HABITAT-CAPABILITY MODEL FOR BROWN BEAR IN SOUTHEAST ALASKA

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Abstract: Habitat-capability models are necessary for evaluating the effects of forest management on the management of indicator species (including brown bears [*Ursus arctos*]) of the Tongass National Forest. Habitat-use data from 95 radio-collared brown bears on Admiralty and Chichagof Islands were used to develop this habitat-capability model. Each of 20 habitats was assigned a habitat-capability value based on bear habitat preference or best professional judgment. The effects of human activity and resource development on brown bears were estimated, based on best professional judgment, as reductions in habitat capability within zones of human influence.

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Once widely distributed across western North America, brown/grizzly bears (*Ursus arctos horribilis*) currently range over a significantly reduced portion of the continent. In 1975, they were declared threatened in the United States south of Canada. Loss of habitat to human encroachment is a serious problem for bear management in the contiguous 48 states and elsewhere (Mattson 1990, McLellan 1990, Schoen 1990, Servheen 1990). Throughout the world, the future of many bear populations, including brown bears, is inextricably linked with forest management (Schoen 1991).

In North America today, the largest population of brown bears occurs in Alaska (Peek et al. 1987) with an estimated 30,000-40,000 bears (Alaska Department of Fish and Game 1978). Brown bears are indigenous to Southeast Alaska where they occur throughout the mainland coast and on the islands north of Frederick Sound. Admiralty, Baranof, and Chichagof Islands have some of the highest brown bear densities (e.g., 2.6 bears/km^2 on northern Admiralty Island) in the world (Schoen and Beier 1990).

Brown bears are one of the special features of the Tongass National Forest. Admiralty, Baranof, and Chichagof Islands are one of the most important brown bear hunting regions in Alaska. Tourism and outdoor recreation are also growing industries in this area. Visitors to Southeast Alaska as well as many residents are interested in an opportunity to observe the brown bear, a symbol of the American wilderness.

The decline in the range and numbers of brown bears during the past century in the contiguous 48 states has heightened management concern for the species and prompted an increase in brown bear research, particularly habitat-related studies. Most research on bear-forestry relationships has been conducted within the last 2 decades (see review in Zager and Jonkel 1983, Contreras and Evans 1986), and several investigations have recently been completed in the coastal forests of British Columbia and Alaska (e.g., Hamilton 1987, Schoen and Beier 1990). The brown bear has been selected as a management indicator species (MIS) in the revised Tongass Land Management Plan (U.S. Dep. of Agric. For. Serv. 1991). Habitat-capability models are needed for each MIS on the Tongass Forest. These models will be used for project-level planning and are necessary for providing information to evaluate the cumulative effects of forest management on wildlife habitats and populations. Cumulative effects analysis is a relatively new but important component of forest planning (Christensen 1986, Weaver et al. 1986) and provides an approach for predicting the long-term effects of land-management activities on brown bear habitat and populations. The model to be described evaluates quality of habitat for brown bears, which is assumed to be related to long-term carrying capacity. Habitats are rated, using habitat-preference data from Schoen and Beier (1990), on the basis of their value to bears during late summer when hyperphagic bears are most concentrated and vulnerable to human activities.

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HABITAT RELATIONSHIPS

Odum (1971:234) described habitat as the organism's "address" or the place it inhabits in fulfilling its life needs (e.g., food, cover, water). Harris and Kangas (1988) proposed that the definition of primary habitat explicitly extends beyond the individual to include an area of sufficient size or configuration to support a population over time. We consider that an effective definition of bear habitat must also incorporate the influence of human activities (Schoen 1990).

The habitat relationships of brown/grizzly bears vary considerably across the diverse array of ecosystems they inhabit from the eastern Rockies, through coastal rain forests, and to the Arctic. The Alaska Department of Fish and Game began brown bear investigations in Southeast Alaska in 1981 with particular emphasis on habitat relationships and the influence of logging and mining activities on bear populations. From 1981 through 1988, 68 brown bears were radiocollared on northern Admiralty Island and 3,020 relocations collected (Schoen and Beier 1990). Habitat use by radio-collared brown bears varied seasonally ($P < 0.01$) (Table 1) and is considered a response to seasonal differences in food availability and quality.

Most brown bears emerge from high-elevation (>300 m) dens between April and May. After den emergence, many bears move to low-elevation old-growth forests, coastal sedge meadows, or south-facing avalanche slopes. During early summer (mid-Jun through mid-Jul), most bears move to forested slopes and alpine/subalpine meadows where they forage on newly emergent vegetation.

Table 1. Seasonal habitat use by 68 radio-collared brown bears[a] on Admiralty Island, Southeast Alaska, 1982-88.[b]

	Percentage of habitat use				
		Summer			
Habitat type	Spring	Early	Late	Fall	Annual
Old-growth forest					
Upland forest	55.9	28.2	24.5	30.6	28.4
Riparian forest	8.7	11.0	53.6	18.8	33.3
Beach fringe	6.8	4.9	2.0	1.5	3.1
Subalpine forest	3.7	14.0	5.2	10.3	8.4
Nonforest					
Avalanche slopes	12.4	15.7	5.5	23.2	11.3
Alpine	3.7	18.9	2.8	7.6	8.4
Estuary	3.8	4.5	5.3	0.6	4.3
Other	5.0	2.8	1.1	7.4	2.8
n relocations	161	772	1,285	340	2,558

[a] Interior bears were not included.
[b] Schoen and Beier (1990).

Bears concentrate along low-elevation coastal salmon streams from mid-July through early September. During this late summer season, 54% of all bear relocations occurred in riparian forest habitat vegetated by a spruce-devils club (*Picea sitchensis-Oplopanax horridus*) community (Schoen and Beier 1990). During this same period, 66% of all bear relocations occurred within a 160-m band on either side of anadromous fish streams (Schoen and Beier 1990). Although this zone included a variety of habitats, it was dominated by the riparian spruce-devils club community. Bears used this habitat for fishing along river banks, for foraging on succulent vegetation and berries, and for security and thermal cover.

Although most bears (>85%) are associated with anadromous fish streams in late summer, some bears (primarily females) do not use coastal fish streams (Schoen et al. 1986). Those bears (termed "interior" bears) remain in interior regions of the island throughout the year, foraging primarily on vegetation and berries in subalpine and avalanche slope habitat. By mid-September, most bears move to upper elevation (>300 m) forests, avalanche slopes, and subalpine meadows where they feed on currant (*Ribes* spp.) and devils club berries before denning.

Winter denning begins in October and November. Mean elevation and slope of 121 den sites of radio-collared bears from Admiralty and Chichagof Islands were 640 m and 35° (Schoen et al. 1987). Fifty-two percent of those dens occurred in old-growth forest habitat. Although cave denning was common on Admiralty Island, many dens were excavated under large-diameter old-growth trees or into the bases of large snags (Schoen et al. 1987).

The seasonal food habits of Admiralty brown bears were described by McCarthy (1989). During spring, the diet of brown bears is dominated by sedges (*Carex* spp.), other green vegetation, roots, and deer (*Odocoileus sitkensis*). Sedges and salmon (*Oncorhynchus* spp.) are the major foods consumed during summer, although skunk cabbage (*Lysichiton americanum*), devils club berries, and other plants, berries, and roots are also used. During fall, salmon, devils club berries, skunk cabbage, sedge, beach lovage roots (*Ligusticum* spp.), and currants dominate the diet. The distribution of bears corresponded closely to the seasonal abundance and quality of the food items listed above. Because bears have relatively inefficient carnivore digestive systems (Bunnell and Hamilton 1983) and are active for only part of the year, they must exploit the most productive feeding sites available. This often brings bears into conflict with humans using those same high-quality lands (Schoen 1990).

In Southeast Alaska, old-growth forest is used extensively throughout the year by brown bears for foraging, cover, and denning. Elsewhere, clearcut logging often results in the production of an abundance of forage plants potentially valuable to bears during early stages of forest succession (Lindzey and Meslow 1977, Mealey et al. 1977, Zager et al. 1983). Theoretically, these sites should provide good or adequate habitat for a generalist species like the brown bear. However, on Chichagof Island, clearcuts were used minimally by bears; only 2.8% of 854 relocations of 27 radio-collared bears occurred in clearcuts during 1983 through 1986 (Schoen and Beier 1990). Although clearcuts only encompassed about 6% of the entire Chichagof study area, they made up a much larger proportion of low-elevation valleys adjacent to streams —the areas used most extensively (>60%) by bears in late summer (Schoen and Beier 1990). Within the individual home ranges of 14 radio-collared brown bears on Chichagof Island, 8 bears were never located in clearcuts and 5 bears used clearcuts less and 1 bear used clearcuts more than their abundance within bear home ranges during late summer from 1983 through 1986 (Schoen and Beier 1990).

We believe brown bears make limited use of clearcuts in Southeast Alaska because other sites (e.g., alpine/subalpine habitat, wetlands, riparian old growth, avalanche slopes) provided more nutritious foraging and better cover habitat than clearcuts (Schoen and Beier 1990). For example, devils club berries, currants, and salmonberries (*Rubus spectabilis*), which are foraged on most extensively by bears (McCarthy 1989), are more abundant in riparian and avalanche slope habitat than in clearcuts. Because younger second-growth conifer stands (25-150 years old) in Alaska produce minimal understory vegetation, second growth provides poor foraging habitat for herbivores and omnivores such as bears (Wallmo and Schoen 1980, Alaback 1982, Schoen and Beier 1990).

HABITAT-CAPABILITY MODEL

This model was designed to evaluate bear habitat on a single- or multiple-watershed scale in 2 stages. First at the habitat level, the model calculates a habitat-capability index (HCI). Second, the model calculates reductions in habitat capability within zones of human influence. Nine major habitat categories were identified for use in this model: old-growth forest, beach-fringe old growth, subalpine forest, second-growth forest, clearcuts, avalanche slopes, alpine, estuary, and other (Table 2). Forest habitats were further subdivided relative to upland or riparian status and presence or absence of anadromous salmon.

This model assumes that habitat quality is related to brown bear preference for different habitats (e.g., alpine, riparian old growth, clearcuts, second growth). While recognizing potential problems associated with population dynamics and interpretation of habitat availability (Johnson 1980, Van Horne 1983, McLellan 1986), we have used habitat preference of radio-collared bears on Admiralty Island as our measure of

Table 2. Description of habitat categories used in the habitat-capability model for coastal brown bears, Southeast Alaska.

Habitat	Description
Physiographic categories	
Beach fringe	Within 150 m of mean high water
Estuary fringe	Within 300 m of mean high water along an estuary
Riparian zone	Zone within 160 m of a stream, influenced by riparian habitat
Upland	Area between the beach and estuary fringes and the subalpine, excluding the riparian habitat
Forest categories	
Old growth	Forest stands greater than 300 years old
Subalpine	Ecological subalpine zone
Clearcut	Stands 0-25 years old
Young second growth	Stands 26-150 years old
Older second growth	Stands 151-300 years old
Nonforest categories	
Avalanche slopes	Recurrent slide zone
Alpine	Ecological alpine community
Estuary	Portion of an estuary below mean high water
Other	Miscellaneous (e.g., muskeg, rock, roads)
Stream categories	
Fish	Anadromous fish present
No fish	No anadromous fish present

habitat capability for brown bears in Southeast Alaska. The ecological basis for inferring habitat quality from preference data is found in habitat-selection theory (Rosenzweig 1981, Fagen 1988). As stated by Ruggiero et al. (1988), "Habitat preferences are based on evolved behavior and thus relate directly to the probability of persistence. Therefore, habitat preferences must be viewed as reliable information about the environments needed for population persistence, and should be considered a valid basis for management decisions."

Habitat Capability

The habitat-level model has M distinct habitat types that occupy an area $A_i (i = 1, 2, \ldots M)$. Each of the habitat categories was assigned a habitat-capability index (HCI) based on habitat preference or best professional judgment (Table 3). Ivlev's (1961) index of electivity was used as the measure of habitat preference by brown bears for the habitat-capability model. To transform Ivlev's indices (which range from -1 to +1) to positive numbers, we calculated (E_i) as follows: $E_i = r_i/(r_i + p_i)$; where E_i = the transformed index of electivity or habitat-preference index, r_i = the proportion of observed use of habitat category i (relocations of radio-collared bears), and p_i = the proportion of habitat category i in the study area (availability). Habitat-capability indices (HCIs) were computed by dividing the preference index for each habitat category by the maximum value for the index ($HCI_i = E_i/E_{max}$), so the highest value habitat has an HCI value of 1.0.

Availability of habitats within the 365-km^2 Admiralty study area was estimated by extrapolation from a habitat-data base derived for a 300-km^2 subsection of this study area. The original availability data (collected for a deer study) were determined from a random sample of 2,495 points systematically overlaid on 1:12,000-scale aerial photographs. These were: old growth, 75.6%; subalpine, 8.1%; alpine, 9.6%; and other, 6.6% (Schoen and Kirchhoff 1990). In the bear model, we recognized a greater variety of habitat categories than in the original study. Old-growth forest was further subdivided into upland, beach fringe, and riparian, and the relative abundance of each habitat was estimated. We also estimated the relative abundance of avalanche slopes and estuaries.

To simplify our habitat-capability model, we assumed the late summer season was the most critical or limiting period for brown bears in Southeast Alaska. We acknowledge that other seasons (e.g., spring when bears are feeding on new growth of sedges at tidewater) also have unique importance to bears and that critical seasons may vary regionally. However, the late summer season (mid-Jul through mid-Sep) is when the most abundant, high-quality food (e.g., spawning salmon) is available. Brown bears are most

Table 3. Habitat capability for brown bear habitats during the late summer season in Southeast Alaska.

Habitat	Use[a] (%)	Availability[b] (%)	Preference[c] index	HCI[d]	Density[e]
Upland forest					
Old growth	24.5	55	0.31	0.34	0.32
Subalpine	5.2	10	0.34	0.37	0.35
Old 2nd growth	--	--	--	0.10[f]	0.10
Young 2nd growth	--	--	--	0.00[g]	0.00
Clearcut	--	--	--	0.10[g]	0.10
Riparian forest					
Old growth	53.6	5	0.91	1.00	0.95
Fish	--	--	--	1.00[g]	0.95
No fish	--	--	--	0.40[g]	0.38
Old 2nd growth					
Fish	--	--	--	0.30[f]	0.29
No fish	--	--	--	0.10[f]	0.10
Young 2nd growth					
Fish	--	--	--	0.20[f]	0.19
No fish	--	--	--	0.00[f]	0.00
Clearcut					
Fish	--	--	--	0.50[f]	0.48
No fish	--	--	--	0.20[f]	0.19
Beach-fringe forest	2.0	3	0.40	0.44	0.42
Estuary-fringe forest	--	--	--	0.60[f]	0.57
Avalanche slope	5.5	5	0.52	0.57	0.54
Alpine	2.8	10	0.22	0.24	0.23
Estuary	5.3	2	0.73	0.79	0.75
Other	1.1	10	0.10	0.11	0.10

[a] Habitat use by radio-collared brown bears on Admiralty Island (n = 1,285 relocations).
[b] Availability of habitats on Admiralty Island study site.
[c] Transformation of Ivlev's (1961) electivity coefficient (E_i).
[d] Habitat-capability index (scaled from 0-1).
[e] Bear density (per km^2) by habitat from Admiralty study site.
[f] HCI determination based on best professional judgment.
[g] Extrapolated from Schoen and Beier (1990) and best professional judgment.

concentrated along low-elevation valley bottoms and coastal salmon streams at this time. These are also the areas of highest human use and where the most intense resource development activities occur (e.g., logging and road building). We believe that brown bears are most vulnerable to human-induced mortality (aside from legal hunting) at this time and place. Late summer habitat use by radio-collared bears, habitat availability, an index of habitat preference, and a habitat-capability index are presented in Table 3. Habitat-use determinations excluded "interior" bears because those bears represented a relatively small proportion of the northern Admiralty Island study population (approximately 10%) and may be somewhat unique to Admiralty Island. Furthermore, those bears are relatively isolated from most forest management activities.

Several additional habitats are listed for which we did not have preference data from Admiralty Island. Although these habitats did not occur on the Admiralty study site or were not delineated, they are important because they are the result of forest-management activities (e.g., clearcuts and second-growth forest) or are used extensively by bears and subject to a disproportionate amount of logging (e.g., riparian old growth). Although we had empirical data on bear preference for riparian habitat in general, we further subdivided riparian into 2 categories (streams with and without anadromous fish) based on best professional judgment (Table 3).

Because clearcuts (0-24 years) and second-growth forests (25-150 years) were not available within the Admiralty study area, their suitability was ranked based on professional judgment (Table 3). The avoidance of clearcuts by radio-collared bears on Chichagof Island (Schoen and Beier 1990) justifies their low rankings relative to old growth. Because of the virtual absence of understory vegetation in Southeast Alaska second growth (Wallmo and Schoen 1980, Alaback 1982), we ranked the habitat capability of second growth as 0. We distinguished an older category of second growth (151-300 years). The habitat capability of older second growth was estimated intermediate between young second growth and old growth because of the increasing production of forage plants as the stands age. Clearcuts and second growth in riparian sites with salmon streams were given higher value than upland sites because of the availability of spawning salmon during late summer (Table 3).

Although availability of suitable den sites is an important component of brown bear habitat, we assume it is not limiting in most circumstances and is unlikely to be substantially affected by forest management. However, to minimize loss of denning habitat as a consequence of logging, Schoen et al. (1987) recommended avoiding logging on mid-volume (20-30 mbf/acre), hemlock-spruce stands on slopes greater than 20° at elevations above 300 m in or adjacent to areas of brown bear concentrations.

The number of brown bears and composition of habitats in the Admiralty study area were used to estimate bear density in each habitat. For this part of the model, we assumed that the density of bears in each habitat was proportional to the HCI value. The density of brown bears on the Admiralty study site was estimated, in a mark-recapture study, at 1 bear/2.6 km^2 (Schoen and Beier 1990). After excluding the "interior" segment (10%) of the population, 127 bears were estimated to inhabit the 365-km^2 study area. The density of bears in the best habitat (HCI = 1.0) was computed as follows:

$$D_{max} = N / \sum_{i=1}^{m} HCI_i A_i;$$

where D_{max} = the density of bears in the best habitat, N = the number of bears in the study area, HCI_i = the habitat-capability index for habitat i, A_i = the area of habitat i. The density of bears in the other habitats was calculated by multiplying D_{max} by each HCI value. The number of bears in an area can then be determined by the following relationship:

$$N = \sum_{i=1}^{m} D_i A_i;$$

where N = the number of bears in an area, D_i = the density of bears in habitat i, and A_i = the area of habitat i. As the mix of habitats is changed by forest management activities, we can estimate the effect on habitat capability by calculating N for the new set of habitat conditions and comparing it with N. Although we have chosen to express habitat capability in terms of the number of bears in an area, we could also evaluate the effects of management activities by examining only the percentage change in habitat capability.

We simulated the effects of timber harvest on bears by running the habitat portion of the model on a hypothetical 65,587-ha watershed of which 31,580 ha were available for timber harvest (Table 4). Timber harvest was restricted to low to mid-elevation, upland, old-growth forest. Riparian areas, beach-fringe forest, and estuary-fringe forests were not harvested. As a result of a 50% harvest, the brown bear population declined by 16% after 10 years and 23% following 50 years (Table 4). This difference 50 years after logging

Table 4. Effect of varying levels of timber harvest on populations of brown bears as estimated by the habitat-capability model.[a]

Percent of area harvested	Percent of brown bear population maintained following timber harvest	
	10 years	50 years
0	100	100
25	92	88
50	84	77
75	76	65

[a] Timber harvest was restricted to low to mid-elevation, upland, old-growth forests. Riparian areas, beach fringe, and estuary fringe forests were not harvested. Total area was 65,587 ha; 31,580 ha were available for timber harvest under this scenario.

reflects the lower habitat value of second-growth forest. All the simulated harvest scenarios resulted in declining bear populations. These results appear reasonable but underestimate the total impact on bears because no riparian forest (the most valuable habitat) was harvested and the influence of human-induced mortality was not yet calculated.

Human-Induced Mortality

After estimating habitat capability, the model incorporates the effects of human-induced mortality as a second step in the analysis. These factors are assumed to have a landscape-level effect and may reduce habitat capability regardless of the habitat. This stage of the model should be considered a working hypothesis.

Large carnivores, like brown bears, which range over extensive areas (from 1,400 to 40,000 ha) should be considered creatures of landscapes rather than of specific habitat types per se (Harris and Kangas 1988, Schoen 1990). Aside from habitat impacts, resource development (e.g., logging, mining, hydroelectric development, tourism) must also be evaluated in terms of human-bear interactions (Peek et al. 1987, Mattson 1990, McLellan 1990, Schoen 1990). Resource development in brown bear habitat (generally wild, undeveloped areas) significantly improves human access and consequently increases disturbance as well as direct human-induced mortality of bears (Pearson 1977, Craighead et al. 1982, Schoen 1990). In general, roads are detrimental to bears because they increase opportunities for human-bear interactions (Elgmork 1978, Zager 1980, Archibald et al. 1987, McLellan and Shackleton 1988, Schoen 1990). Although it is possible to manage legal hunting of bears, it is difficult to control illegal kills, wounding loss, and defense of life or property kills. Once a road has been built for one development project, it often results in additional developments, which increase human-bear interactions, and ultimately reduces the area's capability for supporting viable bear populations (McLellan 1990).

The dense rain forest of Southeast Alaska provides more security cover for bears than more open habitats in the Rocky Mountains or northern Alaska. Road building activities in the Greens Creek drainage of Admiralty Island displaced fewer bears than expected, presumably because of the security cover provided by the dense forest (Schoen and Beier 1990). In Southeast Alaska, bears may remain closer to development activities than they do in the Rocky Mountains because of the dense forest cover. As those bears become habituated to humans and/or associate humans with food (e.g., garbage), human-bear interactions will increase and result in higher bear mortality. Human garbage has been implicated as one of the major contributors to bear attacks on humans and ultimately the reason that many garbage-habituated "problem" bears must be destroyed (Herrero 1985:52, Herrero and Fleck 1990).

The combination of increased road access and bears becoming habituated to garbage dumps (and people) is a major concern of bear managers in the coastal forests of British Columbia and Southeast Alaska (Archibald 1983, Archibald et al. 1987, Schoen 1990). For example, the brown bear season on northeastern Chichagof Island was closed under an emergency order of the Alaska Department of Fish and Game on 30 September 1988 because of high bear mortality resulting from increased road access and the inadequate garbage disposal policies of several small communities and logging camps. Titus and Beier (1991) found a direct correlation ($r = 0.93$, $P < 0.001$) between autumn brown bear kill and cumulative kilometers of road construction on northeastern Chichagof Island during the period 1978 to 1989. The number of illegal bears taken there during that period is a significant unknown. Clearly, the impacts of human activity and development on bears need to be incorporated into any analysis of the effects of land-management activities on brown bears (Schoen 1990).

We subdivided the effects of human activity and development into different levels of impact. These relationships were estimated, based on best professional judgment, as reductions in habitat capability (or potential carrying capacity) within zones of human influence/disturbance (Table 5). These reduction factors should be considered as relative values (e.g., high, 0-0.3; medium, 0.4-0.7; light, 0.8-1.0) rather than

Table 5. Reductions in brown bear habitat capability within zones of human activity/disturbance in Southeast Alaska.

Human activity/landscape modification	Habitat-reduction factor within zone of influence[a] <1.6 km	1.6-8.0 km
Human communities		
>1,000	0.0	0.3
501-1,000	0.0	0.5
11-500	0.3	0.6
<10	0.5	0.8
Landfill without effective incineration	0.0	0.5
Forest Service cabin/developed campground	0.8	1.0
Permanent camp site	0.2	0.5
Temporary camp site	0.5	0.8
Access Point (airstrip, dock, float plane lake)	0.8	1.0
Arterial and collector roads accessible to vehicles and connected to ferry access or town	0.4	0.7
Local roads accessible to vehicles	0.6	0.9
Roads closed temporarily	0.8	1.0
Roads closed permanently	0.9	1.0

[a] Habitat-capability index (HCI) multiplied by this factor equals bear potential within the specified zone. Derivation of reduction factors (ranked on a relative scale) are based on best professional judgment.

specific quantifiable values derived from empirical data.

We estimated that larger communities would have greater impacts than smaller communities (Table 5). For example, brown bears are rarely observed in or adjacent to major cities or towns in Southeast Alaska, whereas bears are much more frequently encountered near small villages. This indicates that suitable habitat is not used adjacent to these areas because the bears are killed or displaced. Even though the habitat may be suitable, value to bears is decreased by human activity. We similarly estimated that permanent camp sites would have more impacts than temporary camps (Table 5). We also assumed that industrial camp sites frequented by transient workers (many with limited experience in Alaska) would be less inclined to tolerate bears than long-term residents of permanent communities.

In Southeast Alaska, landfills without effective fuel-fired incineration and/or bear-proof fencing attract bears from long distances (Schoen and Beier 1990, Titus and Beier 1991). Those bears become habituated to humans and human foods and are more prone to interact with humans, thus decreasing their probability of survival. We estimated significant habitat-reduction factors for landfills without incineration (Table 5).

Road access was considered detrimental to bears. Arterial and collector roads accessible to vehicles were estimated to have greater impacts on bears than local roads and roads closed to vehicular traffic (Table 5). We believe that roads closed administratively (e.g., with gates or excavated pits) would still have some level of off-road vehicle traffic. Although less detrimental to bears than roads accessible to vehicles, roads closed temporarily (e.g., with gates) pose greater impacts than permanently closed roads (e.g., through bridge removal). We believe that all roads, regardless of closure, still have the potential for supporting additional human foot traffic, which also influences bear populations.

In this model, some habitat-capability indices required professional judgment for determining their value (Table 3) and all reductions in habitat capability within zones of human activity/disturbance required professional judgment (Table 5). Brown bear studies from a high road-density area of Southeast Alaska (Titus and Beier 1991) were used to evaluate some of these attributes that influence the habitat capability as related to model evaluation. Specifically, we tested whether radio-collared brown bear telemetry locations exhibited any pattern related to distance from primary roads, secondary roads, blocked roads, and salmon streams. To make this evaluation, we chose a subset of 58 radio-collared brown bears captured from 1989 to 1991 on the northeast portion of Chichagof Island. We selected aerial telemetry locations from 15 July to 15 September to coincide with the late summer season of the habitat-capability model. Two adjacent, uncut, and largely unroaded watersheds that effectively form one watershed (total = 185 km^2) were compared with a watershed (90 km^2) that had undergone the most extensive clearcut logging on the 1,000-km^2 study area. Each watershed had a single, major salmon spawning stream flowing much of its length. Chum (*Oncorhynchus keta*) and pink (*O. gorbuscha*) salmon were the most important species for brown bears. Of 26 anadromous fish streams on the study area, those 2 streams had the highest and fourth highest numbers of spawning pink and chum salmon.

After data screening, 58 aerial telemetry location estimates were available for analysis from 29 brown bears during the late summers of 1990 and 1991. Mean distance from a brown bear telemetry point to primary roads did not differ between watersheds owing to a primary road oriented near the uncut watershed (Table 6). Brown bears were much closer to secondary and blocked roads in the roaded watershed, indicating that they did not avoid those locations. That attribute resulted in more frequent bear-human encounters.

The most important result was that brown bear locations were much farther away from the salmon stream in the highly roaded and clearcut watershed than in the uncut and pristine watershed. We believe that a lack of cover and forested stream buffers contributed to this result. This pattern fits the professional judgment of the capability model whereby the capability is reduced in clearcut habitat and salmon spawning streams.

Brown bears continued to make use of salmon streams in heavily logged watersheds. They seldom used the clearcut habitat, but made frequent use of roads and the patches of remaining forest. That results in more frequent bear-human encounters and increases mortality rates, thereby reducing the habitat capability as suggested by the model. Brown bear mortality on the northeast portion of Chichagof Island supports the reduction in capability within zones of human activity. For example, 2 of 4 brown bears killed outside the legal hunting season during 1990 and 1991 on the northeast portion of Chichagof Island were illegal. Two of those 4 bear deaths were associated with communities and a landfill, and 2 were shot and left to lie along a primary road.

Sensitivity Analysis

An analysis of the sensitivity of the model was conducted to determine the responsiveness of the model to changes in the value of the variables. Each of the habitat variables in the model was modified while the other variables were held constant. Variable values associated with lowest and highest habitat capability were used. The resulting estimate of habitat capability from each run of the model was recorded and the percentage of change determined (Table 7). A high percentage of change indicates the variable has a high potential to affect the estimate of habitat capability. Conversely, a low percentage of change indicates that changes in the variable do not result in large differences in the estimates of habitat capability.

The successional stage (i.e., clearcut, second growth, old growth) variable has the greatest effect on estimates of habitat capability for brown bear (Table 7). Variables representing riparian habitats with fish present have an intermediate influence on the estimates. Presence of estuary fringe has a moderate effect. Riparian habitats without fish and beach fringe habitats have the least relative influence on estimates of habitat capability. Because of our Geographic Information System (GIS) program, we were unable to identify as large a riparian corridor as identified in the model. Therefore, the sensitivity of riparian habitat is underestimated.

Table 6. Mean distances (km) from brown bear telemetry locations to primary roads, secondary roads, blocked roads, and salmon spawning streams in an uncut and largely unroaded watershed versus a highly clearcut watershed during late summer, Chichagof Island, Alaska.

	Watershed type		
	Uncut	Clearcut	p[a]
Primary road	3.0 ± 1.8	2.7 ± 2.6	0.082
Secondary road	7.8 ± 2.0	2.4 ± 1.7	<0.001
Blocked road	2.7 ± 2.1	0.9 ± 1.5	0.001
Salmon spawning stream	0.5 ± 1.0	1.2 ± 1.2	0.025

[a] Based on t-tests after testing for equal variances.

Table 7. Analysis of the sensitivity of variables included in the habitat-capability model for brown bear in Southeastern Alaska.[a]

	Results				
	High value		Low value		
Variable (name in database)	Population	Mean index	Population	Mean index	% Change
Successional stage[b]	182.35	0.40	33.99	0.07	81
Riparian (with fish)[c]	338.35	0.74	147.39	0.32	56
Estuary fringe[d]	235.65	0.52	166.86	0.36	29
Riparian (without fish)[e]	167.71	0.36	147.39	0.32	12
Beach fringe[f]	186.55	0.41	167.28	0.37	10

[a] The Kadashan quadrangle was used for this analysis because the GIS data set is complete for the whole quadrangle. Total land surface of the quadrangle is 48,087 ha. Unmodified habitat capability is 167.49 brown bears; mean habitat-capability index is 0.37.

[b] Successional stage: old growth; poletimber.

[c] Riparian (with fish): riparian area adjacent to a stream with fish; not a riparian area.

[d] Estuary fringe: within 300 m of an estuary; beyond 300 m of an estuary.

[e] Riparian (without fish): riparian area adjacent to a stream without fish; not a riparian area.

[f] Beach fringe: within 150 m of the mean high tide line; beyond 150 m of the mean high tide line.

Model Verification

This model and the associated computer program have been verified through use of the GIS data base available for the Tongass National Forest in Southeast Alaska. The purpose of this verification process was to ensure that the habitat-capability section of the model provides reasonable results on several test areas. First, we ran the model on the northern Admiralty Island study site to confirm that the computer code was correct and that the availability of habitat types was similar to our original estimates. Next we ran the model on the Kadashan quadrangle (Sitka C4) on southeastern Chichagof Island. Using densities derived from Table 3, the model generated a density of 1 bear/2.9 km^2 for the Chichagof test site. This value lies within our estimated range of 1.0 bear/2.6 km^2 to 1 bear/5.2 km^2 based on previous brown bear studies in that area (Schoen and Beier 1990). We also compared population estimates for brown bears generated by the model to an independent measure of the population for Admiralty Island. The model estimated a population of 1,440 brown bears on Admiralty Island (Table 8). Because of the GIS limitation described above for riparian habitat, this number represents a small underestimate. However, the number of brown bears estimated on Admiralty Island based on empirical data was within the range of 1,200 to 1,700 bears (Schoen and Beier 1990). These comparisons suggest the model is performing within reasonable bounds.

CONCLUSIONS

In Southeast Alaska, industrial-scale logging is affecting thousands of hectares of brown bear habitat annually. To ensure the conservation of brown bears, we must begin comprehensive forest planning on a landscape scale with a time perspective of at least a hundred years (Schoen 1991). The model described here evaluates bear habitat on 2 levels. The habitat level is derived largely from empirical data on bear habitat preference. The influence of human activity on bear mortality and disturbance is based on best professional judgment and should be considered a working hypothesis. This habitat-capability model provides wildlife and forest managers with an effective tool for systematically assessing the cumulative effects

Table 8. Verification of the habitat-capability model for brown bear in Southeast Alaska on Admiralty Island.

Habitat categories	Area km^2	%	Mean index	Habitat capability: Total number of bears	Habitat capability: No./km^2	Habitat capability: %
Total area	4,359.00		0.34	1,439.26	0.33	
Habitat (index >0.01)						
Forest						
Old growth, upland	2,585.00	59	0.34	831.22	0.32	58
Old growth, riparian/with fish	4.20	t	1.00	4.00	0.95	t
Old growth, riparian/without fish	5.50	t	0.40	2.10	0.38	t
Forest beach fringe	181.60	4	0.44	76.13	0.42	5
Forested estuary fringe	12.10	t	0.63	7.21	0.60	1
Subalpine forest	643.40	15	0.37	229.88	0.36	16
Nonforest						
Avalanche slope	446.50	10	0.57	242.70	0.54	17
Alpine	143.30	3	0.24	33.48	0.23	2
Estuary	0.41	t	0.79	0.31	0.76	t
Clearcut	2.10	t	0.10	0.21	0.12	t
Other	119.80	3	0.11	12.02	0.10	1
Total habitat	4,143.70			1,439.26	0.35	
Nonhabitat (index = 0.00)	251.50	6	0.00	0.00	0.00	0

of timber management on brown bear populations in Southeast Alaska.

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