Andean bear habitat use in the Oyacachi River Basin, Ecuador

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Abstract: One of the primary threats to Andean bear (*Tremarctos ornatus*) populations in Ecuador is conversion of bear habitat to human uses, resulting in habitat loss and fragmentation. To develop science-based conservation plans, information on the suitability and distribution of Andean bear habitat is critically needed. We studied habitat use in the 721-km^2 Oyacachi River Basin in the eastern Andes Mountains. We used bimonthly sign surveys along 1.6-km transects ($n = 53$) to determine habitat use. We recorded 549 and 202 locations of bear activity during 2000 and 2001, respectively; feeding signs were recorded most frequently (53.3%), followed by scats (19.6%), footprints (13.4%), hair (6.9%), tree marks (4.8%), trails (1.2%), and ground nests (0.8%). The combined total distance of surveyed transects for both years was 1,018 km with a corresponding sign encounter rate of 0.74/km. Use of the different vegetation types within the study area varied among the bimonthly sampling periods. Habitat suitability was calculated with a geographic information system (GIS) based on Mahalanobis distance (D^2), a multivariate measure of dissimilarity, using 8 habitat variables and 437 bear locations. Model validity was confirmed by testing whether the D^2 values of 61 random locations in the Oyacachi River Basin were greater than those associated with 61 test locations. We used a cumulative frequency curve based on D^2 values associated with the 61 independent test locations to define 5 classes of habitat suitability, ranging from most used to avoided areas. The most suitable habitat class occupied 86.3 km^2 (11.9%) of the study area. The results of our study may be applied on a regional scale to define priority conservation areas for Andean bears in the eastern Andes Mountains of Ecuador. Our results indicate the usefulness of field-based studies combined with GIS and statistical analyses as a scientific basis for developing conservation strategies for Andean bears on a landscape scale.

Key words: Andean bear, conservation planning, Ecuador, habitat suitability, habitat use, Mahalanobis distance, *Tremarctos ornatus*

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Habitat loss and fragmentation are 2 of the main challenges in the conservation and management of large carnivores in the world (Peyton et al. 1999, Tirira et al. 2001). Habitat fragmentation can result in small, isolated populations that become increasingly vulnerable to extinction (Diamond 1986, Wilcove 1987). The Andean bear presents a clear example of how habitat fragmentation and illegal hunting have caused severe population reductions; consequently, this species is now considered threatened at a global scale (Hilton-Taylor 2000) and in danger of extinction in Ecuador (Cuesta and Suárez 2001).

The Andean bear is a key species in the conservation and management of Andean habitats due to its large spatial requirements, its ecological role (e.g., potential seed disperser), and its profound charisma (Yerena and Torres 1994, Young 1999, Cuesta 2000). The Andean bear's wide ecological requirements and its seasonal use of different habitats, such as extensive páramo and cloud forest areas, make this species an appropriate subject on which to base conservation planning to preserve the high biodiversity of these ecosystems (Peyton 1999). The seasonal variability in food availability in habitats used by Andean bears triggers wide-ranging movements of the animals within their home ranges, as has been

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documented for other bear species (Schoen 1990). Those movements, however, often are impeded by the loss of cloud forest and páramo areas because of advancing agricultural frontiers and expanding infrastructure (e.g., roads). Sierra et al. (1999) estimated that 38% of the original cover of páramos and cloud forests of Ecuador has been transformed into agricultural or urban lands.

Schoen (1990) suggested that the broad ecological and spatial requirements of bears demand management actions on a regional scale. Because little is known about the habitat relationships of Andean bears, it is fundamental to undertake research that will aid in decision-making supporting regional bear conservation. The objective of our study was to determine suitability of Andean bear habitat in the Oyacachi River Basin, an important area for Andean bears on the eastern slopes of the Andes Mountains in Ecuador.

Study area

Our study area was approximately 50 km east of the city of Quito, within the Cayambe-Coca Ecological Reserve, in the province of Napo. The study area covered 721 km^2, mainly in the Oyacachi River basin, of which 446 km^2 were ancestral territories of the Quichua Community of Oyacachi (Fig. 1).

Elevations within the study area range from 1,600 to 4,500 m with a mean slope of 41° (Cuesta et al. 2001). In the upper portion of the area, the salient geomorphologic features are of glacial origin and include circles, *roches moutonnées* (streamlined knobs projecting from the land surface), and U-shaped valleys filled with moraine deposits, mudslides, and lahars (volcanic mudflows). The lower portion of the study area is highly dissected and covered with cloud forests; heterogeneous landscapes are predominant. The weather in the Oyacachi River basin varies according to elevation. In the upper portion, the mean annual temperature is 9° C with a mean rainfall of 1,500 mm. In the lower valley, the mean annual temperature reaches 17° C, with a mean rainfall of 2,500 mm (López 1992). Six natural vegetation types occur within the study area: upper montane evergreen forest (BSV-ma), montane cloud forest (BN-m), mixed páramo forest (BPM), herbaceous páramo (PH), swampy páramo (PA), and alder (*Alnus* spp.) forests (Báez et al. 1999, Iturralde et al. 2000; Fig. 2).

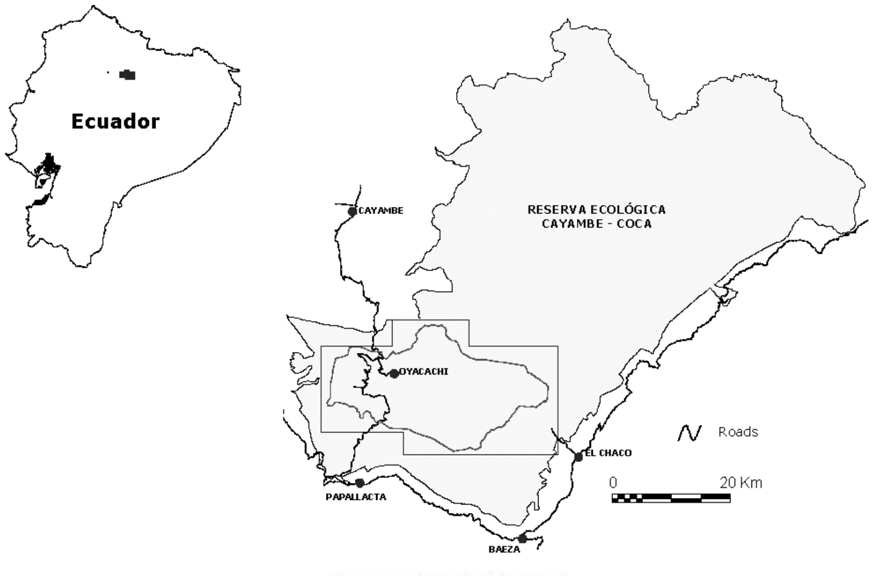
The only human population in the study area lives in the village (600 residents) of Oyacachi, reachable from the town of Cayambe via a road built in 1995. A road south of the study area crosses the páramos toward the town of Papallacta. A footpath connects Oyacachi with the town of El Chaco, located 33 km east and crossing cloud forests within the study area (Fig. 1). The main human activities include extensive livestock management, subsistence agriculture at a range of altitudes, breeding of domestic animals, and handicraft manufacturing (Morales and Schjellerup 1997). The community's relationship with the Andean bear dates back 500 years; the bear used to be considered a divinity (Andrade Marín 1952, Camacho et al. 1999). Presently, a relationship of mutual acceptance seems to have developed; hunting is prohibited by rules of the community (Comunidad Quichua de Oyacachi 2001).

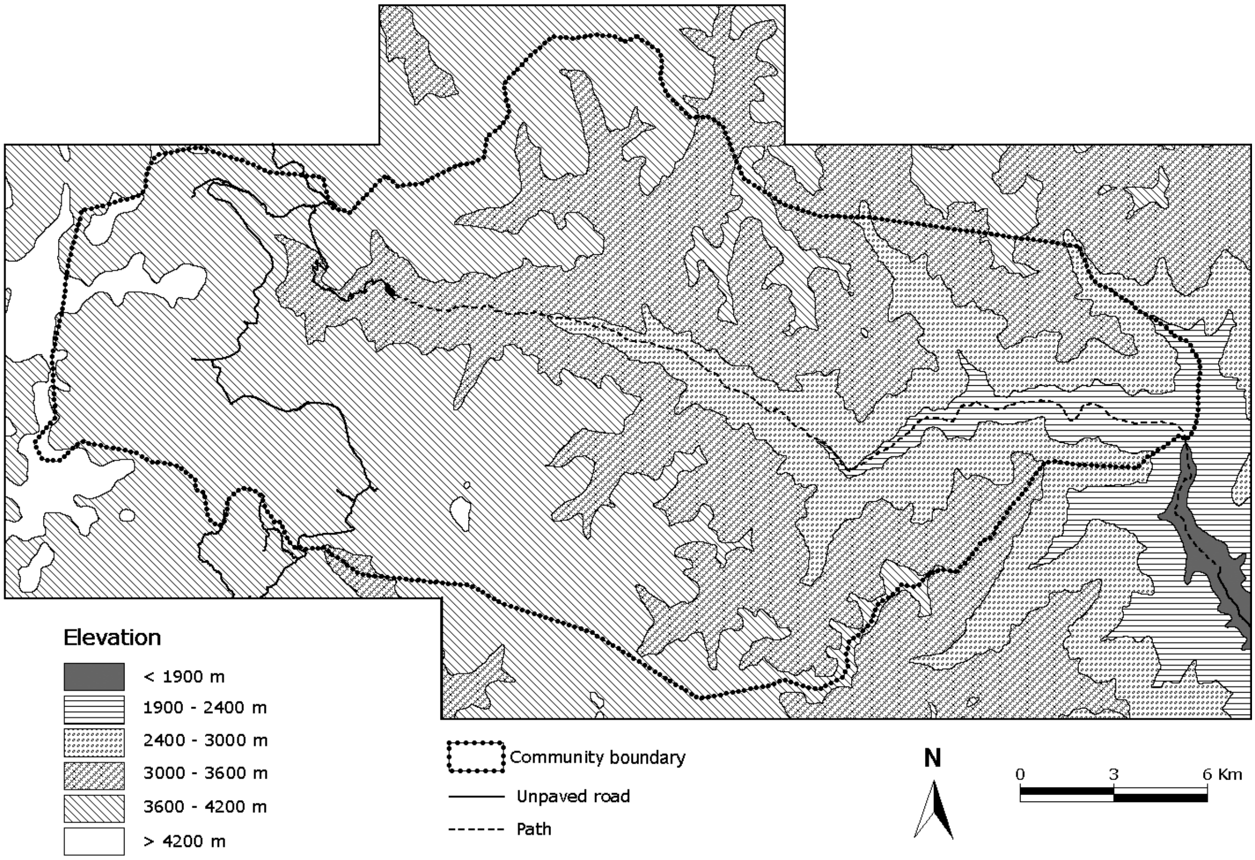
Methods

Field surveys for bear sign

Because of logistical challenges and inaccessibility of the terrain, we chose sign surveys, rather than radiotelemetry, as the basic data collection method for our study. Monitoring of wildlife populations through sign records has been used in many studies to determine population abundance and to quantify habitat use and availability (Nams 1989, Clevenger et al. 1997). Six local researchers from Oyacachi surveyed for sign of bear activity during 2000 and 2001 ($\bar{x} = 22$ days/month). Bear sign information was gathered along 53 transects with a length of 1.6 km each. Placement of transects within the study areas was stratified according to the area represented by each vegetation type in the study area (Kendall et al. 1992). Given the poor accessibility within the study area, starting locations for most transects were placed near the "horse trail" to El Chaco along the Oyacachi River or near the unpaved road that connects Oyacachi village with Papallacta in the southwestern portion of the study area (Fig. 1). Once we located the start of each transect, we followed an upslope direction for those transects starting near the Oyacachi River and a random direction for high-elevation transects. Transect routes were placed in such a manner that various microhabitat conditions (such as different aspects and slopes) were sampled within each vegetation formation. Each transect route was marked with colored flagging at ≈10-m intervals to ensure that subsequent surveys followed the same route.

Detectability of mammal sign may vary among different habitats and among types of sign (Wemmer et al. 1996). To minimize biases due to varying detectability rates, we used a fixed-width transect survey and only considered bear sign within 2 m on either side of the transects (4-m transect width). This limited search


Ecuador
CAYAMBE
RESERVA ECOLÓGICA
CAYAMBE - COCA
OYACACHI
Roads
EL CHACO
0
20 Km
PAPALLACTA
BAEZA


Elevation
< 1900 m
1900 - 2400 m
2400 - 3000 m
3000 - 3600 m
3600 - 4200 m
> 4200 m
Community boundary
Unpaved road
Path
N
0
3
6 Km

distance increased the probability of sign detection. Furthermore, we increased sign detectability by using local field personnel, who were extremely skilled at locating bear sign. Finally, based on the results of a pilot study, Cuesta et al. (2001) found that the proportion of each type of sign was consistent among vegetation types, suggesting that the fixed-width surveys were effective in reducing detectability bias due to different types of sign.

The 53 transects were surveyed once every 2 months. For each site with bear sign, field personnel collected (1) global positioning system (GPS) coordinates of the location, (2) the type of sign, and (3) additional field measurements to characterize the site. The GPS coordinates were then used in combination with GIS to measure topographic, ecological, and anthropogenic variables selected to assess bear habitat use within the study area. We acquired digital cartographic data from the Ecuadorian Instituto Geográfico Militar's (IGM; Quito, Ecuador) topographic charts (scale 1:50,000) and Landsat 5 Thematic Mapper (December 1998; EROS Data Center, Sioux Falls, South Dakota, USA) satellite imagery (Table 1). Each data layer was generated with TNT Mips GIS software (MicroImages, Inc., Lincoln, Nebraska, USA) in a raster format based on 30 × 30-m pixels.

Use of vegetation types

The records obtained during field monitoring allowed us to define habitat use patterns and selection throughout 2000 and 2001. Data were grouped for each bimonthly survey period and differential use of vegetation types was tested with Friedman's method for randomized blocks (Sokal and Rohlf 1981) using $\alpha = 0.05$.

Habitat modeling

Habitat models based on GIS technology are suitable tools to predict the presence and relative use of bear habitat across large landscapes (Clark and van Manen 1992), particularly because such models are appropriate for generalist species (Donovan et al. 1987). We used 8 GIS variables (Table 1) to measure habitat conditions for the bear sign locations sampled during the field surveys. Those habitat conditions were used as the training set to determine habitat use of Andean bears in the Oyacachi study area. We chose the habitat variables based on our field observations and a review of Andean bear literature. Of the 751 bear locations, we used 437 to develop the habitat model; 203 locations were combined with other locations that were within a distance of 5 m, and 111 locations were excluded because of large GPS errors (>100 m). Such large errors usually were caused by poor satellite acquisition due to dense forest canopy and rugged terrain. We calculated a multivariate statistic, Mahalanobis distance, to develop a habitat model (Clark et al. 1993, van Manen et al. 2002):

$$D^2 = (\mathbf{x} - \hat{\mathbf{u}})' \, \Sigma^{-1} (\mathbf{x} - \hat{\mathbf{u}}),$$

where $\mathbf{x}$ is the vector of habitat features at any given point, $\hat{\mathbf{u}}$ is the mean vector of habitat features at the locations sampled during the field surveys, and Σ^{-1} is the inverse of the variance-covariance matrix, calculated from the sampled points.

D^2 is a statistical measure of dissimilarity between the given point and the mean for all locations, and is expressed as a distance. We calculated D^2 with GIS programs based on the values of digital map layers (habitat variables) and "ideal" values of those variables associated with bear sign locations. Low D^2 values indicate that a location has habitat features similar to the "ideal" conditions sampled at the bear sign locations, whereas greater D^2 values indicate increasingly dissimilar conditions. Mahalanobis distance is dimensionless because it is a function of standardized variables, despite the different measurement scales among the original variables. There is no one best combination of variables that results in the lowest D^2 values; a variety of habitat combinations can result in identical distance values (Clark et al. 1993).

We tested the habitat model based on 61 observations of bear sign collected independently from the bimonthly field surveys during 2000 and 2001 (test locations). We divided the distance values associated with the 61 test locations into 5 range classes. These classes were based on discernible discontinuities of percentiles of a cumulative frequency curve and essentially represented 5 suitability classes (Boitani et al. 1999). We used the frequency data analysis function in SPSS 9.0 software (SPSS 1998) to identify percentiles at discontinuities among the 61 test locations.

We further assessed model validity by generating a null model based on 61 random locations within the Oyacachi River Basin for comparison with D^2 values of the 61 test locations. We used those observations to test the hypothesis that D^2 values for the test locations were

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Fig. 1. Location of the Oyacachi River Basin study area in Ecuador for a study of habitat use by Andean bears, 2000–01.

Table 1. Variables selected to determine Andean bear habitat availability, Oyacachi River Basin, Ecuador, 2000–01.

Variable (unit of measure)	Range in study area	Data source and processing
Elevation (m)	1,584–4,312	Base cartography of Instituto Geográfico Militar, Ecuador; scale 1:50,000.
Slope (degrees)	0–76	Derived from elevation using the Slope function in TNT Mips GIS.
Vegetation cover		Vegetation characterizations by Báez et al. (1999) and Iturralde et al. (2000) based on supervised digital classification of a Landsat TM satellite image (December 1998) and field transects.
Distance to water (m)	0–4,623	Base cartography of Instituto Geográfico Militar, Ecuador, using the Distance Raster function in TNT Mips GIS.
Percentage of human disturbance	0–44.4	Percentage of disturbed area (villages, farms) present in a circular area of 10 km^2, centered on the processing pixel, using the Focalvariety function in TNT Mips GIS.
Road density	0–4.9	Density index based on the length of roads present in a circular area of 10 km^2, centered on the processing pixel, using the Focalvariety function in TNT Mips GIS.
Terrain shape index	−22.4–25.4	Calculated from elevation based on McNab (1989).
Land use intensity	1–4	Four categories of use intensity derived from the community management plan and from the vegetation characterizations by Báez et al. (1999) and Iturralde et al. (2000) based on supervised digital classification of a Landsat TM satellite image (December 1998) and field transects.

lower compared with the 61 random sites using a Mann-Whitney *U* test.

Results

Field surveys for bear sign

We recorded 751 locations with signs of bear activity; 549 during 2000 and 202 during 2001. Signs of feeding activity were most frequently observed (53.3%), followed by scats (19.6%), footprints (13.4%), hair (6.9%), tree marks (4.8%), trails (1.2%), and ground nests (0.8%). The combined total distance traversed during both years of monitoring was 1,018 km with an encounter rate of observed sign of 0.74 records per kilometer of transect.

Use of vegetation types

The transect surveys showed differences in bear use among the vegetation types between years and among the bimonthly periods ($\chi^2 = 34.6$, $P = 0.001$). Throughout the 6 bimonthly monitoring periods, the greatest intensity of use occurred in montane cloud forest and herbaceous páramo (Table 2). Our results indicated a relatively continuous use of all vegetation types throughout the year except for swampy páramo and mixed páramo forest, where use was irregular (Table 2). The periods January–February and July–August showed a greater concentration of bear use in montane cloud forests, whereas September–October and November–December reflected a greater use of herbaceous páramo and mixed páramo forest.

Habitat use

We calculated D^2 values for each pixel in the Oyacachi River Basin based on the original 437 locations of bear sign (Fig. 3); D^2 values within the study area ranged from 2.6 to 10,991.1, with a mean of 320.8 (SD = 1,069.9). D^2 values corresponding to the 437 model input positions ranged from 2.7 to 286.3 ($\bar{x} = 11.7$, SD = 23.0), whereas the test locations (independent locations of bear sign) had D^2 values ranging from 2.9 to 5,012.3 ($\bar{x} = 131.6$, SD = 681.3; Fig. 4).

Based on the cumulative frequency curve of the D^2 values for the 61 test locations, we identified 5 percentiles (23.0%, 47.6%, 86.9%, 96.7%, and 100%) to define classes of habitat suitability: $0 < D^2 \leq 7.2$ for class 1, $7.2 < D^2 \leq 10.1$ for class 2, $10.1 < D^2 \leq 23.7$ for class 3, $23.7 < D^2 \leq 200.0$ for class 4, and $D^2 > 200.0$ for class 5 (Table 3, Figs. 3 and 4). Ninety percent of the independent bear sign locations were below a D^2 value of 26; in other words, when we encountered bear sign, the probability of an associated D^2 value >26 was $<10\%$.

Table 2. Percent of Andean bear sign locations found in vegetation types by bimonthly period, Oyacachi River basin, Ecuador, for 2000 (n = 549 locations) and 2001 (n = 202 locations). Blank fields indicate absence of Andean bear sign.

Year Vegetation type[a]	% of locations					
	Jan–Feb	Mar–Apr	May–Jun	Jul–Aug	Sep–Oct	Nov–Dec
2000						
BNM	47.6	30.8	39.6	45.5	14.0	22.0
BPM	3.6	4.1			32.0	14.6
BSV-ma	21.5	20.0	17.0	27.2	18.0	34.1
PA	7.1	2.6	5.7	2.3	2.0	
PH	20.2	42.5	37.7	25.0	34.0	29.3
Total	100.0	100.0	100.0	100.0	100.0	100.0
2001						
BNM	44.7	55.6	22.5	58.6	25.0	13.6
BPM	13.2	2.2	30.0	6.9	28.6	13.6
BSV-ma	18.4	24.4	20.0	3.4	32.1	31.8
PA	5.3	2.2				4.5
PH	18.4	15.6	27.5	31.1	14.3	36.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

[a] BNM = montane cloud forest, BPM = mixed páramo forest, BSV-ma = upper montane evergreen forest, PA = swampy páramo, PH = herbaceous páramo.

The spatial distribution of the first 4 D^2 classes in the study area was fairly homogeneous (Fig. 3). The class 1 area occupied 86.3 km^2, equivalent to 12.0% of the study area extent (Table 3, Fig. 3). Pixels in that class were distributed between 1,955 and 4,391 m elevation ($\bar{x}$ = 3,219, SD = 669) with slopes ranging from 0 to 78 degrees ($\bar{x}$ = 50.5, SD = 14.8). Almost half (38.0 km^2) of the class 1 zone was associated with montane cloud forests and 38.3 km^2 with herbaceous páramo. The distribution of class 1 areas in relation to road density and disturbed areas indicated a negative association of these elements with bear habitat use. Areas with a high percentage of human disturbance tended to be associated with the 2 lowest suitability classes (Fig. 3).

The D^2 values associated with the 61 random locations were greater than those associated with the test locations, with the greatest differences occurring in the lowest range of D^2 values (Table 3, Fig. 5). The Mann-Whitney U-test indicated that the differences between the 2 distributions of D^2 values were significant ($Z = -2.78$, $P = 0.006$).

Discussion

Use of vegetation types

Members of the Ursidae family tend to concentrate their use of the landscape in the most productive habitats (Schoen 1990); this may partially explain the observed variation in use intensity of the vegetation types within the Oyacachi River Basin. Our results showed a distinct pattern of seasonal use, suggesting seasonal variation of food resources available within each vegetation type in the study area. Peyton (1980, 1984) and Suárez (1988) also observed marked seasonal use patterns among different habitats in other portions of the range of the Andean bear.

In our study, alder forests (*Alnus acuminata*) represented the only vegetation type for which we had no record of bear use. We speculate that this low use was due to the lack of primary bear foods and scant cover provided by alder forests (Báez et al. 1999, Iturralde et al. 2000). The bear use that we observed for the remaining vegetation types seemed to be associated with food resources. One of the primary food sources of Andean bears is the meristematic tissue of various terrestrial and epiphytic bromeliads (Davis 1955). Troya (2001) identified several giant bromeliads (*Puya* spp.) and the terrestrial bromeliads *Greigia vulcanica* and *Greigia mulfordii* as the most frequently consumed species in the Oyacachi study area. Terrestrial bromeliads are most common in the páramo areas, whereas epiphytic bromeliads occur in the upper montane evergreen forest. Bear use of upper montane evergreen forest and the montane cloud forest was particularly seasonal (Jan–Feb and Jul–Aug; Table 2), which may reflect the importance of fruit trees, such as *Hyeronima* spp. Indeed, fruiting rates in these forests tend to be greatest during those periods (Skov 1997, Troya 2001).

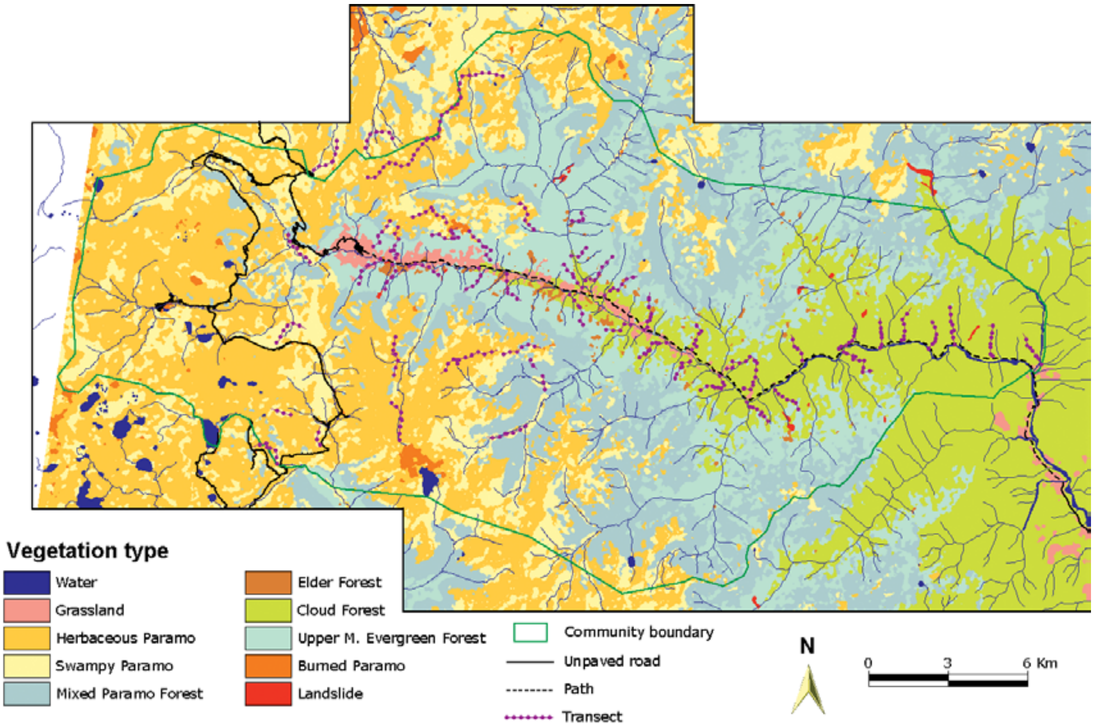

Fig. 2. Vegetation types of the Oyacachi River Basin, Ecuador, for a study of habitat use by Andean bears, 2000–01.

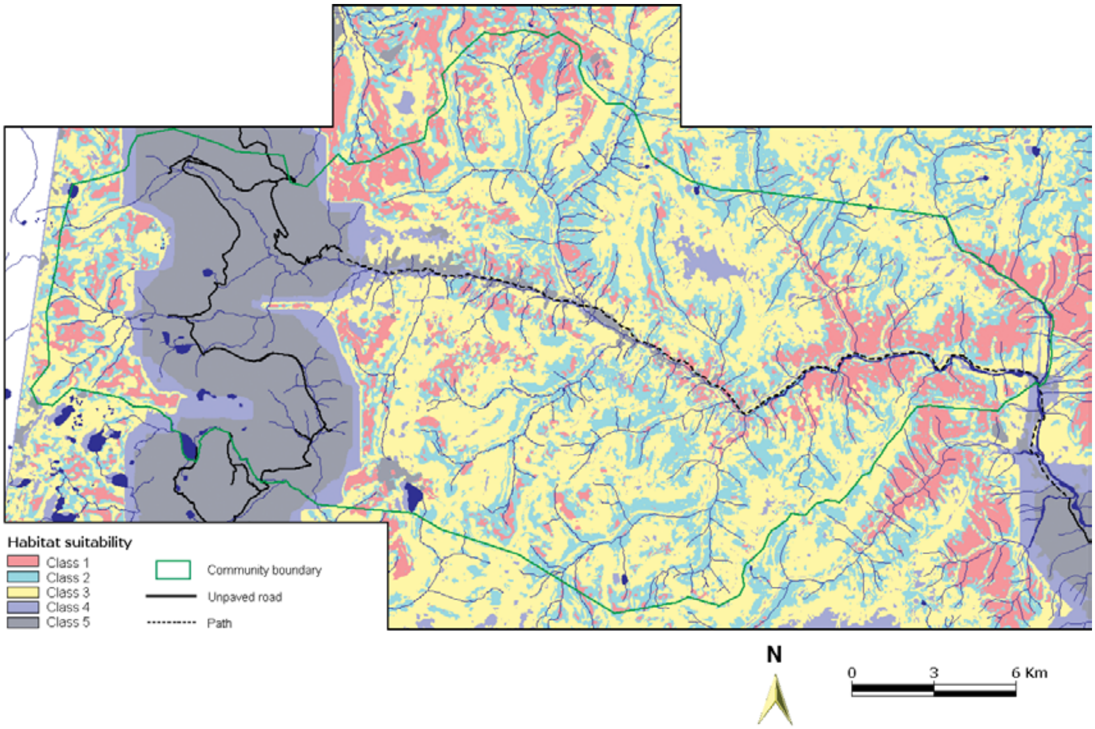

Fig. 3. Mahalanobis distance (D^2) values for a study of Andean bear habitat use in the Oyacachi River Basin, Ecuador, 2000–01. Five habitat suitability classes were defined; class 1: $0 < D^2 \leq 7.2$; class 2: $7.2 < D^2 \leq 10.1$; class 3: $10.1 < D^2 \leq 23.7$; class 4: $23.7 < D^2 \leq 200$; and class 5: $D^2 > 200$.

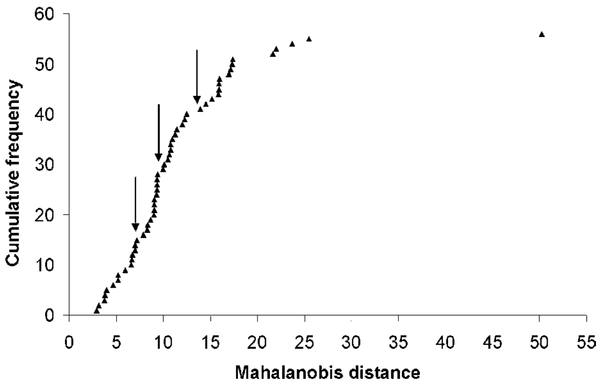

Fig. 4. Cumulative frequency of 61 test locations (independent locations of bear sign) and associated Mahalanobis distance values for a study of Andean bear habitat use in the Oyacachi River Basin, Ecuador, 2000–01. Four outlying observations were excluded for scaling purposes. Arrows indicate discontinuities used to define classes of Mahalanobis distance values.

Results from studies in Venezuela also indicate that Andean bears prefer to feed in páramo areas with a high concentration of giant bromeliads (*Puya* spp.) and forested areas where trees have a high concentration of epiphytic bromeliads (*Gusmania* spp.) (Goldstein 1992).

Although food is only one of many resources that large mammals select for, it is particularly important for bears because of their large size and relatively inefficient digestive system (Pritchard and Robbins 1990). Our study suggests that selection of vegetation types may be associated with food abundance, but it will be necessary to conduct additional studies to determine availability and quality of food resources throughout the year. That information should be helpful to better interpret seasonal movement patterns of Andean bears among vegetation types.

Habitat suitability

Our analysis indicates that the Mahalanobis distance statistic can be an effective measure to define potential suitability of Andean bear habitat. For the Oyacachi River Basin, bear locations were associated with low D^2 values (mode = 3.6, $n = 437$). Of the independent test locations, 23.0% occurred in areas with D^2 values <7.2, 47.6% occurred with D^2 values <10.1, and 86.9% occurred with D^2 values <23.7 (Fig. 4). The distribution of D^2 values associated with the 61 null model (random) locations was different from those associated with the test locations (Table 3, Fig. 5); this difference was mostly evident for the low range of D^2 values, which represents the best bear habitat. Many bear locations, however, were in areas with intermediate D^2 values (Table 3), which resulted in convergence of the cumulative D^2 values for the null model (random locations) and the test locations (Fig. 5). This convergence may indicate that a large portion of the study area represents habitats for which model predictions are marginal. We speculate that a larger sample than 61 test locations may be needed to improve the power to test the model. Despite the probable lack of power to properly test all aspects of the Mahalanobis distance model, we found that D^2 values successfully predicted areas that receive frequent use by Andean bears.

Elevation and vegetation type seemed to have a strong influence on habitat suitability in the study area (Fig. 3). The 2 variables are intimately linked to the type and concentration of food resources and protection provided by the structure of certain vegetation types. Such habitat components are important for all bear species, and the Andean bear is no exception (Peyton 1980, Clevenger et al. 1992). The montane cloud forest has been defined by several authors (Peyton 1980, Yerena and Torres 1994) as a critical ecosystem to support viable bear populations. The high α-diversity of these forests regarding herbs, vines, and epiphytes (Jorgensen et al. 1995), in conjunction with the high β-diversity of Andean ecosystems (Jorgensen et al. 1999), likely provides many of the resources needed by Andean bears. To better understand the seasonal movement patterns of Andean bears, it is important to study the variability of food availability and abundance during different seasons and among the vegetation types used by this species.

Other topographic variables also seemed to influence model predictions. Andean bears in our study area seemed to use a wide range of landscape features, from steep ravines to flat areas. The slope associated with bear sign locations ranged from 0° to 70° ($\bar{x} = 20.8°$, SD = 14.9). However, elevations above 4,300 m with slopes $>60°$ were not used; these areas generally are covered with a small shrub, *Loricaria thuyoides*, which is not used by Andean bears for cover or food.

The influence of anthropogenic variables on bear habitat use was evident as well (Fig. 3), but seemed to occur on a larger scale compared with vegetation type. Some human activities, such as road construction or agricultural frontier expansion, have been correlated with substantial range and population reduction of European brown bears (*Ursus arctos*) (Elgmork 1978, Clevenger et al. 1992) and American black bears (*Ursus americanus*) (McLellan and Shackleton 1988). Because similar processes are occurring in Andean bear habitat,

Table 3. Five classes of Mahalanobis distance values (D^2), their area, frequency of occurrence of test locations (independent locations of Andean bear sign), and frequency of null model locations for a study of Andean bear habitat in the Oyacachi River Basin, Ecuador, 2000–01.

D^2 class	Area (km^2)	Percent of area (%)	Frequency of test locations	Percent test locations (%)	Frequency of null model locations	Percent of null model locations (%)
Class 1 $0 < D^2 \leq 7.2$	86.3	12.0	14	23.0	7	11.5
Class 2 $7.2 < D^2 \leq 10.1$	172.8	23.9	15	24.6	19	31.2
Class 3 $10.1 < D^2 \leq 23.7$	308.3	42.7	24	39.3	24	39.3
Class 4 $23.7 < D^2 \leq 200$	46.5	6.4	6	9.8	3	4.9
Class 5 $D^2 > 200$	108.6	15.0	2	3.3	8	13.1
Total	722.5	100.0	61	100.0	61	100.0

the inclusion of anthropological variables in the model was important to identify bear habitats that are within human influence zones.

We used 5 classes of D^2 values (Table 3) to define broad categories of bear habitat suitability (Fig. 3). Class 1 represented features closest to the "ideal" habitat of the Andean bear, as measured from known bear locations. The second and third classes included areas that have increasingly different habitat features from those ideal conditions; those areas may be considered of lower habitat suitability but still important bear habitat within the study area. The fourth class included areas that generally surrounded the 3 previous classes, representing marginal habitat that received only occasional use by bears and may not be suitable for permanent bear presence. However, class 4 areas may be crucial to connect important class 1 areas (Boitani et al. 1999). Finally, the fifth class comprised areas that generally were not used by Andean bears.

Management and research implications

The temporal variation in bear use that we observed among the different vegetation types may indicate continuous movements of bears within an altitudinal gradient. Thus, the integrity of habitats along this altitudinal range should be considered when defining conservation areas for Andean bears so that these movements can be maintained (Yerena and Torres 1994). For example, expansion of the agricultural frontier (low elevations) into montane cloud forests (high elevations) may reduce bear access to important food sources, such as tree-borne fruits, that are not present in the páramos (highest elevations).

Our method of defining habitat suitability has a number of desirable qualities to promote understanding of wildlife habitat use and apply this understanding to conservation management. Biological, topographical, and anthropogenic variables all are part of Andean bear habitat and were included in the model. Furthermore, all variables are also present in landscapes of the eastern Andes in northern Ecuador to allow model extrapolation. Application of the model at a regional scale would allow the definition of conservation priority areas in Ecuador that could help guide conservation of critical habitats to maintain viable populations of the species in the future. Predictions from the habitat model can be used in conjunction with other data to identify potential sites for conservation purchases, to establish or preserve movement corridors, and to mitigate negative effects of certain land management practices, such as construction of roads or increasing intensity of human use (Clark et al. 1993). The information obtained during this study, however, should not be seen as absolute criteria for the definition of Andean bear conservation areas. It will be necessary to conduct further model testing and development, define conservation priorities, and to find effective mechanisms to achieve a better integration of the socio-economic, political, and legal issues to ensure the effectiveness and viability of defined conservation areas in the long term.

As other studies have already shown (e.g., Clevenger and Purroy 1996), biological monitoring by means of sign records can be highly effective to generate basic ecological data on habitat use, diet, and even population trends. For example, the encounter rate of bear sign that we obtained (0.74/km transect) indicates that it may be

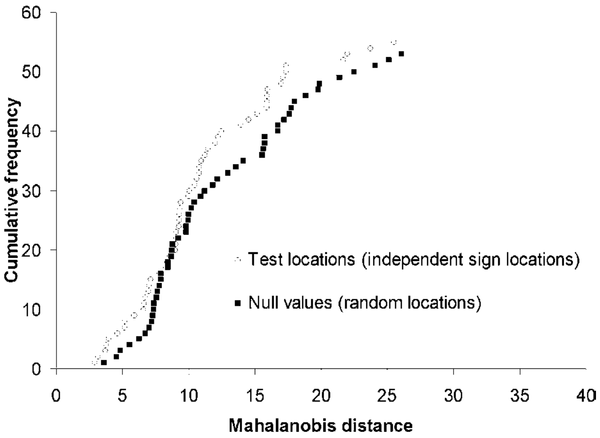

Fig. 5. Cumulative frequency of 61 independent bear sign and 61 random (null model) locations with associated Mahalanobis distance values, Oyacachi River Basin, Ecuador, 2000–01 for a study of Andean bear habitat use. Six outlying observations were excluded for scaling purposes.

possible to establish a long-term monitoring program to generate baseline ecological information on trends of wildlife populations in the study area (Kendall et al. 1992).

Finally, the participation of local researchers from the Oyacachi community was essential for the execution of this study. Because the local researchers were highly knowledgeable about their environment, this approach allowed us to enhance the success of finding bear locations, to maintain intensive monitoring throughout the entire study period, and to efficiently cover a relatively large and inaccessible study area. Participation of local researchers also made it easier for the rest of the community to understand the conservation objectives of this study. The internalization of this process has been so successful that some people have already identified the need to include bear habitat conservation areas in their territory zoning. Our study clearly shows that effective wildlife conservation is critically dependent on the involvement of communities that depend on natural resources in the area (Fiallo and Jacobson 1995, Kellert 1994).

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