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EVALUATION OF A MULTIVARIATE MODEL OF MOUNTAIN GOAT WINTER HABITAT SELECTION

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Abstract: A predictive model of winter habitat selection by mountain goats (*Oreamnos americanus*) in south coastal Alaska was developed using discriminant function analysis (DFA). Thirty-two individual goats on the Upper Cleveland Peninsula (UCP) were radio-collared and monitored on a biweekly basis for 1-3 years to provide information on winter habitat selection. DFA was used to separate winter habitat areas from randomly selected areas on the UCP. Distance to cliffs, aspect, and timber volume provided the greatest discrimination power. The model was tested by placing radiocollars on 13 resident goats in a subpopulation located 75 km south of the UCP and on 15 goats transplanted to previously unoccupied habitat on an island 35 km south of the UCP. Relocation flights over 2 winters in the first test area and over 1 winter in the second revealed that the model correctly predicted winter use areas in 81 and 82 percent of the cases, respectively. Accuracy of predictions was significant at the $P < 0.05$ level.

Human habitation and development continue to expand in the range of northern wild sheep and goat populations. Wildlife management strategies designed to maintain populations of these species hinge, to a large degree, on protecting critical habitats to minimize the impact of land use or resource extraction. The potential impacts to mountain goats from logging coastal old growth forest is of particular concern in southeast Alaska where several studies of habitat selection have demonstrated that some low to mid-elevation, south-facing slopes with commercial timber are used heavily by mountain goats for winter habitat (Schoen and Kirchhoff 1982, Smith and Raedeke 1982, Fox 1983, Smith 1986). However, simply knowing the attributes of critical habitat is not enough. To be effective in influencing land use decisions, biologists must be able to identify critical habitats in a timely fashion over relatively large areas using tools commonly available to resource managers. The use of habitat models is often chosen to fill this need (O'Neil et al. 1988, Hobbs and Hanley 1990, Allen et al. 1991)

Several investigators have developed models of habitat selection for goats in southeast Alaska using discriminant function analysis (DFA) (Schoen and Kirchhoff 1982, Fox 1983). These studies demonstrated that DFA could be used to differentiate between goat habitat and random locations in a given study area. Anderson (1990) similarly applied DFA to distinguish between resting sites used by bobcats (*Felis rufus*) and random sites. Dubuc et al. (1990) used DFA to differentiate between watersheds used, or not used, by river otters (*Lutra canadensis*) in Maine. However, none of these studies provided independent tests of the accuracy of this modelling approach.

This study applied a habitat selection model using DFA generated in 1 study area to predict habitat selection in 2 other areas in south coastal Alaska. The objective was to determine whether biophysical information available on standard forest inventory and topographic maps could be used to accurately predict the location of winter habitat for coastal mountain goat populations. If successful, the model would give forest and wildlife managers a quantitative tool for use in designing timber sales, roads, or habitat retention areas.

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STUDY AREAS

Three separate study areas were used in this analysis (Fig. 1). The Upper Cleveland Peninsula

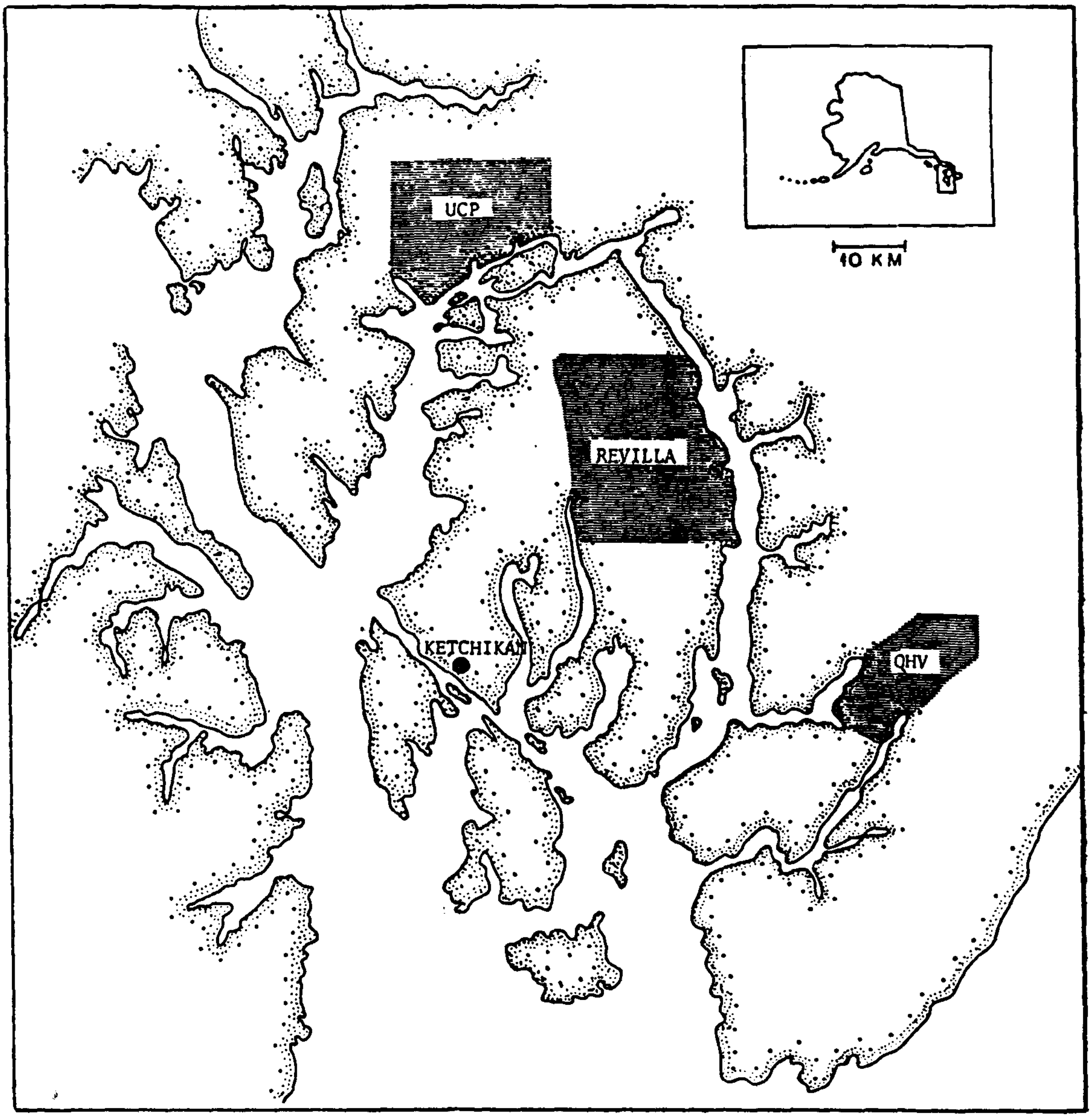

Fig. 1. Location of Upper Cleveland Peninsula (UCP), Quartz Hill vicinity (QHV), and Revillagigedo Island (Revilla) study areas near Ketchikan, Alaska.

(UCP) is located approximately 80 km north of Ketchikan, Alaska. The UCP is typical of coastal goat habitat with elevations ranging from sea level to over 1,500 m. This area is described in detail in Smith (1986). The UCP was selected as the "base" area for development of the habitat selection model.

The Quartz Hill vicinity (QHV) area is located on the coastal mainland approximately 70 km east of Ketchikan and 80 km southeast of the UCP. This area is biophysically similar to the UCP and sustained goat populations of comparable density to the UCP (Smith 1984a). The Revillagigedo Island study area (Revilla) is on the northeast third of Revillagigedo Island approximately 50 km northeast of Ketchikan, midway between the UCP and QHV. Although biophysically similar to the UCP and QHV, this area was not occupied by goats until they were transplanted to the area in 1983 (Smith and Nichols 1984). The QHV and Revilla areas are described in detail in Smith (1984b).

METHODS

Standard U.S. Geological Survey topographic maps, overprinted with USDA Forest Service timber types and expanded to 1:31,680 scale, were used for development and testing of the model. Independent grid overlay systems similar to those used by Schoen (1977) were developed for each study area by overlaying a 10 x 10 matrix with 100 grid cells per section, on the topographic maps. Each cell contained approximately 2.6 ha of land. This size was considered large enough to permit accurate mapping of goat relocations, yet fine enough to permit a single point sample of habitat parameters to describe the cell.

Habitat variables used for the predictive model included elevation, aspect, slope, distance to the nearest cliff (i.e., area of measurable slope >5O°), and timber volume. These parameters have the most influence on goat habitat use in Southeast Alaska (Fox et al. 1982, Schoen and Kirchhoff 1982, Fox 1983, Smith 1986).

Habitat variables were scaled or converted to numeric values as follows. Elevations were scaled in 36 m (100 ft) increments. Aspects were grouped as flats, N (including NW and NE), E and W, and S (including SE and SW). Slope categories were 0-15°, 16-20°, 21-25°, 26-30°, 31-37°, 38-50°, 51-65° and >66°. Distance to cliffs was in 0.4 km units. Standard USDA Forest Service timber volume classes (0, <8, 8-20, 21-30 and >30 thousand board feet per acre [mbf/a]) were used (No metric equivalent exists for these classes [Schoen and Kirchhoff 1990]). Additional details of methodology for parameter measurement are provided in Smith (1986).

A predictive model of goat winter habitat was developed using stepwise DFA to separate cells used by a sample of goats in winter from randomly selected cells in the same area as previously reported for goats by Schoen and Kirchhoff (1982) and Fox (1983). For this analysis, the 1,526 grid cells randomly selected and sampled by Smith (1986) to determine habitat availability on the UCP were divided into 2 groups. The first group consisted of those cells used by goats on the UCP during the winter (Nov 1-Mar 31). Additional UCP cells used by goats as reported in Smith (1986), but not included in the random sample, were added to the first group. This was called "winter habitat." The remaining random cells, which were unused by the collared goats, were considered "other" habitat.

The discriminant function derived with the UCP data base was used to predict the location of winter habitat on the QHV and Revilla study areas. Systematic samples of 25% of the grid cells on the QHV and Revilla study areas, consisting of all cells with even x and y coordinate values, were sampled for elevation, aspect, slope, distance to cliffs, and timber volume as was done for the UCP cells. Each of the cells was then classified by the DFA as most likely belonging in the "winter habitat" or "other" group.

Maps of "winter habitat" were developed using a 2-step process. First, cells identified by the DFA as being in the "winter habitat" group were mapped on the study area grid overlays. Second, lines were drawn around these "winter habitat" cells and any nonsampled cells that shared at least 3 corners with sampled cells that were classified as "winter habitat."

This "3-corner" rule for classifying nonsampled cells on the QHV and Revilla study areas was tested by randomly sampling 250 additional cells on the QHV, not included in the systematic sample. These cells were chosen so that 50 cells with 0, 1, 2, 3 and 4 corners, respectively, contacted systematically sampled cells classified by the DFA as "winter habitat." When these 250 cells were then processed by the DFA, 4% of those with 0 corners in contact with systematically sampled "winter habitat" cells were also classified as "winter habitat." This percentage increased to 29% for cells with 1 corner in contact with "winter habitat," 54% for cells with 2 corners, 79% for cells with 3 corners and 80% for cells with all 4 corners in contact with "winter habitat." Thus the "3-corner" rule appears to be a conservative approach to completing mapping from the 25% systematic sample.

To test the accuracy of the predictions of "winter habitat," goats were radio-collared and monitored in the QHV and Revilla study areas. In the QHV area, 13 goats, distributed over all major ridge complexes in the study area, were radio-collared in summer 1982. Winter relocations were obtained for these goats on a biweekly basis during winters 1982-83 and 1983-84. In the Revilla, 15 of 17 goats transplanted to the Revilla as described by Smith and Nichols (1984) were fitted with radiocollars and released in the center of the study area in 1983. These goats were also located on a biweekly basis during the winter of 1983-84.

Winter relocations for goats collared on the QHV and Revilla study areas were mapped to determine whether they fell within the predicted "winter habitat" areas. Chi-squared goodness-of-fit tests were used to assess the level of significance of the goats' selection for the predicted "winter habitat" (Sokal and Rohlf 1969).

RESULTS

The DFA of UCP cells used by radio-collared goats during winter (*n* = 313) versus unused, random UCP cells (*n* = 1,436) identified slope category as the most powerful discriminating variable for separating the 2 cell groups. The standardized canonical coefficients (Table 1) indicate that slope angle contributed nearly twice as much to the separation of the groups in multivariate space as did distance to cliffs, and more than twice as much as timber volume. The latter 2 variables were relatively close in terms of their discriminating power. Aspect and elevation contributed less to the discrimination, but were, nevertheless, significant in terms of overall separation.

From the signs of the coefficients it is evident that slope, aspect, and timber volume make positive contributions to the function (i.e., steeper slopes, more southerly aspects, and higher timber volumes are characteristic of habitat cells) while elevation and distance to cliffs make negative ones (i.e., higher elevations and greater distances from cliffs are more characteristic of random cells).

Table 1. Standardized canonical coefficient of the discriminant function analysis of "winter habitat" versus "other" cells on the Upper Cleveland Peninsula (UCP), Alaska study area, 1981-84.

Variable	Constant
Elevation	-0.12220
Aspect	0.15548
Slope	0.70545
Distance to cliff	-0.40808
Timber volume	0.31803

The derived discriminant function had relatively large Wilks λ (0.81) and relatively small separation of group centroids in multivariate space (1.05 for "winter habitat" cells versus 0.23 for "other" cells), which indicates there is substantial overlap of the groups. This is not surprising, inasmuch as many of the "other" cells are, in fact, biophysically identical to the cells used by goats during the winter. In fact, many of the "other" cells were probably used by radio-collared goats during times between location, or by unmarked goats throughout the winter.

Nevertheless, the canonical correlation of the equation (0.44) is high enough to suggest that this function can adequately discriminate among the cell groups. This conclusion is also supported by the results of the classification table which indicates that the function correctly classified 84% of the "winter habitat" cells and 71% of the "other" cells when the cells were reprocessed through the function (Table 2). The most important test of the DFA, however, is how well it predicts areas that will be used by goats during winter.

Of the 1,906 cells systematically sampled on the QHV study area, the DFA classified 808 (42%)

Table 2. Results of classification of "winter habitat" and "other" cells on the Upper Cleveland Peninsula, Alaska (UCP) study area when reprocessed through the discriminant function analysis.

		Predicted group	
Actual group	(*n*)	Winter habitat	Other
Winter habitat	313	264 (84%)	49 (16%)
Other	1436	411 (29%)	1025 (71%)

Table 3. Variable scales and codes for use with classification coefficients for predicting winter goat habitat based on discriminant function analysis of "Habitat" vs. "Random" cells on the Upper Cleveland Peninsula, Alaska (UCP) study area, 1981-84.

Variable	Scale	Code
Elevation	100 ft (36m) contours	100 = 1
		200 = 2
		300 = 3
		...
Aspect	n/a	flat = 1
		N, NE, & NW = 2
		E & W = 3
		S, SE, & SW = 4
Slope	degrees	0-15 = 1
		16-20 = 2
		21-25 = 3
		26-30 = 4
		31-37 = 5
		38-50 = 6
		51-65 = 7
		66+ = 8
Distance to cliff	miles (0.4km intervals)	0 = 0
		< 0.25 = 1
		0.25 < X < 0.50 = 2
		0.51 < X < 0.75 = 3
		...
Timber volume	mbf/acre	0 = 0
		< 8 = 1
		8-20 = 2
		21-30 = 3
		30+ = 4

as habitat cells. Of the 5,690 cells sampled on the on the Revilla, the DFA classified 2,362 (42%) as habitat. After drawing lines around groups of cells, the total proportion of each area predicted to be "winter habitat" was approximately 40%.

In the QHV area, 81% of all winter relocations of radio-collared mountain goats (n = 280) occurred within the borders of the predicted habitat. An additional 17% of the QHV relocations occurred in cells adjacent to the border. In the Revilla, 82% of all winter relocations (n = 60) were within the borders and another 8% occurred in cells adjacent to the border. Chi-squared analysis of goodness-of-fit indicates that in both the QHV and Revilla study areas, goats made significant ($P < 0.001$) selection for the predicted habitat cells.

Table 4. Classification coefficients for use in predicting goat winter range based on discriminant function analysis of habitat selection patterns of 20 Upper Cleveland Peninsula (UCP) goats from 1981-84.

	Classification coefficient	
Variable	"Habitat"	"Random"
Elevation (C_e)	0.3792435	0.3967944
Aspect (C_a)	1.2069100	1.0750910
Slope (C_s)	1.2243040	0.7473263
Distance to cliff (C_d)	1.8619730	2.2229880
Timber volume (C_t)	2.1358060	1.7548600
Constant	-12.9007500	-10.4777900

DISCUSSION

Although the underlying assumptions of DFA were strained in this application, DFA is an extremely robust procedure and violation of some assumptions is not fatal to the results. The most serious criticisms of using DFA in habitat analysis are that authors attempt to infer cause-and-effect relationships (Williams 1983) or that DFA may invent erroneous statistical relationships with no possible biological significance (Rextad et al. 1988). This study avoided these problems by simply applying DFA to make predictions which were then tested using an independent procedure. Thus as a management tool, this approach appears logically sound, practical, and easily applied.

Based on the degree of accuracy of predictions, the function derived from the UCP could be used with confidence to predict the location of winter habitat in other areas that are biophysically similar to the UCP. This may include much of the coastal goat range in southern Southeast Alaska and north coastal British Columbia. To apply the function, topographic and timber type maps like those used in this analysis should be overlaid with a similar grid system. Then the elevation, aspect, slope, distance to cliffs, and timber volume should be determined for all or a systematic sample of cells. All values must be scaled as indicated in Table 3. The values for each cell would then be entered into the equation:

$$SCORE_i = Elevation * (Ce_i) + Aspect * (Ca_i) + Slope * (Cs_i) + Distance\ to\ cliff * (Cd_i) + Timber\ Volume * (Ct_i) + (Constant_i)$$

for both the "Habitat" and "Random" coefficients given in Table 4. The resulting scores would be compared and the cell would be classified as belonging in the group for which it has the higher score. Predicted "Habitat" cells can then be mapped for use in decision-making.

With the increasing availability of GIS technology, it may now be possible to conduct similar analyses much faster and more thoroughly than presented here. A wider range of multivariate techniques is also being developed and applied to habitat modelling. Other methods of discriminant analysis use Kernal density estimation (Hand 1982) and new methods of spacial data analysis and image analysis (Ripley 1988, Cressie 1991) can also be used. Regardless of the statistical approach used, additional efforts should be made to test the accuracy of habitat selection models with the empirical approach used in this study to avoid the problems identified by Rextad et al. (1988).

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