ESTIMATING RESOURCE SELECTION FUNCTIONS USING SPATIALLY EXPLICIT DATA

LOWELL H. SURING[1], USDA Forest Service, Forestry Sciences Laboratory, Boise, Idaho 83702, USA
WALLACE P. ERICKSON, Western EcoSystems Technology, Inc., Cheyenne, Wyoming 82001, USA
SHAY HOWLIN, Western EcoSystems Technology, Inc., Cheyenne, Wyoming 82001, USA
KARIN PRESTON, USDA Forest Service, Chugach National Forest, Anchorage, Alaska 99503, USA
MICHAEL I. GOLDSTEIN, USDA Forest Service, Chugach National Forest, Anchorage, Alaska 99503, USA

Abstract: The generation and availability of spatially explicit data through geographic information systems (GIS) offers the opportunity to greatly expand the variety of variables used in the development and application of resource selection functions (RSFs). However, use of GIS capabilities in the analysis of habitat selection does bring potential difficulties (e.g., large number of variables, response of organisms to variables used, and pattern vs. process). The use of GIS techniques can also lead to a false confidence in the results unless care is taken in data acquisition, synthesis, and analysis. With cautious application, this capability provides researchers and managers the potential to gain additional insight to environmental factors that may influence the distribution of organisms of interest. We created and used a GIS database to aid in the development and application of RSFs for female brown bears on the Kenai Peninsula, Alaska. More than 30 variables were initially considered for inclusion in the analyses based on a previously developed cumulative effects model. We described the process we used to select variables for GIS database development, development of the database, final selection of variables for use in the development of RSFs, development of RSFs, and application of RSFs. The resulting data bases and maps of probability of use of female brown bears created in the GIS environment allowed resource managers to consider the distribution of brown bears while planning development activities (e.g., transmission line placement and recreation trail development).

Key words: Alaska, brown bear, Geographic Information System, GIS, Kenai Peninsula, resource selection function, *Ursus arctos*

Data are spatially explicit when they can be associated with specific locations on the ground using a 2- or 3-dimensional reference system (Henebry and Merchant 2002). Geographic information systems (GIS) are used to organize, manipulate, visualize, and analyze these data (Hunsaker et al. 1993, McCloy 1995). Many previous studies of habitat use and availability considered only single categorical habitat variables (Neu et al. 1974, Erickson et al. 1998). The generation and availability of spatially explicit data through GIS offers the opportunity to greatly expand the types of variables used in the development and application of resource selection functions (RSFs). This capability provides researchers and managers the potential to gain additional insight to environmental factors that may influence the distribution of organisms of interest. However, use of GIS capabilities in the analysis of habitat selection brings difficulties such as potentially large numbers of variables, understanding the response of organisms to the variables used, and the potential that the patterns being analyzed are not related to ecological processes. The use of GIS techniques may also lead to false confidence in the results unless care is taken in data acquisition, synthesis, and analysis. However, with cautious application, GIS techniques can provide additional insights into resource selection that can better contribute to the conservation of wildlife resources.

Development of numerous predictor variables for consideration in RSFs may be facilitated with the use of a GIS. However, consideration of large numbers of potential variables in the RSF process can make model selection difficult (Burnham and Anderson 1998, Manly et al. 2002). The potential for spurious results increases during model selection as the number of variables increases. The candidate set of variables should be defined before analysis begins and should have a biological basis. An informed choice of variables based on knowledge of the ecological processes being modeled is essential to success (Van Horne 2002).

In 1998, the Alaska Department of Fish and Game (ADF&G) designated brown bears (*Ursus arctos*) on the Kenai Peninsula as a species of special concern (Del Frate 1999). This designation resulted because the population is small, is potentially isolated from other populations, and is subjected to increasing human development in one of the fastest growing areas of the State (Suring and Del Frate 2002). Information was needed on how brown bears use the landscape on the Kenai Peninsula. We created and used a GIS database to aid in the development of RSFs for female brown bears. The processes and techniques we used in that analysis serve as an example of an approach to using GIS technology in the examination of resource use and applying the findings to management questions.

[1]Email: lsuring@fs.fed.us

Using the RSF models, we evaluated the potential effects of two case studies on brown bears. Both development projects span the Kenai Peninsula. The Iditarod Trail project involved construction or reconstruction of approximately 174 km of recreation trail aligned as closely as possible to the original Iditarod Trail between the communities of Seward and Girdwood, Alaska (USDA Forest Service 2002). This also included construction of approximately 81 bridges along the route. The Southern Intertie project involved a consortium of electrical associations and communities that proposed construction of a 138-kilovolt electric power transmission line between the Kenai Peninsula and Anchorage through the Kenai National Wildlife Refuge (USDA Rural Utilities Service 2002). An alternative route was proposed that followed the northwest coast of the Kenai Peninsula. One of the issues identified during review of these two projects was the potential effect development may have on brown bears.

STUDY AREA

The study was conducted within the known range of brown bears on the Kenai Peninsula (Del Frate 1993). The 23,000 km^2 Peninsula is located in south central Alaska between Prince William Sound to the east, Cook Inlet to the west, and the Gulf of Alaska to the south (Fig. 1). The Peninsula is connected to the Alaska mainland by a narrow isthmus approximately 18 km wide, which may effectively isolate brown bears on the Peninsula from other populations. The major physiographic landform on the eastern two-thirds of the peninsula is the rugged, heavily glaciated Kenai Mountain Range, which rises to 2,000 m. The Kenai lowlands landform, a glaciated plain with limited relief interspersed with numerous lakes, dominates the western one-third. Most stream systems on the Kenai Peninsula support runs of wild salmon (*Oncorhynchus* spp.) (Alaska Department of Fish and Game 1998).

Forests on the Kenai Peninsula lowlands support typical northern boreal forest species, including white spruce (*Picea glauca*), black spruce (*Picea mariana*), black cottonwood (*Populus trichocarpa*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). Mature forest vegetation on dry upland sites includes white spruce, paper birch, quaking aspen, or some combination of these species; black spruce dominates poorly drained sites (Lutz 1956, Spencer and Hakala 1964). Deciduous tree species typically occur in early to mid successional stages following fire.

METHODS

Habitat Use and Availability

From 1995 through 1998 we recorded 6,361 telemetry locations on 43 female brown bears that met our criteria for selection and entered into the analysis. Telemetry locations were collected approximately every 6 hours. Locations of the bears were recorded during spring and summer and were further stratified with and without cubs. These stratifications were based on timing of availability of salmon for food and differences in landscape use patterns. The locations were assumed to represent sites used by brown bears. Because of brown bears' ability to move large distances on the Kenai Peninsula, resources within the entire known range of brown bears on the peninsula were considered available to all individuals. Landscape use and availability were compared at a study area-wide spatial scale and at the four strata. Eleven thousand random points were established across the entire Kenai Peninsula study area to represent available sites at this spatial scale. Thirty

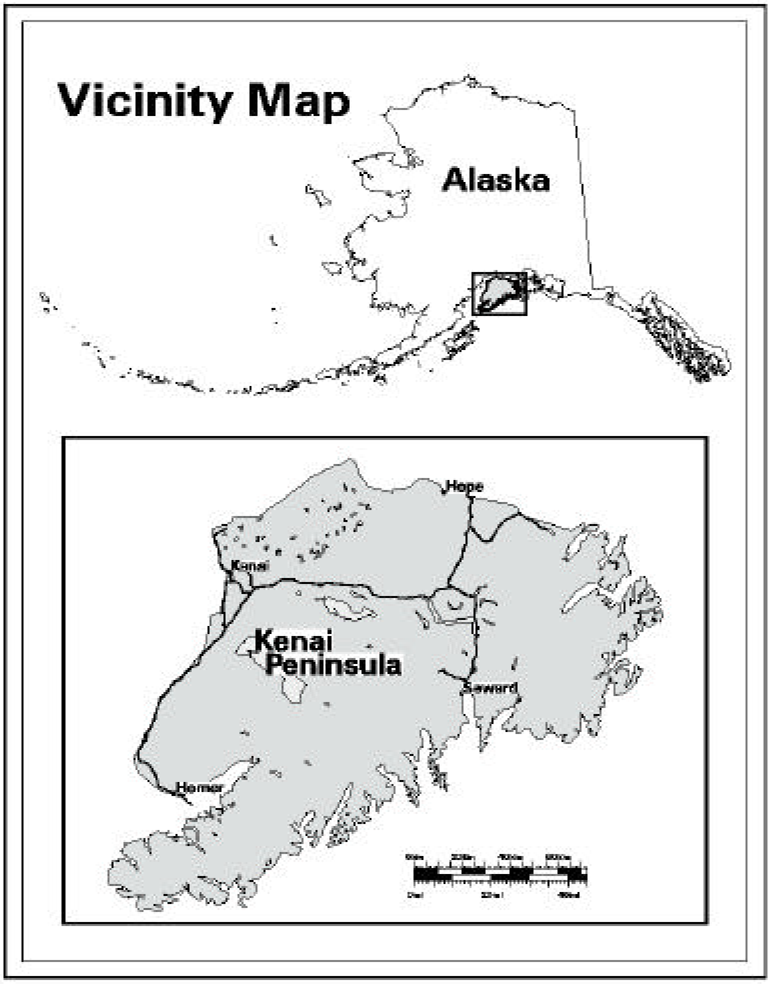

Fig. 1. Location of the Kenai Peninsula in southcentral Alaska.

variables were recorded for each animal location and each randomly selected available site. These variables were partitioned into two classes, landscape variables and human activity variables. Not all of the variables evaluated in the model development process are described here.

Landscape Variables

Selection of potential variables to evaluate the landscape use patterns of the bears was based on variables included in a cumulative effects model previously developed for the Peninsula (Suring et al. 1998). Landscape characteristics used to describe habitat included land cover, salmon spawning habitat, and topography. Landscape data were developed, stored, and manipulated using ArcInfo® GRID functions with a 28.5 m cell size. Digitized land cover maps available for the Kenai Peninsula included one based on a recent earth cover classification effort (Ducks Unlimited, Inc. and Spatial Solutions, Inc. 1999). This map covered the entire Kenai Peninsula with the exception of the eastern coastline from Seward to Whittier. Also available was a land cover map developed for the Chugach National Forest (CNF) and adjacent areas on the eastern Kenai Peninsula (Markon and Williams 1996).

These land cover maps contained similar descriptions of cover classes that were based on versions of the Viereck et al. (1992) classification system. The cover classes in the CNF land cover map facilitated consolidation to the 14 cover classes used in the Kenai Peninsula map. These maps were combined to cover the whole Kenai Peninsula through GIS processes. The cover classes in the resulting map were combined into 7 land cover types (i.e., water, barren, conifer forest, deciduous forest, mixed forest, shrubs, and herbaceous) to facilitate analyses. Land cover at each relocation point and associated random points was determined. A "distance to cover" variable was calculated by determining the distance from relocation and random points to the nearest pixel characterized as cover (i.e., either forest or shrub).

Potential salmon spawning habitat on the Kenai Peninsula was derived from digital maps of lakes and streams on the CNF (USDA Forest Service 1996) and from digital maps of lakes and streams in the Kenai and Seldovia quadrangles (Environmental Systems Research Institute 1983). Using biological knowledge of the area, categories of potential salmon spawning habitat were assigned to each stream as appropriate (i.e., high to moderate, low, none). Streams without spawning salmon were eliminated from the file. Distances from relocation points and random points to the nearest salmon stream and lake were calculated. A 1-km^2 moving-window GIS routine was 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 were then determined.

A 1:250,000 digital elevation model was acquired from the U.S. Geological Survey (EROS Field Office, Anchorage, Alaska, USA) and was used to describe aspect and elevation on the Kenai Peninsula.

Human Activity Variables

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. Aerial surveys were conducted to collect GPS locations of trespass cabins not included in the tax assessment data base. These data were combined to create a cover of human habitations across the Kenai Peninsula. 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 were then associated with relocation points and random points.

Roads.—Roads for the Kenai and Seldovia quadrangles on the western Kenai Peninsula were extracted from digital maps developed for the Alaska Department of Natural Resources (DNR) and combined through standard GIS techniques with associated information on use type, class, capacity, and surface type (Environmental Systems Research Institute 1983). Information from the roads database on the CNF (USDA Forest Service 1996) was used to create a coverage compatible with the covers for the western Kenai Peninsula. All covers were combined to describe roads on a Kenai Peninsula-wide basis. Small segments of road not included in the resulting cover were digitized from the "Road & Recreation Map for Kachemak Bay" (Alaska Road & Recreation Maps 1991). 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 were then associated with relocation and random points.

Recreation Sites.—A point coverage describing the location of all recreation sites was extracted from the CNF Kenai Management Area Recreation Site database (USDA Forest Service 1996). State of Alaska recreation areas and other sites accessible by road were derived from DNR covers for the Kenai and Seldovia quadrangles (Environmental Systems Research Institute 1983). These covers were combined and points added from road and recreation maps for the Kenai Peninsula (Alaska Road & Recreation Maps 1980, 1991) to create a comprehensive coverage of recreation sites. Road-accessible sites were considered "high-use" recreation sites. Recreation sites not accessible by road were considered "low-use" recreation sites. A 1-km^2 moving-window GIS routine was used to calculate the density of high use, low use, and all recreation sites in number per km^2 for each pixel in the study area. These values were then associated with relocation and random points.

Recreation Trails.—Trails for the Kenai and Seldovia quadrangles were extracted from DNR covers (Environmental Systems Research Institute 1983). Trails on the Kenai Management Area of the CNF (USDA Forest Service 1996) were then combined with the western Kenai Peninsula coverage. Trails not in this cover that were represented on road and recreation maps for the Kenai Peninsula (Alaska Road & Recreation Maps 1980, 1991) were added. This included portages for designated canoe trails and rivers designated as canoe trails. Trails were designated "high-use trails" or "low-use trails" depending on accessibility and distance from human population centers. A 1-km^2 moving-window GIS routine was used to calculate the density of high use, low use, and all recreation trails in m per km^2 for each pixel in the study area. These values were then associated with relocation and random points.

Analysis

We performed independent sample t-tests, univariate regressions, and correlation analyses on 30 variables to compare used and available sites. We required variables to have univariates significance levels of <0.1 to remain in the analyses. Correlations had to be < an absolute value of 0.7 for both variables to remain in the analyses. Landscape use by 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 considered important for inclusion in the RSF models when significant differences occurred between used and available locations (L. H. Suring, USDA Forest Service, unpublished data). Through this process variables were eliminated so the models included those most specifically impacting habitat selections by bears. From 2 to 6 variables were selected for models for each stratum.

The RSFs developed for the whole study area were incorporated into GIS routines to assign relative probabilities of use for female brown bears across the study area for each of the four strata. GIS technology was then used to map the estimated relative probabilities of use. The resulting data files and maps were used to evaluate the potential effects of development activities on brown bears and to compare alternative management scenarios.

RESULTS

Across the study area, probability of use was related to distance to cover and density of all salmon spawning streams for all strata (Table 1). During spring, density of roads and human development also influenced probability of use. During summer, brown bears without cubs were closely associated with salmon streams while distribution of brown bears with cubs was more closely related to salmon spawning lakes.

CASE STUDIES

The following case studies demonstrate application of information generated through RSFs and GIS in the evaluation of developments within brown bear habitat on the Kenai Peninsula.

Southern Intertie Project

Relative probability of use from the study area-wide models for all four strata was summarized within 1,000 m of each alternative route to evaluate the potential effect of each alternative on brown bears. The total area affected by the applicant's proposed route (i.e., 19,250 ha) was approximately one-third larger than the alternative coastal route (i.e., 12,426 ha). Mean relative probability of use within the 1,000-meter buffer of the applicant's proposed route was higher than the alternative coastal route for all strata and was nearly double for female bears in the summer with cubs according to the RSF model (Fig. 2). Female bears in the summer with cubs indicated larger areas of low, medium, and high relative probabilities of use for the applicant's proposed route when compared with the alternative coastal route (Fig. 3).

Quantification of the potential effect of construction and operation of the proposed transmission line on brown bears was one of several issues addressed in evaluation of the alternatives. However, this aspect was a major factor leading to a finding by the Kenai National Wildlife Refuge that the proposed transmission line was incompatible with purposes for which the Refuge was established (USDA Rural Utilities Service 2002). That, in turn, was a major factor in selection of the coastal route as the selected alternative.

Iditarod Trail

Relative probability of use for all four strata was summarized within 1,000 m of the proposed route to evaluate the potential effect of this project on brown bears. Mean relative probability of use within the 1,000-meter buffer of the proposed route showed the potential for affecting habitat that may be used by female bears in the summer without cubs according to the RSF model (Fig. 4). Female bears in the summer without cubs indicated relatively small areas of high and medium relative probability of use within the immediate project area

Table 1. Summary of resource selection functions (RSF) for female brown bears across the study area on the Kenai Peninsula, Alaska (from: L. H. Suring, USDA Forest Service, unpublished data).

	RSF response to variables by analysis strata			
	Spring		Summer	
Variable	With cubs	Without cubs	With cubs	Without cubs
Distance to cover	Decreases	Decreases	Decreases	Decreases
Density of all salmon spawning streams	Increases	Increases	Increases	Increases
Density of high potential salmon streams				Increases
Distance to all salmon streams				Decreases
Distance to salmon spawning lakes			Decreases	
Density of all roads	Decreases			
Density of human development		Decreases		Decreases

and a large area of low relative probability of use (Fig. 5). This project is still going through evaluation and public review. The potential effect of construction and use of the proposed recreation trail on brown bears using the RSF model predictions is one of several issues to be addressed in evaluation of the project. This information will be a key factor in the evaluation process.

CONCLUSIONS

It is important to link the objectives in model development with the type of model used and the application of the results. Our objective was to provide quantitative information on the landscape-use patterns of brown bears that could be incorporated into management decisions about development of the landscape. We combined GIS technology with development and application of RSFs to meet this objective.

ACKNOWLEDGEMENTS

This study was conducted under the direction of the Kenai Peninsula Interagency Brown Bear Study Team (a consortium of cooperating scientists from ADF&G, USDA Forest Service, US Fish and Wildlife Service, and National Park Service). R. Ernst, Kenai National Wildlife Refuge, provided locations of recreation cabins on the southwest Kenai Peninsula. This study was funded partially by Alaska’s Federal Aid in Wildlife Restoration Program and by the Chugach National Forest.

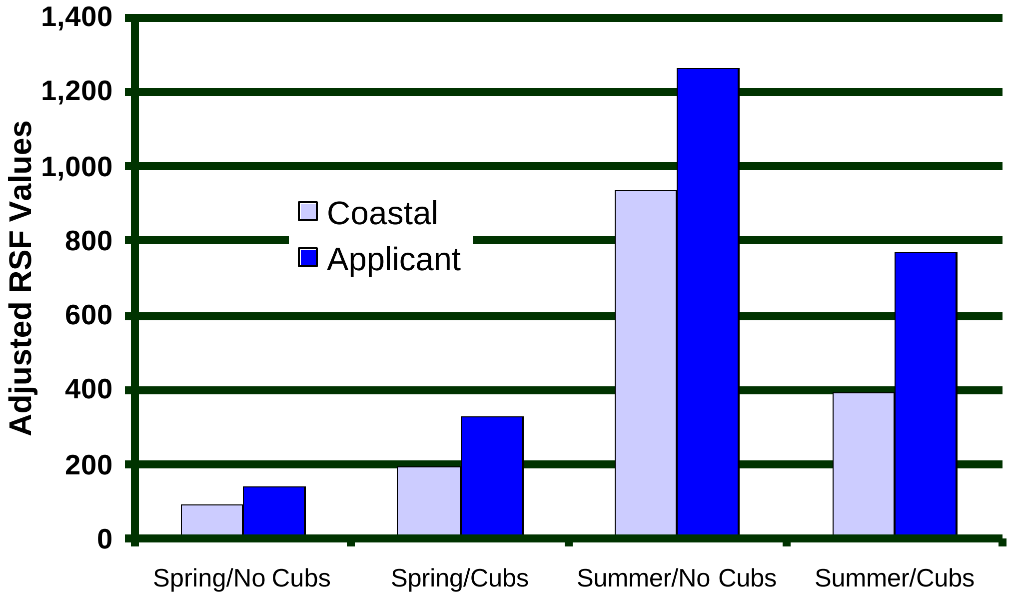

Fig. 2. Mean relative probability of use of female brown bears by strata within 1,000 m of alternative routes for construction of the Southern Intertie electricity transmission line on the Kenai Peninsula, Alaska.

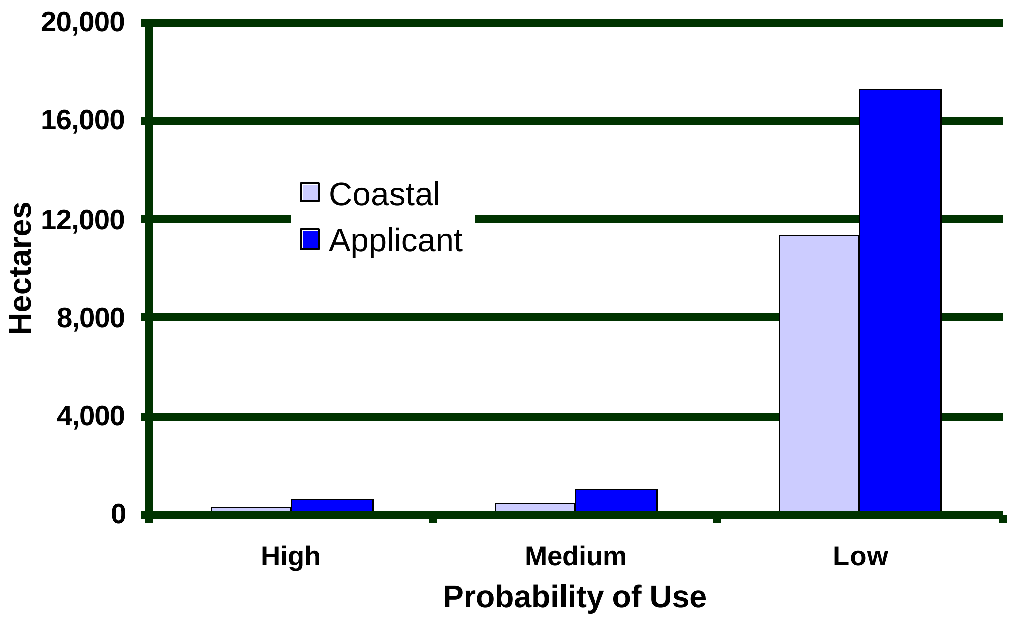

Fig. 3. Area of high, medium, and low relative probability of use of female brown bears with cubs in the summer within 1,000 m of alternative routes for construction of the Southern Intertie electricity transmission line on the Kenai Peninsula, Alaska.

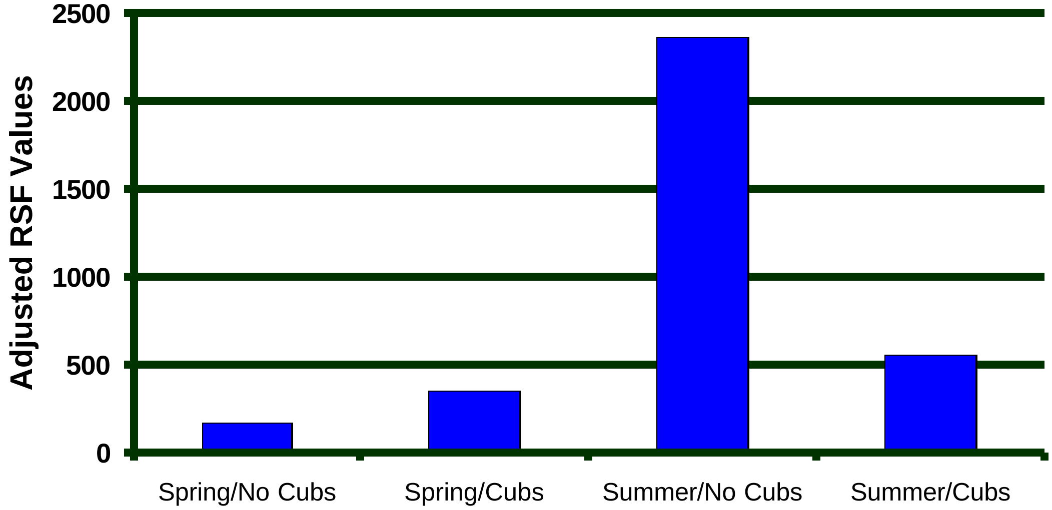

Fig. 4. Mean relative probability of use of female brown bears by strata within 1,000 m of the proposed route for construction of the Iditarod Trail on the Kenai Peninsula, Alaska.

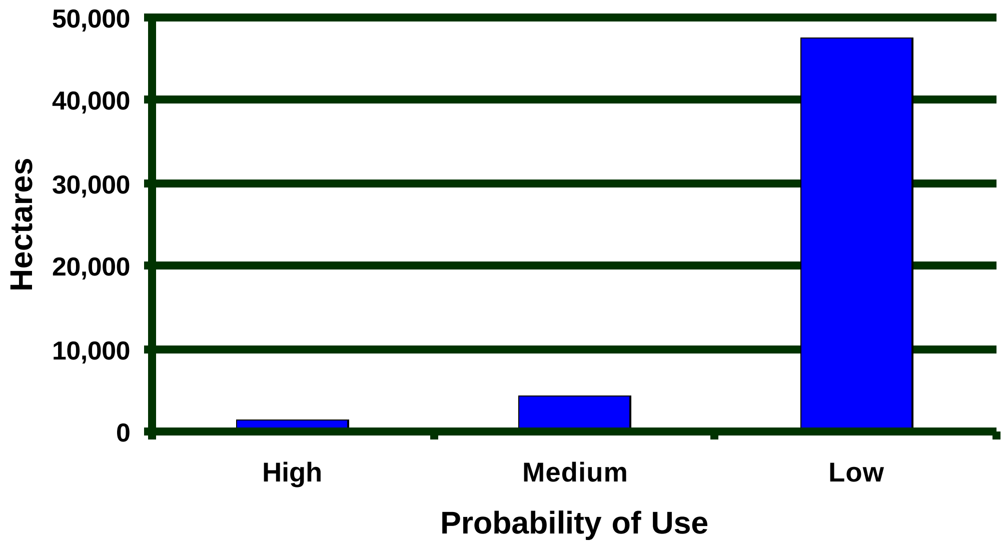

Fig. 5. Area of high, medium, and low relative probability of use of female brown bears without cubs in the summer within 1,000 m of the proposed route for construction of the Iditarod Trail on the Kenai Peninsula, Alaska.

LITERATURE CITED

ALASKA DEPARTMENT OF FISH AND GAME. 1998. Catalog of waters important for spawning, rearing or migration of anadromous fishes. Alaska Department of Fish and Game, Juneau, Alaska, USA.

ALASKA ROAD AND RECREATION MAP. 1980. Kenai Peninsula. Southcentral Alaska. Alaska Road and Recreation Maps, Anchorage, Alaska, USA.

_____. 1991. Kachemak Bay. Kenai Peninsula, Alaska. Alaska Road and Recreation Maps, Anchorage, Alaska, USA.

BURNHAM , K. P. AND D. R. ANDERSON. 1998. Model selection and inference. A practical information-theoretic approach. Springer, New York, New York, USA..

DEL FRATE, G. G. 1993. Units 7 and 15 brown bear. Pages 49–57 *in* S. Abbott, editor. Management report of survey and inventory activities 1 July 1992–30 June 1994. Federal Aid in Wildlife Restoration Project W-23-4 and W-23-5, Study 4.0. Alaska Department of Fish and Game, Juneau, Alaska, USA.

_____. 1999. Units 7 and 15 brown bear. Pages 55–65 *in* M. Hicks, editor. Management report of survey and inventory activities 1 July 1996–30 June 1998. Federal Aid in Wildlife Restoration Project W-24-5 and W-27-1, Study 4.0. Alaska Department of Fish and Game, Juneau, Alaska, USA.

DUCKS UNLIMITED, INC. AND SPATIAL SOLUTIONS, INC. 1999. Kenai Peninsula earth cover classification users guide. Project numbers AK-0033-001 and –002, Ducks Unlimited, Inc., Rancho Cordova, California.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE, INC. 1983. Alaska land and resource mapping program final report. Volume 2. Data base users guide. Alaska Department of Natural Resources, Anchorage, Alaska, USA.

ERICKSON, W. P., T. L. MCDONALD, AND R. SKINNER. 1998. Habitat selection using GIS data: a case study. Journal of Agricultural, Biological, and Environmental Statistics 3:296-310.

HENEBRY, G. M., AND J. W. MERCHANT. 2002. Geospatial data in time: limits and prospects for predicting species occurrences. Pages 291-302 *in* J. M. Scott, P. J. Heglund, M. L. Morrison, J. B. Haufler, M. G. Raphael, W. W. Wall, and F. B. Samson, editors. Predicting species occurrences. Issues of accuracy and scale. Island Press, Washington, D.C., USA.

HUNSAKER, C. T., R. A. NISBET, D. C. LAM, J. A. BROWDER, W. L. BAKER, M. G. TURNER, AND D. B. BOTKIN. 1993. Spatial models of ecological systems and processes: the role of GIS. Pages 248-264 *in* M. Goodchild, B. Parks, and L. Steyaert, editors. Environmental modeling with GIS. Oxford University Press, New York, New York, USA.

LUTZ, H. J. 1956. Ecological effects of forest fires in the interior Alaska. U.S. Department of Agriculture Technical Bulletin 1133.

MANLY, B. F. J., L. L. MCDONALD, D. L. THOMAS, T. L. MCDONALD, AND W. P. ERICKson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second Edition. Kluwer Academic Publishers, Boston, Massachusetts, USA.

MARKON, C. J. AND B. E. WILLIAMS. 1996. Development of a geographical information system for the Chugach National Forest. Pages 155-163 *in* J. D. Greer, editor. Remote sensing: people in partnership with technology. Remote Sensing Working Group, Society of American Foresters, Washington, D.C., USA.

MCCLOY, K. R 1995. Resource management information systems. Taylor and Francis, London, United Kingdom.

NEU, C. W, C. R. BYERS, AND J. M. PEEK. 1974. A technique for analysis of utilization-availability data. Journal of Wildlife Management 38:541-545.

SPENCER, D. L., AND J. L. HAKALA. 1964. Moose and fire on the Kenai. Tall Timbers Fire Ecology Conference 3:11–33.

SURING, L. H., AND G. DEL FRATE. 2002. Spatial analysis of locations of brown bears killed in defense of life or property on the Kenai Peninsula, Alaska, USA. Ursus 13:237-245.

_____, K. R. BARBER, C. C. SCHWARTZ, T. N. BAILEY, W. C. SHUSTER, AND M. D. TETREAU. 1998. Analysis of cumulative effects on brown bears on the Kenai Peninsula, southcentral Alaska. Ursus 10:107–117.

USDA FOREST SERVICE. 1996. Resource information management data dictionary. U.S. Department of Agriculture Forest Service, Chugach National Forest. Anchorage, Alaska, USA.

_____. 2002. Specialist report for Iditarod Trail project - brown bear concerns. U.S. Department of Agriculture Forest Service, Chugach National Forest. Anchorage, Alaska, USA.

USDA RURAL UTILITIES SERVICE. 2002. Southern intertie project final environmental impact statement. U. S. Department of Agriculture Rural Utilities Service, Washington, D. C., USA.

VAN HORNE, B. 2002. Approaches to habitat modeling: the tensions between pattern and process and between specificity and generality. Pages 63-72 *in* J. M. Scott, P. J. Heglund, M. L. Morrison, J. B. Haufler, M. G. Raphael, W. W. Wall, and F. B. Samson, editors. Predicting species occurrences. Issues of accuracy and scale. Island Press, Washington, D.C., USA.

VIERECK, L. A., C. T. DYRNESS, A. R. BATTEN, AND K. J. WENZLICK. 1992. The Alaska vegetation classification. U.S. Department of Agriculture Forest Service General Technical Report PNW-GTR-286.