Delineating priority habitat areas for the conservation of Andean bears in northern Ecuador

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Abstract: We sought to identify priority areas for the conservation of Andean bear (*Tremarctos ornatus*) habitat in the northern portion of the eastern Andean cordillera in Ecuador. The study area included páramo and montane forest habitats within the Antisana and Cayambe-Coca ecological reserves, and unprotected areas north of these reserves with elevations ranging from 1,800 to 4,300 m. We collected data on bear occurrence along 53 transects during 2000–01 in the Oyacachi River basin, an area of indigenous communities within the Cayambe-Coca Ecological Reserve. We used those data and a set of 7 environmental variables to predict suitability of Andean bear habitat using Mahalanobis distance, a multivariate measure of dissimilarity. The Mahalanobis distance values were classified into 5 classes of habitat suitability and generalized to a resolution of 1,650-m × 1,650-m grid cells. Clusters of grid cells with high suitability values were delineated from the generalized model and defined as important habitat areas (IHAs) for conservation. The IHAs were ranked using a weighted index that included factors of elevation range, influence from disturbed areas, and current conservation status. We identified 12 IHAs, which were mainly associated with páramo and cloud forest habitats; 2 of these areas have high conservation priorities because they are outside existing reserves and close to areas of human pressure. The distribution of the IHAs highlighted the role of human land use as the main source of fragmentation of Andean bear habitat in this region, emphasizing the importance of preserving habitat connectivity to allow the seasonal movements among habitat types that we documented for this species. Furthermore, the existence of areas with high habitat suitability close to areas of intense human use indicates the importance of bear–human conflict management as a critical Andean bear conservation strategy. We suggest that a promising conservation opportunity for this species is linked to its occurrence in highland habitats, which play a key role in the maintenance of long-term water supplies.

Key words: Andean bear, Andes Mountains, conservation planning, Ecuador, geographical information system, GIS, habitat suitability, Mahalanobis distance, *Tremarctos ornatus*

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Habitat loss is the single largest cause of species endangerment worldwide (Hilton-Taylor 2000, Pitman et al. 2002). Defining effective conservation areas for biodiversity protection is a fundamental necessity in countries where an accelerated degradation and destruction of natural habitats is fragmenting and isolating wildlife populations. However, the lack of biological information and difficulties in addressing the causes for biodiversity loss in the short term necessitate prioritizing conservation efforts by means of 2 main criteria: selection of large tracts of relatively undisturbed vegetation and selection of habitats associated with species that require large areas (Poiani et al. 2001). Such landscape species often occur in ecologically diverse areas, and their habitat requirements in time and space make them particularly vulnerable to land-use and resource-harvesting practices of people. Thus, identifying ecological requirements of landscape species is useful to aid the design and management of landscapes for biodiversity conservation (Simberloff 1999, Sanderson et al. 2002).

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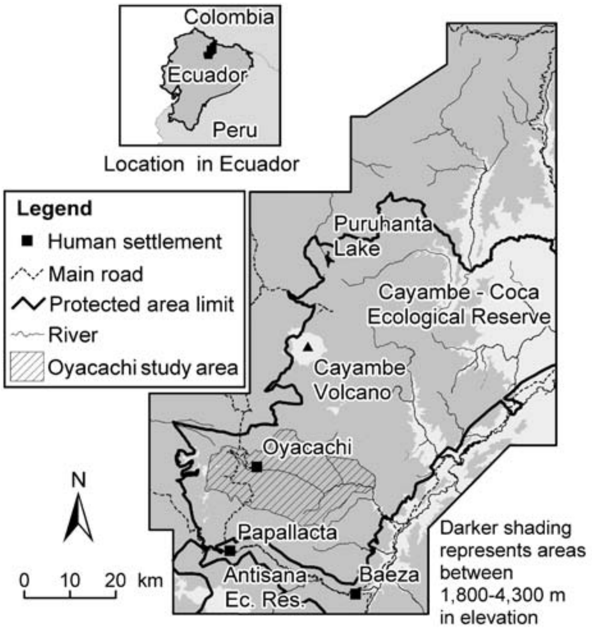

Fig. 1. Study area in the northeastern Ecuadorian Andes to identify priority conservation areas for Andean bears.

Páramo and cloud forests represent the primary habitats of Andean bears (*Tremarctos ornatus*) in the northern Andes (Ecuador, Colombia, and Venezuela). The seasonal variability in food availability in habitats used by Andean bears may result in wide-ranging movements, which are increasingly obstructed by the loss of favorable habitat due to advancing agricultural frontiers and expanding infrastructure. Peyton et al. (1998) estimated that approximately 18% of potential bear range in the Andes Mountains was contained within 58 protected areas. However, many of those areas were small, particularly in the northern Andes. The median size of 43 parks in Venezuela, Colombia, and Ecuador was 1,250 km^2, which may be insufficient to ensure long-term species persistence (Peyton et al. 1998).

In Ecuador, the Andean bear inhabits approximately 58,000 km^2 of páramo and cloud forest habitats, of which almost 19,000 km^2 are within the Ecuadorian system of protected areas and remaining areas are undeveloped but not legally protected (Rodriguez et al. 2003). Those habitats have been reduced by approximately 40% from their original distribution, thereby creating a series of "islands" in the regional landscape (Sierra et al. 1999). The conversion of those areas to agricultural uses has fragmented bear habitat and isolated populations (Peyton 1999, Suárez 1999). Andean bear distribution in Ecuador is fragmented among many habitat patches (subpopulations), with the largest patches distributed within the eastern Andean range ($n = 10$, $\bar{x} = 4{,}340$ km^2). Many of the remaining habitat patches ($n \approx 15$) in Ecuador are small ($\bar{x} = 1{,}140$ km^2; EcoCiencia/World Wildlife Fund, Quito, Ecuador, unpublished data). Although no reliable population data are available, the Cayambe-Coca Ecological Reserve and Sangay National Park likely contain the largest Andean bear populations in Ecuador (Suárez 1999).

The Andean bear's broad ecological requirements and its seasonal use of different habitats make it an appropriate species on which to base conservation planning to preserve the high biodiversity of these ecosystems (Yerena 1998, Peyton 1999). The conservation of Andean bears in Ecuador depends on proper protection and management of their habitat. Studies to determine the distribution of the Andean bear and availability of suitable habitats can be important to delineate conservation units. Knowledge of the extent, shape, and spatial distribution of those units is important to help reduce the effects of fragmentation, thereby improving the long-term viability of Andean bear populations (Yerena and Torres 1994, Suárez 1999). However, important habitat areas for Andean bears have not been delineated for northern Ecuador. Therefore, we sought to delineate important habitat areas in the northern portion of the eastern Ecuadorian Andean cordillera and rank their relative importance for Andean bear conservation.

Study area

Our study area included the Cayambe-Coca Ecological Reserve, the northern section of the Antisana Ecological Reserve, and adjacent páramo and cloud forest areas in the Sucumbíos and Carchi provinces in the northeastern Andes Cordillera of Ecuador (Fig. 1). The study area covered 6,048 km^2, and elevations ranged from 1,800 to 4,300 m. The Cayambe-Coca and Antisana ecological reserves made up 47.7% (2,884 km^2) and 3.2% (194 km^2), respectively, of the study area (Fig. 1). Due to the geographical position of the area, its altitudinal range, and the different climatic strata of the region, the flora and fauna are extremely diverse (Paredes et al. 1999). These ecosystems are known for high alpha diversity and endemism and for their fragile soils and topography (World Wildlife Fund 2001); the area is part of the Tropical Andes biome defined by Myers et al. (2000) as one of the 10 worldwide biodiversity "hotspots".

In the higher elevations of the study area, the prominent geomorphologic features are of glacial origin and include cirques, *roches moutonnées* (smooth knobs projecting from the land surface), and U-shaped valleys filled with moraine deposits, mudslides, and lahars (volcanic mudflows). The terrain of the lower elevations is highly dissected and covered with cloud forests; heterogeneous landscapes are predominant (Cuesta et al. 2003).

Four major watersheds begin inside the Cayambe-Coca Ecological Reserve: the Aguarico River (1,395 km^2), the Quijos River (2,504 km^2), the Mira River (67 km^2), and the Esmeraldas River (2,624 km^2). Because of these hydrological resources, this protected area represents the most important water reserve of the northern portion of the country (Paredes et al. 1999). The area consists of 4 major land-cover types (Valencia et al. 1999; EcoCiencia, Quito, Ecuador, unpublished reports): (1) humid páramo (includes herbaceous páramo, frailejones [*Espeletia pycnophylla*] páramo, cushion páramo, and mixed-forest páramo), (2) high evergreen upper montane forest, (3) montane cloud forest, and (4) disturbed areas (Table 1). The disturbed land-cover type corresponded to landscapes dominated by a matrix of anthropogenic land uses such as agriculture and urban areas. This land-cover type is predominant in the inter-Andean valleys located west of the study area, which have been used by humans for millennia. In contrast, most of the disturbed areas in the eastern slopes of the Andes correspond to recent deforestation and colonization frontiers associated with roads built to connect the Ecuadorian highlands with the lowlands in the Amazon basin (Young 1998). Human activities (such as extensive cattle breeding, hunting) in non-disturbed land-cover types (páramo and montane forests) are limited and have relatively low impact on the structure of those natural habitats. However, the intensity of these activities varies spatially with accessibility and proximity to populated areas.

Methods

We ranked areas for the conservation of Andean bear habitat in the study area using a 3-stage approach by (1) applying a statistical model to predict suitability of Andean bear habitat based on occurrence data, (2) using the predictions of that model to delineate important habitat areas, and (3) ranking and assessing the conservation importance of those areas.

Model application

A quantitative model is important to objectively delineate areas of suitable bear habitat. We relied on an accompanying study in the Oyacachi River basin to predict bear habitat suitability on a regional scale (Cuesta et al. 2001, 2003). The 721-km^2 Oyacachi study area was located in the southern portion of the Cayambe-Coca Ecological Reserve (Fig. 1). The field data for that model were based on bear sign locations that were collected along 53 transects during 2000–01 (Cuesta et al. 2001, 2003). Habitat suitability was determined using the multivariate statistic Mahalanobis distance (Clark et al. 1993) and a set of environmental variables considered to be the most relevant to Andean bear habitat use (Cuesta et al. 2003). We used that model to extrapolate the Mahalanobis distance values to the regional study area. Mahalanobis distance is a multivariate measure of dissimilarity (Clark et al. 1993). As such, our extrapolation represents how dissimilar (or similar) habitats are compared with those used by Andean bears in the Oyacachi River basin. Similar Mahalanobis distance values can suggest similar habitat potential, despite differences in habitat configurations (Knick and Rotenberry 1998). An advantage of this statistic is that it accounts for correlation among variables and avoids the assumption of multivariate normality (Clark 1993, Knick and Rotenberry 1998).

Table 1. Altitudinal range and area of land-cover types within the northeastern Ecuadorian Andes study area. Adapted from a study of Andean bear habitat in the Oyacachi River basin (Cuesta et al. 2003).

Land-cover type	Altitudinal range (m)	Area (km^2)	Proportion of study area (%)
Humid páramo	3,400–4,300	1,837	30.4
High evergreen upper montane forest	3,000–3,600	1,428	23.6
Montane cloud forest	1,800–3,000	1,979	32.7
Disturbed areas		804	13.3
Total		6,048	100.0

We used geographic information system (GIS) software (TNT Mips, V6.3, MicroImages, Inc., Lincoln, Nebraska, USA) to build a raster GIS database for 7 environmental variables (30- × 30-m grid cells) for the entire region: elevation, slope, terrain shape index, distance to rivers, road density, percentage of developed area, and land-cover type (Table 2). Despite the relatively coarse scale of the source topographic data, we chose a resolution of 30 m to maintain compatibility with the Mahalanobis model generated for the Oyacachi watershed across the whole region. In addition, high resolution digital elevation models (DEM) have been successfully extracted from small-scale topographic information in areas where large elevation gradients and extreme

Table 2. Geographic information system (GIS) variables used in this study to determine suitability of Andean bear habitat for the northeastern Ecuadorian Andes.

Variable	Description	Source
Elevation (m)	Elevation (m)	Digital elevation model (DEM) interpolated from contour lines (1:250,000 scale); Geographic Institute of the Army of Ecuador (IGM)
Slope (degrees)	Slope steepness (degrees)	Calculated from elevation using the *Slope* function (TNT Mips)
Terrain shape index	Mean difference in elevation between the central pixel and its 24 neighbors in a window of 5 × 5 pixels	Calculated based on McNab (1989)
Land-cover type	One disturbed and three natural land-cover types (see text)	Supervised digital classification of a Landsat TM satellite image (Path 10, Row 60; December 20, 1998; 30-m resolution)
Distance to rivers	Distance to the nearest stream (m)	Calculated from a stream coverage (1:50,000 scale) produced by the IGM with the *Distance* function (TNT Mips)
Road density	Ratio of road pixels to the total number of pixels within a 10-km^2 circular window	Calculated from a raster layer of roads (1:50,000 scale)
Percent of developed area	Ratio of disturbed area pixels to the total number of pixels within a 10-km^2 circular window	Calculated using the disturbed areas class of the land-cover type raster layer

topographic relief generate high planimetric density of topographic data (i.e., contour lines; Zomer et al. 2002). Mahalanobis distance was calculated for the regional study area using that GIS database. The model results were extrapolated only to areas with biophysical characteristics similar to the Oyacachi study area (Cuesta et al. 2001, 2003). Because elevation is the primary ecological gradient, we restricted model application to areas between 1,800 m and 4,300 m, which was the elevation range monitored in the Oyacachi study.

Delineating important habitat areas (IHAs)

We used the results from the Mahalanobis distance model to identify IHAs for the conservation of Andean bears by delineating zones with high habitat suitability values (low Mahalanobis distance values). Cuesta et al. (2003) tested the habitat model using independent locations and divided the associated distance values into 5 range classes. These classes were based on discernible discontinuities of percentiles of a cumulative frequency curve (23.0%, 47.6%, 86.9%, 96.7%, and 100%), representing 5 habitat suitability classes (Boitani et al. 1999). Areas with Mahalanobis distance values ≤ 7.2 were considered the most suitable habitat (class 1). We used those 5 classes for our subsequent analyses by overlaying a square GIS "window" (2.72-km^2; 1,650 × 1,650 m) with the grid of Mahalanobis values (30- × 30-m grid cells). We calculated the most frequent class value (mode) inside each square to assign that value to the entire 2.72-km^2 window area. Because of the lack of baseline ecological data on Andean bears, we defined an area of 2.72 km^2 based on average daily area requirements of adult female American black bears (*Ursus americanus*; Clark et al. 1993). That process was designed to reduce the spatial resolution of the habitat data, thereby facilitating the identification of IHAs by delineating contiguous areas of ≥ 10 grid cells (2.72-km^2) with class 1 values. We considered grid cells to be adjacent when cells with class 1 values shared at least 1 entire edge with a neighboring cell of class 1. No reliable information exists on minimum viable populations for Andean bears, so we defined this arbitrary minimum area as a means to define IHAs with favorable habitat that would potentially support a small population of bears. Preliminary population data from the Oyacachi study area suggest that 6 or 7 females may occupy a contiguous area of 27 km^2 (F. Cuesta, EcoCiencia, unpublished data). Until more detailed ecological data become available, these IHAs simply represent a starting point for prioritizing conservation efforts.

Ranking of important habitat areas

After identifying and delineating the IHAs, we ranked their importance based on 3 criteria: (1) altitudinal range, (2) human influence, and (3) current conservation status. We assigned scores between 0 and 1 for each of these factors, except for the altitudinal range criterion, which was weighted by assigning values between 0 and 2. We used the overall scores to rank the areas and to identify preliminary strategies for their conservation. The scores were additive on a scale of 0–4, with higher scores indicating greater priority for conservation.

Altitudinal ranges. Cuesta et al. (2003) found that Andean bears use páramos at high elevations and montane forest at lower elevations more intensely than other vegetation types throughout the year. They suggested this may be due to a greater concentration and year-round availability of food items (such as palmetto trees [Arecaceae family] in the cloud forest and terrestrial bromeliads [*Puya* spp. and *Gregia* spp.] in the páramo) in these areas. Following that study, we defined 4 altitudinal ranges: 1,800–2,400 m (range 1), 2,400–3,000 m (range 2), 3,000–3,600 m (range 3), and 3,600–4,200 m (range 4). We determined the percent covered by each altitudinal range in each IHA and multiplied those percents by 2 for ranges 1 and 4 and 1 for ranges 2 and 3. Ranges 1 and 4 generally correspond with cloud forest and páramo areas, respectively, and were assigned a greater weight to emphasize their importance. These elevation belts have been identified as the best bear habitat within the range of the species (Suárez 1985, Yerena and Torres 1994, Peyton 1999, Troya et al. 2004).

Influence of disturbed areas. Natural habitats surrounded by anthropogenic influences are more likely to be exposed to edge effects and isolation, affecting the quality of habitat and ultimately leading to loss of biodiversity due to local extinctions (Diamond 1986, Wilcove 1987). The degree of connectivity of remaining habitat patches depends on the pattern and distribution of human disturbances. A high degree of internal fragmentation often leads to greater human-caused mortality because of more interactions (such as crop and cattle predation by bears and their subsequent killing by farmers). We ranked the potential for human impacts by calculating the percent of each IHA within 6 km from human disturbance zones. This distance is an approximation, based on own observations in the field, of how far people in the Oyacachi village travel to check on their cattle. Areas completely inside this zone were given a value of 1, indicating the greatest need for conservation or management measures. This value diminished proportionally with increasing amount of area outside the zone of influence. A value of 0 was assigned to IHAs entirely outside this zone.

Status of protection. By means of this criterion, we gave priority to IHAs that were entirely or partially outside of the Cayambe-Coca and Antisana ecological reserves (Fig. 1). We assigned values to each IHA by calculating the percent of their extent outside ecological reserves. Areas completely outside reserves were given a value of 1, with diminishing values toward 0 for IHAs with increasing area inside the protected areas.

Qualitative assessment of conservation importance

These methods provided a quantitative and objective approach to delineate and rank IHAs. However, strictly quantitative criteria cannot capture all important aspects of potential conservation areas. Therefore, we also used qualitative considerations: watershed and biodiversity protection are 2 important biological and economical incentives for resource protection in Ecuador (Josse 2000).

Hydrological resources. One of the most important indices in assessing the conservation potential of large ecosystems in the Andean mountains is the presence of intact watersheds (Olson and Dinerstein 1994, Peyton 1999). The relatively undisturbed, high-elevation watersheds in the Cayambe-Coca Ecological Reserve and surrounding areas provide one of the major water sources in Ecuador (Paredes et al. 1999). Therefore, to define the potential importance of IHAs for protecting water resources, we delineated watersheds in the study area (Watershed Tool, TNT Mips GIS). We used the DEM for the area to derive hydrological parameters of flow direction and flow accumulation based on which watersheds were delineated. We then calculated the number and total area of watersheds that intersected with each of the IHAs.

Number of vegetation types. Effective conservation planning requires conservation of functional landscape units that guarantee adequate access to resources by bears throughout the year. The intensity with which Andean bears use different vegetation types changes seasonally (Peyton 1980, Suárez 1985, Cuesta et al. 2003). Therefore, we used the digital land-cover data to determine the extent and number of vegetation types included in each IHA as indicators of vertical connectivity and beta diversity. We examined the pattern and extent of 3 primary vegetation types used by Andean bears in the study area: upper montane evergreen forest, montane cloud forest, and humid páramo (EcoCiencia, Quito, Ecuador, unpublished report).

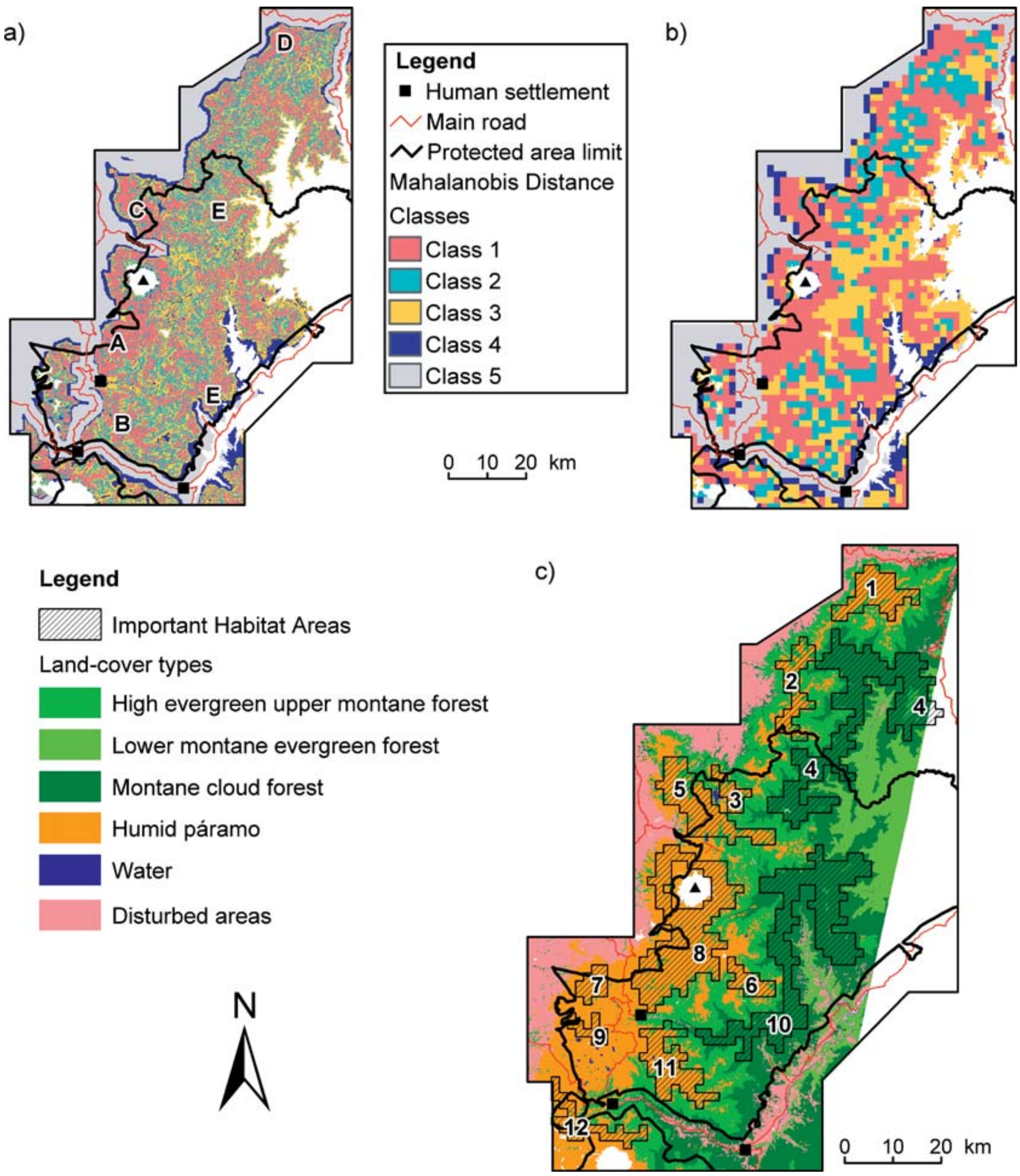

Fig. 2. Delineation of important habitat areas (IHAs) for Andean bears in the northeastern Ecuadorian Andes. (a) original model of Andean bear habitat suitability (30-m × 30-m grid cells), (b) generalized model of suitability of Andean bear habitat (1,650-m × 1,650-m grid cells), (c) IHAs defined as clusters of ≥10 cells with class 1 values based on the generalized model. The areas are superimposed to the main land-cover types in the study area.

Results

Habitat suitability

Areas with high habitat suitability (class 1 areas) covered 27.3% of the study area and were concentrated in zones with a predominance of páramo or cloud forests (Table 3, Fig. 2a). Contiguous class 1 areas occurred between the slopes of the Cayambe volcano and the upper watershed of the Oyacachi River (area A in Fig. 2a), the páramo in the southern portion of the Cayambe-Coca Ecological Reserve (area B), the páramo surrounding Lake Puruhanta (area C), the mosaic of upper montane forest and páramos in the northern portion of the study

Table 3. Mahalanobis distance classes used in this study as an index to suitability of Andean bear habitat within the northeastern Ecuadorian Andes. Mahalanobis distance classes were defined based on a 2000–01 field study in the Oyacachi River basin (Cuesta et al. 2003).

Mahalanobis distance (D^2) class	Value range	Area (km^2)	Proportion of study area (%)
Class 1	$0 < D^2 \leq 7.2$	1,650	27.3
Class 2	$7.2 < D^2 \leq 10.1$	1,133	18.7
Class 3	$10.1 < D^2 \leq 23.7$	1,338	22.1
Class 4	$23.7 < D^2 \leq 200$	516	8.6
Class 5	$D^2 > 200$	1,411	23.3
Total		6,048	100.0

area (area D), and in heterogeneous areas of cloud forest in the lower portion of the study area (area E). Class 2 and 3 areas comprised 40.8% of the study area, and their spatial configuration was distinctive. Class 3 areas were more abundant (22.1%) across the landscape, but their distribution was heterogeneous, forming a background for class 1 and 2 areas (Table 3, Fig. 2a). Class 2 areas were slightly less common (18.7%) and mainly defined connection zones between class 1 areas. Class 4 and 5 areas covered 31.9% of the study area; the distribution of these areas generally resembled the spatial patterns of the road network and agricultural land uses (Table 3, Fig. 2a).

Delineating important habitat areas

The generalized model was based on 2.72-km^2 grid cells (Fig. 2b). We used the spatial patterns of the 5 habitat classes to define IHAs. We identified 12 contiguous zones consisting of at least 10 grid units belonging to habitat class 1 (Fig. 2c). The total extent of these areas was 1,820 km^2, representing 30% of the study area. Individually, the area of the 12 IHAs ranged from 30.2 to 397.7 km^2 (Table 4). IHAs 3, 6, 7, and 9 were relatively small (<44 km^2) and together represented only 2.4% of the study area. IHAs 1, 2, 5, 11, and 12 were between 76 and 161 km^2 and together covered 9% of the study area. Finally, the 3 largest IHAs (4, 8, and 10) had extents greater than 340 km^2 and represented 18.6% of the study area (Table 4, Fig. 2c).

Ranking of IHAs

The scores assigned to the IHAs based on the altitudinal coverage criterion ranged from 1.35 to 1.90 (Table 4). Areas that received the 3 highest scores were 7, 12, and 8 because those areas were mostly in elevation range 4 (3,600–4,200 m), which was weighted more (Table 4). In contrast, IHAs 2, 4, and 10 received low scores because approximately 60% of their extents were within altitudinal ranges that received lower weights (Table 4). Overall, most IHAs had substantial portions of their areas within the 6-km disturbance zone. IHA 7 received a high score (0.95) for anthropogenic influence because 94.8% of its area was inside the zone of human influence. Finally, we observed high variation of scores for the conservation status criterion. IHA 1 was located completely outside protected areas and thus received a score of 1. Most of IHAs 6, 9, 10, and 11 were within the Cayambe-Coca Ecological Reserve in a zone isolated from major anthropogenic disturbances

Table 4. Important habitat areas (IHAs) for Andean bears in the northeastern Ecuadorian Andes and scores used to rank their conservation value. IHAs were defined as areas with ≥10 contiguous grid cells with Mahalanobis distance values in class 1 based on the generalized model of suitability of Andean bear habitat (1,650-m resolution).

			Ranking score			
IHA	Area (km^2)	Portion of study area (%)	Altitudinal coverage	Influence of disturbed areas	Conservation status	Sum of scores
1	101.0	1.67	1.68	0.83	1.00	3.51
2	84.4	1.4	1.35	0.86	0.91	3.12
3	35.5	0.59	1.57	0.64	0.20	2.41
4	386.6	6.39	1.36	0.40	0.72	2.48
5	161.0	2.66	1.62	0.69	0.53	2.84
6	43.6	0.72	1.68	0.12	0.00	1.80
7	38.1	0.63	1.90	0.95	0.24	3.09
8	340.3	5.63	1.87	0.49	0.26	2.62
9	30.2	0.5	1.63	0.68	0.05	2.36
10	397.7	6.58	1.38	0.66	0.00	2.04
11	125.3	2.07	1.82	0.54	0.00	2.36
12	76.2	1.26	1.89	0.45	0.28	2.62
Total	1,820.0	30.1				

Table 5. Number and surface area of watersheds associated with 12 important habitat areas (IHAs) for Andean bears in the northeastern Ecuadorian Andes identified in this study.

IHA	Number of watersheds	Area (km^2)
1	41	435
2	41	339
3	19	235
4	161	1,099
5	56	524
6	22	313
7	17	153
8	109	850
9	16	210
10	138	1,178
11	54	357
12	62	172
Total	736	5,865

(Table 4, Fig. 2c). Consequently, those areas obtained lower scores or 0 for the conservation status criterion.

After summing scores corresponding to the 3 criteria, IHAs 1, 2, and 7 received the highest scores (3.51, 3.12, and 3.09, respectively; Table 4). Most of the 12 IHAs had total scores distributed in a relatively small range between 2.04 to 2.84 (areas 3, 4, 5, 8, 9, 10, 11, 12). IHA 6 received the lowest score (1.80; Table 4).

Hydrological resources and vegetation types

A total of 1,560 watersheds were derived from the DEM within the study area. Of those, 736 were at least partially associated with one or more of the 12 IHAs. Total area covered by these watersheds was 5,865 km^2, representing 97% of the study area (Table 5).

The majority of IHAs were associated with 2 vegetation types. Areas 7 and 9 included mostly páramo within their boundaries (Table 6, Fig. 2c). Similarly, >90% of areas 8 and 12 were in páramo vegetation. Areas 4 and 10 were primarily associated with cloud forests. The remaining IHAs had varying percents of páramo and high evergreen upper montane forests; the percent of páramo in those areas was consistently greater than the percent of high evergreen upper montane forests (Table 6).

Discussion

The establishment of nature reserves often is based on general biodiversity patterns. However, those nature reserves do not always incorporate the full ecological requirements of large carnivores, and many protected areas would not support viable populations of these species in the long term (Peyton 1999, Suárez 1999). Our approach was designed to address those concerns by identifying areas that may complement the current system of protected areas and provide long-term protection for viable populations of Andean bears on a regional scale. Therefore, we focused on the role of the Andean bear not only as an umbrella species, but also as an indicator species of the integrity of páramo and montane forest landscapes in the Northern Andes.

Digital map layers and GIS allowed us to predict suitability of Andean bear habitat on a regional scale using field-based data and multivariate statistical techniques. The model results should be interpreted within the context of the environmental and socio-economic conditions of the area where the field data were collected (Oyacachi River basin; Cuesta et al. 2003). Extrapolation of the model to a larger area was conducted on the assumption that observed habitat relationships of Andean bears were constant through the

Table 6. Vegetation types associated with the 12 important habitat areas (IHAs) identified in this study for Andean bears in the northeastern Ecuadorian Andes.

	Humid páramo		High evergreen upper montane forest		Montane cloud forest		Number of vegetation types represented[a]
IHA	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	
1	84.8	84.0	15.9	15.8			2
2	56.4	66.8	28.0	33.1			2
3	26.2	73.9	9.2	25.9			2
4	0.3	0.1	21.0	5.6	353.8	93.8	2
5	127.5	79.2	33.2	20.6			2
6	35.1	80.6	8.4	19.3			2
7	37.8	99.3	0.3	0.7			1
8	314.8	92.5	23.9	7.0			2
9	29.9	98.9	0.2	0.7			1
10	0.5	0.1	10.6	2.7	386.2	97.1	2
11	99.6	79.5	24.9	19.9	0.5	0.4	2
12	67.9	90.4	7.2	9.6			2

[a] The minimum surface considered for a vegetation type to be represented inside a IHA was 2.72 km^2.

region. At the scale of analysis of our study this assumption seems valid, because environmental conditions in the study area were similar to those in the Oyacachi study. However, effective on-the-ground conservation strategies require consideration of different socio-economic conditions throughout the study area.

We observed 2 general trends in the distribution of suitable habitat within the study area. First, most areas belonging to the highest suitability class (class 1) were associated with large and contiguous tracts of páramo and cloud forest present at the highest and lowest elevation ranges, respectively (Fig. 2a). The distribution of areas corresponding to lower suitability categories resembles a background matrix (class 3) in which class 2 areas connect patches of the most suitable habitat (Fig. 2a). Thus, one important conservation strategy may be to protect high-quality páramo and cloud forest habitats while maintaining connectivity between these elevational zones.

A second pattern that we observed is that habitat suitability strongly corresponded to distribution of roads and disturbed areas, delineating unsuitable habitat (class 5 area; Fig. 2a). However, some class 1 areas were adjacent to roads, producing a sharp boundary between suitable and non-suitable habitats (Fig. 2a). Because open páramo habitats provide less protection for wildlife than cloud forests, the presence of roads there has more potential to increase hunting pressure. In addition, the existence of potentially high-quality bear habitat near agricultural areas and pastures may result in crop or livestock depredation. Thus, conservation strategies alleviating these conflicts should consider the spatial configuration of Andean bear habitat. The existence of areas with high habitat suitability close to areas of intense human use suggests the importance of bear–human conflict management as a critical Andean bear conservation strategy.

The distribution of Andean bear habitat in the study area corroborates the patterns described for Andean bear distribution in the northern Andes. At a regional scale, the roads and associated areas of human use reduce habitat connectivity (Kattan et al. 2004). Agricultural areas near the Colombian border to the north and northeast, fragmented inter-Andean valley to the west, and disturbed areas along the road to Amazonian lowlands to the south and southeast of the study area define the macro configuration of bear habitat, creating large tracts of suitable habitat that are mostly disconnected (Fig. 2a).

Roads may be an important barrier to bear movements and population connectivity. There is evidence that bears avoid roads, and that roads pose a mortality threat (Peyton 1999, Rodriguez et al. 2003). However, the effects of roads on habitat connectivity may depend on human use of those roads. For example, the road between the Cayambe-Coca Ecological Reserve and the Antisana Ecological Reserve (Fig. 1) is associated with an area of dynamic land-use changes (conversion of forest and páramos to agricultural uses) and also coincides with the route of 2 oil pipelines. Consequently, this road likely is an effective barrier to bear movements between the 2 ecological reserves (Figs. 2b and 2c). In contrast, the road from Oyacachi to Papallacta (Figs. 1, 2b, 2c) may be less of a barrier to bear movements because this road has regulated and restricted use and it is not associated with human colonization of new areas within the Cayambe-Coca Ecological Reserve.

Area ranking

The level of threat to the integrity of ecosystems in northern Ecuador is not homogeneous and, consequently, there is a need to protect those areas that are most vulnerable before they are degraded (Stoms 2000). Also, in practice only a portion of relatively undisturbed habitats can be managed for conservation in the long term, which emphasizes the need to identify conservation areas that maximize biodiversity gains (Woodhouse et al. 2000). In addition to the need to complement existing protected areas, a ranking to focus conservation efforts is needed. Because conservation planning involves more than just biological factors, we also integrated criteria with measures of altitudinal coverage, human influence, and level of protection. Our ranking based on altitudinal range was intended to emphasize the conservation value of páramo (3,600–4,200 m) and cloud forest (1,800–2,400 m) areas (Cuesta et al. 2003). However, the elevation criterion had relatively little influence on final ranking because some areas already were protected (area 10) or were subject to relatively low human pressure (area 4; Table 4). In terms of the level of threat due to human activities, the 2 extremes of human influence are represented by areas 6 and 7 (Fig. 2c). Area 6 only has 11% of its surface within the 6-km buffer area of human influence because it is located within the core of the Cayambe-Coca Ecological Reserve. In contrast, area 7 is on the margin of the reserve and bordered by agricultural areas (Fig. 2c).

The conservation status criterion allowed us to rank areas not in the current system of protected areas. Only areas 1, 2, and 4 had substantial portions outside protected areas (Fig. 2c). Although the remaining areas mostly were located in the Cayambe-Coca Ecological Reserve or the Antisana Ecological Reserve, their delineation likely is important from a park management perspective. For example, areas 3, 5, 7, 8, 9, and 12 all contain potentially important habitat for Andean bears and represent contiguous areas with proportions inside an existing reserve, but are subject to a high level of human pressure extending up from the inter-Andean valley (Fig. 2c). These areas could be used to design comprehensive management strategies aimed at mitigating human impacts on reserves.

The final ranking of IHAs showed that areas 1 and 2 were most important for additional protection of Andean bear habitat in the study area (Table 4; Fig. 2c). Those areas are outside the Cayambe-Coca Ecological Reserve and cover important páramo areas north of the reserve. Degradation of those areas is likely in the near future because of their proximity to highly dynamic agricultural borders that threaten the remnant areas of montane cloud forest near the disturbed inter-Andean valley. Area 4 represented the highest-ranked IHA covered mainly by cloud forest (rank 7; Tables 4 and 6; Fig. 2c). Higher levels of human influence in the highlands may explain why páramo-dominated areas generally were ranked higher than cloud forest areas. Despite the apparent dichotomy in conservation priorities between páramo and cloud forest areas, conservation strategies for the Andean bear within the study area should remain based on maintaining landscape diversity to ensure seasonal access to resources in both páramo and forest areas (Cuesta et al. 2003, Kattan et al. 2004).

Management and research implications

We identified several issues relevant to conservation of Andean bears in northeastern Ecuador and elsewhere. For example, the delineation and ranking of IHAs indicated the importance of maintaining connectivity of bear habitat both within and between different altitudinal ranges (such as between areas 6 and 8; Fig. 2c). The important habitat areas we delineated were associated either with páramo and high montane evergreen forest at high elevations or with cloud forests at lower elevations (Table 4, Fig. 2c). Given the ecological requirements of the Andean bear, effective conservation strategies should emphasize conservation areas that promote connectivity between páramo and forest ecosystems. In this context, the IHAs we delineated could be considered focal areas in a core–corridor strategy for conservation of bear habitat at finer scales.

For our study area, we suggest that watersheds represent useful conservation planning units. The use of watersheds as planning units not only adds functional importance to the conservation planning process for the preservation of hydrological resources, but also facilitates delineation of conservation units in the field and therefore its protection from external pressures and implementation of management actions (Peres and Terborgh 1995). In addition, the preservation of watersheds would explicitly promote the achievement of vertical connectivity between high- and low-elevation habitats while facilitating connections among IHAs. Finally, the integration of hydrological criteria at a landscape scale allows special management of areas important not only for Andean bears, but also other biotic communities associated with aquatic environments (headwaters, wetlands), such as neotropical amphibian communities (e.g. *Atelopus* spp.).

Although IHAs for bear conservation represent 30% of the study area, the associated watersheds influenced by management of these areas cover 97% of the study area (Table 5). Also, most of IHAs are located in páramo zones, which are the headwater areas for many watersheds that drain toward the inter-Andean region. Because any management strategy will affect the quantity and quality of water resources downstream, the distribution of IHAs in such highland areas could represent an opportunity to promote their conservation and sustainable management with the goal of preserving water resources in the long term. This is particularly important in the highlands, where land tenure issues would restrict the establishment of conservation areas for Andean bears alone. The link between bear habitat conservation and management of water resources may provide a useful framework for the development of effective conservation strategies because it involves many different stakeholders, from the central government to local people interested in the conservation of these resources.

The conservation priorities identified in our study should be considered an initial step in defining conservation areas for Andean bears in northern Ecuador. This is a hierarchical process, and the next step is to further evaluate information regarding different threats and conservation opportunities in each priority area. The definition and analysis of these local criteria should be rooted in a participatory process involving local people, government officials, and conservation organizations. Furthermore, Andean ecosystems are highly threatened due to an expanding agricultural frontier and the development of new infrastructure such as roads and dams. Therefore, future research should specifically examine landscape permeability between IHAs, similar to studies on grizzly bears (*Ursus arctos*) in North America (Singleton et al. 2004).

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