Research Article

Patterns of Landscape Use by Female Brown Bears on the Kenai Peninsula, Alaska

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Abstract

*We describe landscape use of female brown bears (*Ursus arctos*) on the Kenai Peninsula, Alaska, USA. Radiocollars, fitted to 43 adult female brown bears, provided radio relocations, which we used to describe habitat use patterns by season and reproductive class at the landscape scale. Brown bears were associated with areas with low densities of human developments and roads, as well as riparian areas that were close to cover. Presence of streams and lakes that supported spawning salmon (*Oncorhynchus *spp.) positively influenced summertime distribution of bears. Female brown bears with cubs avoided concentrations of other bears. Resource managers may use this information to respond to brown bear conservation issues associated with increasing human populations and associated development in the establishment of road density standards, seasonal road closures, management of recreation sites, and vegetation management on the Kenai Peninsula.* (JOURNAL OF WILDLIFE MANAGEMENT 70(6):1580–1587; 2006)

Key words

Alaska, brown bear, habitat selection, radiotelemetry, Ursus arctos*.*

Brown bears on the Kenai Peninsula use a diverse array of resources (e.g., mountainside den sites, areas of early green up in the spring, riparian areas and salmon streams in the summer, upland berry patches in the fall). The Kenai Peninsula also supports significant human development; the human population increased from just over 9,000 in 1960 to nearly 50,000 by 2000 (Camp 2001). Increasing land development and human activity on the Kenai Peninsula has generated concern about potential impacts to brown bear populations (Schwartz and Arthur 1997). In 1998, the Alaska Department of Fish and Game designated the Kenai Peninsula brown bear population as one of special concern (Del Frate 1999). Factors influencing this designation included small population size, potential isolation from mainland brown bear populations, and increasing human development.

The persistence of brown bear populations depends on habitat quality, human density, and human behavior (Mattson et al. 1996, McLellan 1998, Apps et al. 2004). All 3 variables are in flux on the Kenai Peninsula, and to effectively manage this brown bear population information is needed on landscape-level habitat use. Efforts to develop a structure for interagency management of brown bears led the Interagency Brown Bear Study Team to develop a habitat capability–cumulative effects model (Suring et al. 1998). Initial applications of that model showed large reductions in habitat effectiveness as a result of past land management (e.g., road development, recreation, housing development). Current and planned developments on the Kenai Peninsula have the potential to increase human encroachment on brown bear habitat. Identifying areas in which increased human activity and development may threaten viability of a brown bear population can help in the development and refinement of management standards to minimize that risk.

Our objectives were to describe relationships between landscape use patterns of female brown bears and landscape features, human activities, and human developments and predict the relative probability of landscape use of brown bears based on mapped habitat variables and human activity patterns.

Study Area

We conducted our study within the known range of brown bears on the Kenai Peninsula, Alaska (Del Frate 1993). Located in south-central Alaska between 59°–61°N and 148°–152°W, the Kenai Peninsula lies between Prince William Sound to the east, Cook Inlet to the west, and the Gulf of Alaska to the south. The Peninsula is connected to the Alaska mainland by a narrow isthmus approximately 18 km wide (Peterson et al. 1984, Schwartz and Franzmann 1991), which may limit movement of brown bears off of and on to the Kenai Peninsula. The major landform on the eastern two-thirds of the Peninsula is the rugged, heavily glaciated Kenai Mountain Range, which rises to 1,950 m. The Kenai Lowlands, a glaciated plain interspersed with numerous lakes, dominates the western one-third (Spencer and Hakala 1964). Most stream systems on the Kenai Peninsula supported wild runs of 2–5 species of Pacific salmon (Alaska Department of Fish and Game 1998).

Forests on the Kenai Peninsula lowlands included northern

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boreal trees, such as white spruce (*Picea glauca*), black spruce (*Picea mariana*), black cottonwood (*Populus trichocarpa*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). Mature forests on dry upland sites included white spruce, paper birch, and quaking aspen; black spruce dominated poorly drained sites (Lutz 1956, Spencer and Hakala 1964); Sitka spruce (*Picea sitchensis*) occurred in wetter, maritime coastal areas. Lutz spruce (*Picea lutzii*), a hybrid of Sitka and white spruce, occurred in forested areas throughout the Kenai Peninsula. Deciduous trees typically occurred in early to mid successional stages following fire. The Kenai Mountains also support coniferous and mixed hardwood forests up to approximately 500 m elevation (Peterson et al. 1984). Mountain hemlock (*Tsuga mertensiana*), mountain alder (*Alnus crispa*), willow (*Salix* spp.), and bluejoint reedgrass (*Calamagrostis canadensis*) grew in the transition zone between forest and alpine tundra. Alpine communities tended toward lichen tundra, dwarf shrub tundra, or a combination of both. Lichen tundra was found on ridges and mountain tops while dwarf shrub tundra occurred below the lichen zone. Ice fields, glaciers, and snowfields, with associated bare rock and scree slopes, occurred throughout the Kenai Mountains.

Methods

Capture, Radiocollaring, and Telemetry

We located adult female brown bears from the air using fixed-wing aircraft. We then captured these bears using immobilizing darts fired from a Bell Jet Ranger, Hughes 500, or Robinson R44 helicopter. We immobilized bears with a combination of teletamine hydrochloride and zolazepam hydrochloride (Telazol® Fort Dodge Laboratories, Inc., Fort Dodge, Iowa). We examined captured bears, ear-tagged them, and then measured them for total length, skull width and length, and chest girth following a protocol described by Schwartz and Franzmann (1991).

We fitted brown bears with conventional Very High Frequency (VHF) or with Global Positioning System (GPS) collars (Telonics Inc., Mesa, Arizona). We handled animals fitted with VHF collars only at initial capture and then prior to battery failure to remove or replace the collar. We handled bears with GPS collars ≤ 3 times: at initial capture, in midsummer, and in late fall when the GPS collar was replaced with a VHF transmitter. GPS collars stored fixes internally, and we downloaded data when we recovered the collars. From 1995 through 1998, the GPS units fixed their position every 5.75 hours. In 1999 and 2000, we deployed and programmed 8 GPS collars to establish a position every 15 minutes from July through September to facilitate objectives for a related study. Following initial capture, we also relocated each brown bear, regardless of collar type, at approximately weekly intervals from a fixed-wing aircraft. We obtained aerial relocations during daylight hours when weather conditions were favorable.

Habitat Variables

We used variables from the cumulative effects model developed for the Kenai Peninsula (Suring et al. 1998) to guide selection of variables used to describe landscape use of female brown bears. Additional background on these variables and their inclusion into Geographic Information System (GIS) databases are found in Suring et al. (2004).

Physical habitat.—Landscape characteristics used to describe habitat use included availability of cover, salmon spawning habitat, and topography. Using a land cover map (Ducks Unlimited and Spatial Solutions 1999) we derived a variable termed “distance to cover,” which we defined as the distance between female brown bear locations or random points and the nearest pixel which could have provided cover (i.e., either a forest or shrub land cover class). We categorized streams relative to salmon spawning habitat potential as high to moderate, low, or none, based on criteria described by Alaska Department of Fish and Game (1998). We derived aspect and elevation from a digital elevation model.

Human development.—We used digital maps of the locations of roads, recreation trails, recreation sites, and buildings across the Kenai Peninsula in these analyses. We considered roads on the Kenai Peninsula with a medium duty capacity as high use and roads with light duty or unimproved dirt capacity as low use. We designated recreation trails as high use or low use depending on accessibility and distance from human population centers. We considered road-accessible recreation sites high-use sites and recreation sites not accessible by road low-use sites.

Error associated with telemetry locations.—Relocation errors associated with our telemetry data may limit their suitability to coarse-grained habitat selection studies (i.e., $>$100 m cells) as suggested by Schwartz and Arthur (1999). However, we used GIS data files with a 28.5-m cell size to describe landscape features and the density of human activities. To determine the potential error associated with combining brown bear relocation points with the GIS variables, we employed the following analyses. Based on Schwartz and Arthur (1999) we considered each brown bear location and random sample point to be the center of a 100-m radius circle. We calculated the mean value for each variable (landscape features and density of human activities) from all cells within that circle as a representation of values within 100 m of an analysis point. We compared the mean values using correlation analysis to the absolute value of each variable, as measured at the brown bear location or random sample point in the circle’s center. The mean values of variables in cells within 100 m of a relocation point or a random sample point were highly correlated (i.e., $>$0.7) with the value at the point, suggesting minimal potential error associated with determining the value of habitat variables at brown bear relocation points.

Statistical Analysis

Based on our theory of animal response (i.e., during spring, females with cubs would tend to use upland habitats and generally avoid salmon streams until later in the summer; lone females would be more closely associated with stream systems; Dahle and Swenson 2003), we selected 4 strata a priori for analyses. We conducted analyses separately for: 1)

Table 1. Models of relative probability of resource use for female brown bears on the Kenai Peninsula, Alaska, USA, 1995–1998.

Model	*N*	Coefficient	SE	*t*-statistic	*P* value
Spring (with cubs)					
Distance to cover	21	−0.4638	0.1650	−2.8113	0.0108
Density of all salmon spawning streams	21	0.0019	0.0005	3.9036	0.0009
Density of all roads	21	−0.0017	0.0008	−2.0551	0.0532
Intercept	21	−0.9820	0.2036	−4.8238	0.0001
Spring (without cubs)					
Distance to cover	10	−0.6234	0.2422	−2.5740	0.0300
Density of human development	10	−19.5641	0.1573	−124.4010	0.0000
Density of all salmon spawning streams	10	0.0034	0.0008	4.5280	0.0014
Intercept	10	−2.1477	0.2412	−8.9040	0.0000
Summer (with cubs)					
Distance to cover	24	−0.2823	0.1565	−1.8031	0.0845
Density of all salmon spawning streams	24	0.0034	0.0003	10.0884	0.0000
Distance to salmon spawning lakes	24	−0.0023	0.0013	−1.7542	0.0927
Intercept	24	0.0005	0.4550	0.0012	0.9991
Summer (without cubs)					
Distance to cover	26	−0.4836	0.1945	−2.4859	0.0200
Density of human development	26	−0.4310	0.1774	−2.4288	0.0227
Distance to all salmon streams	26	−0.0142	0.0058	−2.4594	0.0212
Density of all salmon streams	26	0.0034	0.0004	8.8106	0.0000
Density of high potential salmon streams	26	0.0013	0.0003	5.2212	0.0000
Intercept	26	−0.3584	0.2585	−1.3868	0.1778

female bears with cubs in spring (den emergence, 14 Jun), 2) female bears without cubs in spring, 3) female bears with cubs in summer (15 Jun, den entrance), and 4) female bears without cubs in summer. We only included brown bears with ≥20 relocations by stratum in our analysis.

We used *t*-tests and univariate regressions to reduce the list of physical habitat and human development variables for potential inclusion in multiple regression models from 36 to 16. We further reduced the list of variables by assessing multicollinearities ($r > 0.7$). Because densities of high-use and low-use trails were correlated with density of all trails, the density of all trails was retained. The density of low-use roads was correlated with the density of all roads, so the density of all roads was retained. Because the density of low-potential salmon streams was correlated with the density of all salmon streams, the density of all salmon streams was retained. We combined the results of the paired *t*-tests (paired by bear) with the linear coefficients from each univariate logistic regression to obtain the list of candidate modeling variables for each stratum.

For analysis of probability of use, we fit logistic regression models using data from each female brown bear and data from 11,000 random available points across the study area. We used backward model selection and incorporated a jackknife procedure to test the significance of the coefficients in the models (Manly 1997). We evaluated the effect of changes in the value of individual variables on probability of use by running each model while holding all other variables at a constant value.

We used landscape characteristics associated with telemetry locations from female brown bears during 1999 and 2000 to evaluate the resulting models by strata (following the process described by Howlin et al. 2004). The basic assumption of this evaluation process was that habitat selection observed in 1999 and 2000 should have occurred where the models predicted the highest selection. We used simple linear regression of the observed versus predicted counts to estimate the magnitude and the direction of the slope. A positive slope with a 95% confidence interval that did not include zero indicated an acceptable level of predictive ability (Johnson et al. 2000). A negative slope or positive slope with a 95% confidence interval that included zero provided limited predictive ability.

Results

From 1995 through 1998, we recorded 6,361 telemetry locations on 43 adult female brown bears that met our criteria during spring (7.0% without cubs, 19.4% with cubs) and summer (36.1% without cubs, 37.5% with cubs). From 1999 through 2000, we recorded 25,390 telemetry locations on 14 brown bears that were used for evaluation of the models. We recorded the majority of these locations during summer (41.3% without cubs, 56.7% with cubs; 1.9% with cubs during spring). Study bears used approximately 80% of the study area.

Final models of resource use contained 3–5 variables (Table 1). Spring variables included distance to cover, density of roads and other human developments, and density of all salmon streams. Summer variables included distance to cover, density of human development, distance to all salmon streams, density of all salmon streams, density of salmon spawning lakes, and density of high potential salmon streams. We chose final models based on model validation (Table 2). We did not monitor brown bears without cubs in

Table 2. Evaluation of models of relative probability of resource use for female brown bears on the Kenai Peninsula, Alaska, USA, 1995–1998.

Model	*N*	Estimate	SE	*t*-statistic	*P* value	95% CI Lower	95% CI Upper
Spring							
With cubs	495	0.698	0.149	4.70	0.0008	0.407	0.989
Without cubs[a]							
Summer							
With cubs	14402	0.796	0.052	15.30	<0.0001	0.694	0.898
Without cubs	10493	0.420	0.055	7.61	<0.0001	0.312	0.528

[a] The model-evaluation data set did not include entries for this stratum. As a result, we did not evaluate this model.

the spring of 1999 or 2000 so we did not evaluate the model that we developed for this stratum.

For all strata, probability of occurrence increased with proximity to cover and declined considerably (i.e., 60–70%) as distance to cover increased >200 m (Fig. 1). Probability of occurrence also decreased with increased density of human developments and roads (Fig. 2). Tolerance of brown bears to human presence (as reflected by density of buildings) reached low levels in the spring with a very low density of development (i.e., <1 structure/km^2). Tolerance increased somewhat in the summer, although probability of occurrence still declined nearly 60% as the density of structures increased from 0 to 2/km^2. In spring and summer probability of occurrence increased as the density of salmon streams increased, independent of whether the bears had cubs (Fig. 3). Brown bears with cubs also showed a positive association with salmon spawning areas with limited numbers of accessible fish (e.g., salmon spawning lakes) in the summer, whereas bears without cubs were linked to highly productive salmon spawning streams where fish were more accessible. Proximity to salmon streams resulted in increased probability of occurrence in summer (Fig. 3). That probability only decreased to 0.8 at 2 km from salmon streams and 0.5 at approximately 5 km from salmon streams.

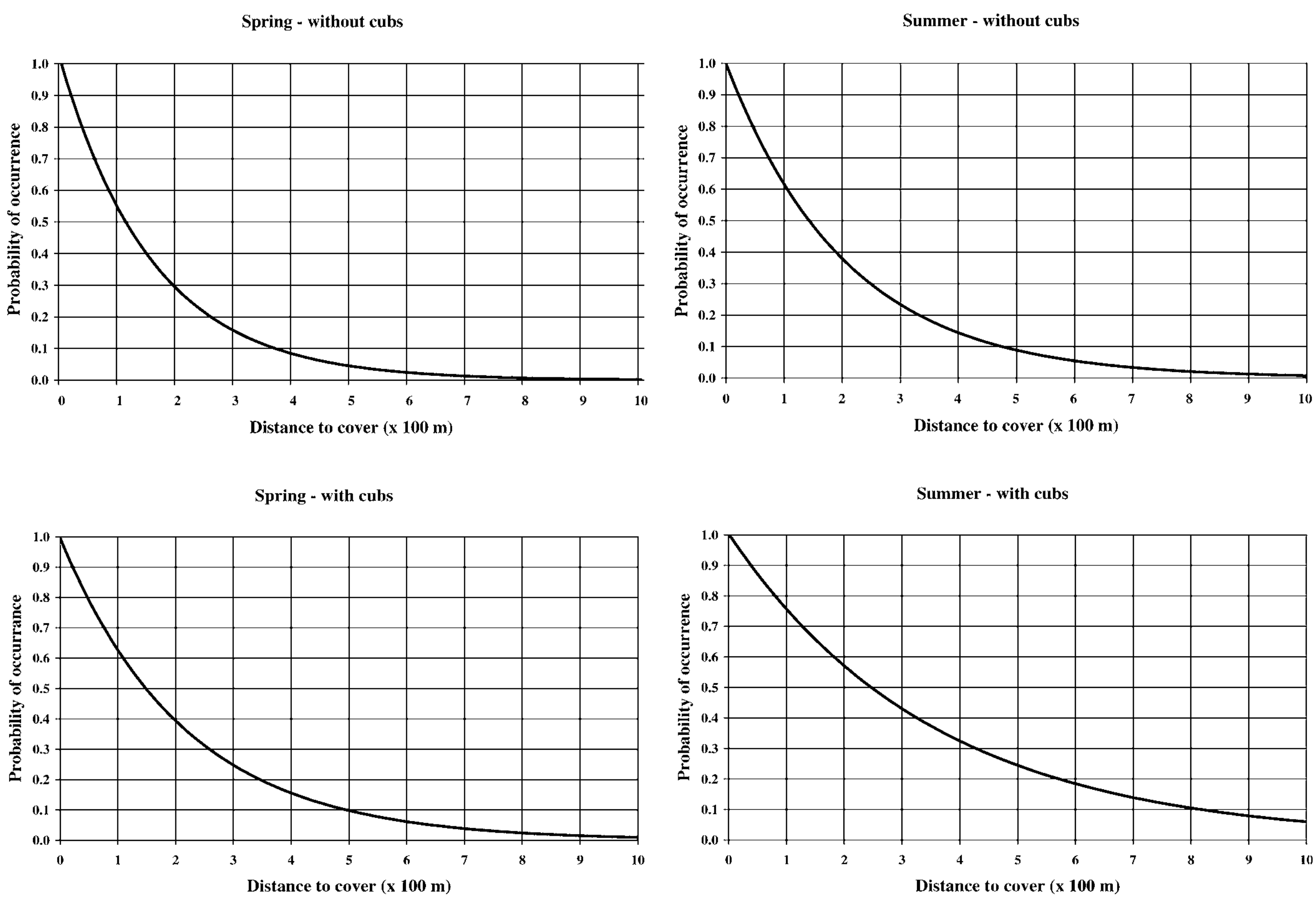

Figure 1. Effect of distance to cover on probability of occurrence of female brown bears on the Kenai Peninsula, Alaska, USA, 1995–1998.

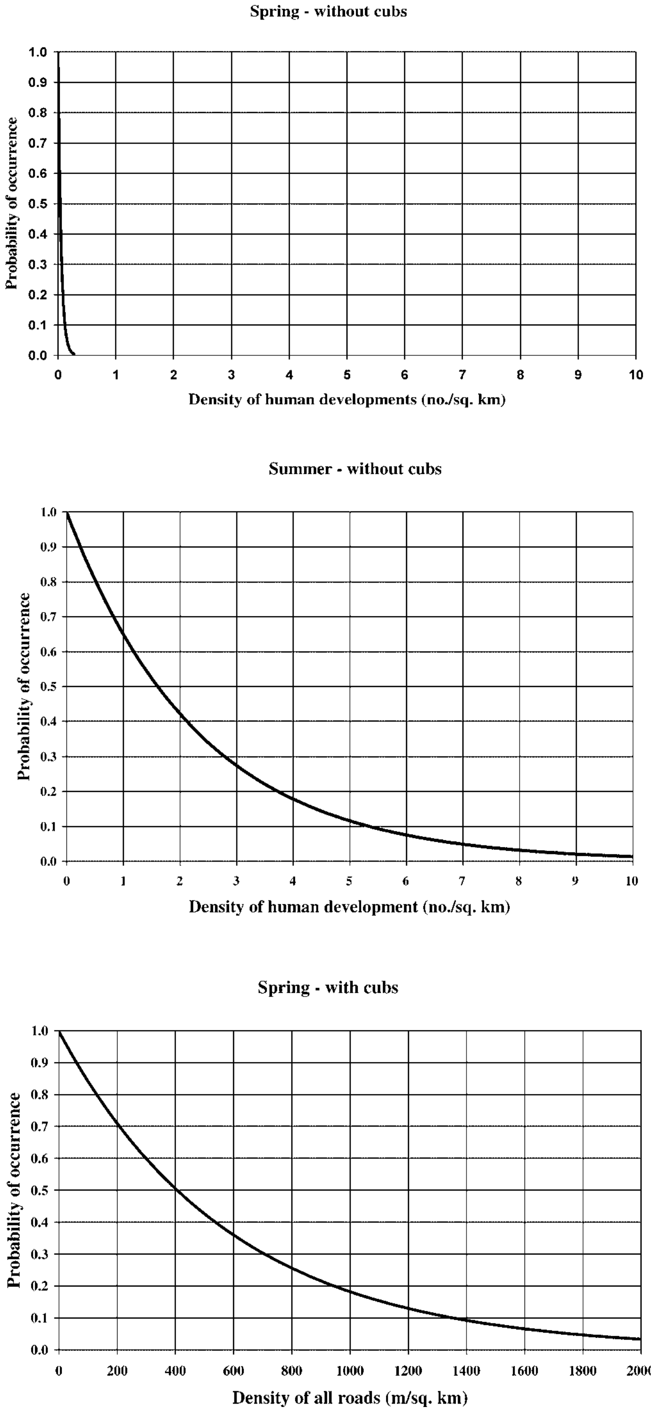

Figure 2. Effect of roads and other human developments on probability of occurrence of female brown bears on the Kenai Peninsula, Alaska, USA, 1995–1998.

Discussion

Response to Availability of Streams and Salmon

Our analysis of resource use on the Kenai Peninsula indicated an association of female brown bears with cubs with less productive salmon spawning areas (i.e., salmon lakes and streams with low potential for spawning salmon). However, the nutritional requirements of these bears are higher than other segments of the bear population because of reproductive costs to females and growth of cubs (Hilderbrand et al. 2000). These patterns appear to be associated with avoidance of areas used by other brown bears and humans in an effort by females to increase offspring survival. Brown bears with cubs have been reported to modify their movements and become subdominant to males and females without young to avoid confrontations with other brown bears (Craighead et al. 1995, Wielgus and Bunnell 1995, Dahle and Swenson 2003, Ben-David et al. 2004). Social dominance has also been shown to influence how much time individual bears spend foraging on streams (Egbert and Stokes 1976, Chi 1999, Gende 2002, Nevin and Gilbert 2005*a*).

When perceived risk from other brown bears influenced feeding behavior of females with cubs, energy intake declined by 37% (Nevin and Gilbert 2005*b*). Subdominant brown bears often forage at sites where water depth may limit catch rates (Quinn and Kinnison 1999; e.g., salmon spawning lakes on our study area) or number of fish (Gende and Quinn 2004). Subdominant brown bears have been observed to immediately move away from more productive sites following capture of fish (Gende and Quinn 2004). This limited time at foraging sites may result in subdominant brown bears selecting salmon with low energy content that are less vigorous and easier to catch (Gende et al. 2004). Subdominant bears may also preferentially scavenge dead salmon that have spawned, which are lower in nutritive quality than live fish (Hendry and Berg 1999) and subdominant bears often carry fish away from streams to avoid conflict with other brown bears (Quinn and Buck 2000). The cost of restricting their fishing behavior in response to perceived risk may be considerable. Previously reported reduction in salmon consumption observed for females with cubs (50,000 kJ/d) is equivalent to the daily metabolic maintenance cost of a 200-kg bear (Hilderbrand et al. 1999, Gende 2002, Nevin and Gilbert 2005*b*).

Response to Availability of Cover

Brown bears selected resources that were close to cover during both seasons; we assumed that cover provided security. The availability of cover may be most important near salmon spawning areas because brown bears and humans tend to congregate in these areas. Blanchard (1983) documented a majority of bear observations (i.e., 79%) in cover >3 m tall. The availability of security cover is considered important in how human activities influence brown bears (Archibald 1983, LeFranc et al. 1987). Availability of cover and stream buffers also appeared to be important to brown bears on Chichagof Island in southeast Alaska, where Schoen et al. (1994) observed locations of radiocollared bears much farther away from salmon streams in a highly roaded and clearcut watershed than in a nearby pristine watershed. Grizzly bears in Yellowstone National Park used areas ≥500 m from cover significantly more when areas were closed or had restricted human use compared to areas that were open to human use (Gunther 1990). In British Columbia, responses of brown bears to people on foot and to moving vehicles were greater

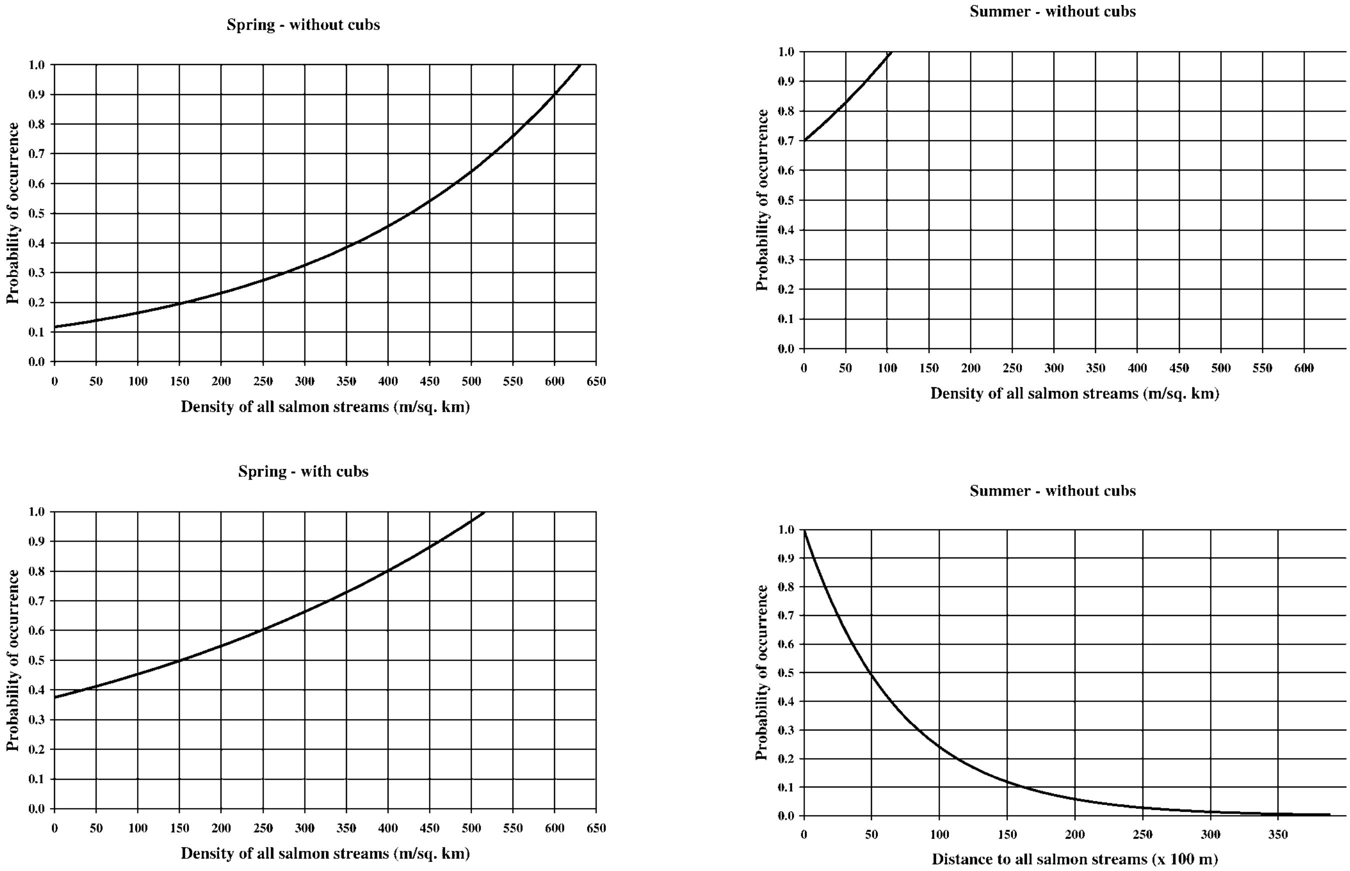

Figure 3. Effect of salmon streams on probability of occurrence of female brown bears on the Kenai Peninsula, Alaska, USA, 1995–1998.

when brown bears were in the open than in cover (McLellan and Shackleton 1989).

Response to Roads and Other Human Developments

We showed that relative probability of use by female brown bears on the Kenai Peninsula declined as road densities increased. Because they tend to use large areas, large carnivores like bears are particularly susceptible to the effects of roads (Noss et al. 1996, Gucinski et al. 2001). Previous work showed that on the Kenai Peninsula the probability of brown bears being killed in defense of life or property increased as the density of roads increased (Suring and Del Frate 2002). Road construction and use has substantially reduced habitat effectiveness for brown bears in other areas. Grizzly bears in Yellowstone National Park avoided areas $\leq$500 m from roads; foraging was also disrupted within 2 km of roads (Mattson et al. 1987). Kasworm and Manley (1990) reported an 80% reduction in habitat use by grizzly bears within 1,000 m of roads open to motorized vehicles in Montana; mean distance from grizzly bear radiolocations to a road nearly doubled after a closed road was opened to vehicle traffic. Mace et al. (1996) also reported avoidance of areas within 0.5 km of roads used by $>$10 vehicles per day. Female brown bears in our study responded similarly to that reported from other areas, despite the fact that road densities on the Kenai Peninsula are generally an order of magnitude lower than on other study areas in North America (m vs. km/km^2; e.g., Mace et al. 1996). Some habitat value may be maintained near roads if traffic and firearms are restricted during resource extraction and roads are closed to all use (including all-terrain vehicles) after resource extraction has been completed (Boone and Hunter 1996, Wielgus et al. 2002, Wielgus and Vernier 2003).

We also showed that density of human development was negatively associated with relative probability of occurrence by female brown bears on the Kenai Peninsula. Elsewhere brown bears have been reported to alter their behavior patterns in response to disturbance by humans (Reinhart and Mattson 1990). The development of housing subdivisions and vacation cabins associated with the increasing human population on the Kenai Peninsula has resulted in substantial reductions in the amount of habitat available for use by brown bears (Suring et al. 1998).

Management Implications

Comprehensive planning across the Kenai Peninsula should include management of human access, development of recreation facilities, and development of housing subdivisions in a manner that minimizes their influence on landscape use patterns of brown bears. Our results indicated that brown bears on the Kenai Peninsula heavily use areas within 2 km of salmon spawning areas. However, roads, permanent and seasonal residences, and recreation sites have often been constructed in proximity to streams and lakes containing salmon because of human demand for access to these areas. Road construction within this zone should be discouraged and other development should be limited. If development occurs, it should be concentrated, rather than dispersed, to maximize the effectiveness of the remaining habitats (Suring et al. 1998) and to minimize the potential of bears being killed in defense of life or property (Creachbaum et al. 1998, Suring and Del Frate 2002). The models developed for female brown bears through this study and mapping of the relative probabilities of occurrence through GIS methods provide additional valuable information for conservation planning on the Kenai Peninsula (e.g., Goldstein et al. 2004, Suring et al. 2004).

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