review for Montana. Committee on Effects of Recreation on Wildlife, Montana Chapter of the Wildlife Society. 307 pp.

Kobler, A., and Adamik, G. 1999. Brown bears in Slovenia; identifying locations for construction of highways in Slovenia. In: Evink, G. L., P. Garrett, and D. Zeigler (Eds.) Proceedings of the third international conference on wildlife ecology and transportation. Florida Department of Transportation, Tallahassee, Florida. pp 29-38.

Kohn, B., J. Frair, D. Unger, T. Gehring, D. Shelley, E. Anderson, and P. Keenlance. 1999. Impacts of a highway expansion project on wolves in Northwestern Wisconsin. Pages 53-65 in Evink G.L., P. Garrett, D. Zeigler, eds. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

Land, D., and M. Lotz. 1996. Wildlife crossing designs and use by Florida panthers and other wildlife in Southwest Florida. Pages 323-328 in Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors. Proceedings of the Florida Dept. of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

Langton, T.E. S. (ed). 1989. Amphibians and Roads. Proceedings of the toad tunnel conference. Rendsburg, Federal Republic of Germany, 7-8 January 1989. ACO Polymer Products, Shefford Bedfordshire, United Kingdom. 202 pp.

Leeson, B.F. 1996. Highway conflicts and resolutions in Banff National Park, Alberta, Canada. Pages 80-84 in Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors. Proceedings of the Florida Dept. of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

Maehr, D. S., E.D. Land, and M.E. Roelke. 1991. Mortality patterns of panthers in Southwest Florida. Proc. Annual Conf. Proc. Annu. Conf. Southeast Fish and Wildl. Agencies 45: 201-207.

Maxell, B.A., and D. G. Hokit. 1999. Amphibians and Reptiles. Pages 2.1-2.29 in Effects of recreation on Rocky Mountain wildlife: A Review for Montana. Committee on Effects of Recreation on Wildlife, Montana Chapter of the Wildlife Society. 307 pp.

Macdonald, L.A., and S. Smith. 1999. Bridge replacements: an opportunity to improve habitat connectivity. Pages 231-235 in Evink G.L., P. Garrett, D. Zeigler, eds.. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

Munro, R., B.N. McClellan, J.G. Woods, and D. Shackleton. *In press*. The effect of transportation corridors on grizzly and black bear habitat selection near Golden, British Columbia. Ursus.

Paquet, P.C., and C. Callaghan. 1996. Effects of linear developments on winter movements of gray wolves in the Bow River Valley of Banff National Park, Alberta. Pages 46-66 in Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds.. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors. Proceedings of the Florida Dept. of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

Paquet, P. C., J. Weirczhowski, and C. Callaghan. 1996. Summary report on the effects of human activity on gray wolves in the Bow River Valley, Banff National Park, Alberta. Dept. of Canadian Heritage, Ottawa, Ontario, Canada.

Primm, S., and E. Underwood, 1996. Reconnecting Grizzly Bear Populations in Fragmented Landscapes. In: Ricketts, T.H., E. Dinerstein, D. M Olson, C.J. Loucks, W. Eichbaum, D. DellaSalla, K. Kavanagh, P. Hedao, P. T. Hurley, K. M. Carney, R. Abell, and S. Waters (Eds.). 1999. Terrestrial Ecoregions of North America: a Conservation Assessment. Island Press. Washington D.C. Essay 6, pages 40-42.

Proctor, M.F., B.N. McClellan, and C. Strobeck. *In press*. Habitat and population fragmentation of grizzly bears in southeastern British Columbia, Canada. Ursus.

Rauer, G., and A. Zedrosser. *In press.* Roads as migration barriers for brown bears in Austria. Ursus.

Redmond, R.L., M.M. Hart, J.C Winne, W.A. Williams, P.C. Thornton, Z.Ma, C.M. Tobalske, M.M. Thornton, K.P. McLaughlin, T.P. Tady, F. B. Fisher, S.W. Running. 1998. The Montana Gap Analysis Project: Final Report. Unpublished report. Montana Cooperative Wildlife Research Unit, The University of Montana, Missoula. Xiii + 136 pp. + appendices.

Ruediger, Bill, James Claar, and James Gore, Restoration of Carnivore Habitat Connectivity in the Northern Rockies. In: Evink, G.L., P. Garrett and David Zeigler, Eds. 1999. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida. 330 pp.

Roof, J., and J. Wooding. 1996. Evaluation of the S.R. 46 wildlife crossing in Lake County, Florida. Pages 329-336 in Evink G.L., P. Garrett, D. Zeigler, and J. Berry, eds.. Trasportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors. Proceedings of the Florida Dept. of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar [April 30-May 2, 1996, Orlando, FL.] 336pp.

Ruediger, B., J.J. Claar, and J.F. Gore. 1999. Restoration of carnivore habitat connectivity in the Northern Rocky Mountains. Pages 5-20 in Evink G.L., P. Garrett, D. Zeigler, eds. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

Servheen C., and P. Sandstrom. 1993. Ecosystem management and linkage zones for grizzly bears and other large carnivores in the northern Rocky Mountains in Montana and Idaho. Endangered Species Technical Bulletin XVIII(3):10-13.

Servheen, C., J.S. Waller, and P. Sandstrom. 2001. Identification and management of linkage zones for grizzly bears between the large blocks of public land in the northern rocky mountains. U.S. Fish and Wildlife Service. Missoula, Montana. 83 pp.

Singleton P.H., and J.F. Lehmkuhl. 1999. Assessing wildlife habitat connectivity in the Interstate-90 Snowqualamie Pass corridor, Washington. In: Evink, G. L., P. Garrett, and D. Zeigler (Eds.) Proceedings of the third international conference on wildlife ecology and transportation. Florida Department of Transportation, Tallahassee, Florida. pp 75-83.

Simonyi, A., M. Puky, T. Toth, L. Pasztor, B. Bako, and Z. Molnar. 1999. Progress in protecting wildlife from transportation impacts in Hungary and other European countries. Pages 279-288 in Evink G.L., P. Garrett, D. Zeigler, eds. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

Singleton, P.H., and J.F. Lehmkuhl. 1999. Assessing wildlife habitat connectivity in the Interstate 90 Snoqualmie Pass corridor, Washington. Pages 75-84 in Evink G.L., P. Garrett, D. Zeigler, eds. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

USDA Forest Service. 1990. CEM – A Model for Assessing Effects on Grizzly Bears. USDA Forest Service, USDI National Park Service, USDA Fish and Wildlife Service. Missoula Montana. 251 pp.

U.S. Department of Transportation, Federal Highway Administration, and Office of Natural Environment, February, 2000. Critter Crossings: Linking Habitats and Reducing Roadkill, Federal Highway Administration, Washington, D.C., 31 pp.

Veenbaas, G., and J. Brandjes. 1999. Use of fauna passages along waterways under highways. Pages 253-258 in Evink G.L., P. Garrett, D. Zeigler, eds. Proceedings of the Third International Conference on Wildlife Ecology and Transportation. FL-ER-73-99. Florida Dept. of Transportation, Tallahassee, FL. 330pp.

Walker, R., and L. Craighead. 1997. Analyzing wildlife movement corridors in Montana using GIS. 1997. Environmental Sciences Research Institute. Proceedings of the 1997 International ESRI Users conference.

Weaver, J., R. Escano, T. Puchler, and D. Despain. 1986. A cumulative effects model for grizzly bear management in the Yellowstone ecosystem. In Proceedings: Grizzly Bear Habitat Symposium. Missoula, Montana.

Yanes, M., J.M. Valasco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71(3): 217-222.