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Landscape assessment of habitat suitability and connectivity for Andean bears in the Bolivian Tropical Andes

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Abstract: The survival of large and mobile species in the face of habitat loss and fragmentation depends on several factors, including the landscape configuration of subpopulations and the dispersal capabilities of the species. We performed a landscape analysis of the Bolivian Tropical Andes to determine whether remaining habitat patches were suitable in terms of ecological characteristics and potential connectivity for the long-term survival of the Andean bear (*Tremarctos ornatus*). First we built a ruled-based model to identify key patches or areas large enough to sustain a viable population by using knowledge of Andean bear habitat requirements and movement patterns. Second, we estimated potential functional connectivity among these areas applying a cost-distance analysis based on estimates of the resistance to movement through the landscape. Finally, we quantified the proportion of these key patches and corridor habitats within the Bolivian protected area system. The rule-based model identified 13 key patches covering 21,113 km² corresponding to a maximum estimated population of 3,165 adult bears. Using cost-distance analysis, all 13 key patches were potentially connected to ≥ 1 other key patch. Twelve of the patches were at least partially protected by national parks, and 40% of areas considered suitable as corridors were included within a protected area. Although the current protected area system includes suitable bear habitat, large portions of key patches and corridors are unprotected, which could eventually lead to fragmentation and habitat loss if these areas are not protected.

Key words: Andean bear, Bolivia, cost-distance analysis, functional connectivity, patch size, rule-based model, *Tremarctos ornatus*, Tropical Andes

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Habitat loss and fragmentation associated with human activities are considered major threats to global biodiversity and the main causes of species extinction (Schmiegelow and Mönkkönen 2002, Fahrig 2003, Foley et al. 2005). When habitat becomes fragmented, populations may suffer increased extirpation risk initially from demographic and environmental processes and later from genetic processes (Lande 1988, Woodroffe and Ginsberg 1998, Frankham 2005). In such situations, the survival of remnant populations not only depends on morphological, ecological, and behavioral attributes that determine their adaptability to a changing environment, but also on an individual's movement capabilities (Tischendorf and Fahrig 2000a, Crooks

2002, Hanski and Gaggiotti 2004, Mortelliti and Boitani 2008). Movement, however, is not entirely dependent on species' characteristics but also on the landscape features (Tischendorf and Fahrig 2000b). For instance, the response of vertebrates such as large carnivores to habitat loss and fragmentation primarily depends on the connectivity among remnant habitat patches, rather than morphological and behavioral limitations (Crooks and Soule 1999, Crooks 2002). Because landscape connectivity depends on both landscape structure and species behavior, connectivity can be species- and landscape-specific (Tischendorf and Fahrig 2000b).

Landscape connectivity represents “the degree to which the landscape facilitates or impedes movement among resource patches” (Taylor et al. 1993), and influences the effect of physical structure of the

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landscape on individual movements, population, population dynamics, and community structure. Landscape connectivity can be viewed from structural or functional perspectives. Structural connectivity describes physical relationships between habitat patches without any explicit consideration of behavioral responses of organisms or processes across the landscape. On the other hand, functional connectivity goes beyond the spatial information of the landscape by describing how the movement of organisms is either facilitated or limited by the landscape (Taylor et al. 1993). The distinction between structural and functional connectivity is fundamental to understanding that connectivity is not a generalized feature of the landscape (Taylor et al. 1993). For instance, a structurally disconnected landscape can be functionally connected if organisms are capable of crossing the hostile matrix, in effect, connecting resource patches (Tischendorf and Fahrig 2000b). Conversely, a structurally connected landscape can become functionally disconnected if an organism does not use or cross the matrix in order to connect resource patches (Tischendorf and Fahrig 2000b). These differences accentuate the importance of evaluating landscape connectivity from the perspective of the species.

Studies of species distribution within fragmented landscapes generally emphasize the structural aspect of the landscape (Ferreras 2001, Verbeylen et al. 2003, Kramer-Schadt et al. 2004, Magle et al. 2009), or specific elements such as patch area and inter-patch distances (Moilanen 1999, Crooks 2002), ignoring the complexity of how organisms perceive and interact with the landscape. However, assessing functional connectivity is often challenging due to the difficulty in obtaining the data on how members of a species perceive their landscape, at what scale, and their actual movements among patches (Hansen and Urban 1992).

With a widespread distribution along the Andes Mountains, Andean bears (*Tremarctos ornatus*) play an important role as an umbrella (Peyton 1999), landscape-indicator (Sanderson et al. 2002), and flagship species for biodiversity conservation (Peyton 1999), and are listed as Vulnerable on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2010). However, little is known about the ecology of this species, and conservation decisions are often made based on incomplete existing information on the biology and ecology of this species.

We conducted a landscape analysis of the Bolivian Tropical Andes to determine whether the remaining habitat patches are suitable in terms of ecological characteristics (access to food, shelter, and water) and functional connectivity for the Andean bear. We modified the habitat and potential distribution model of Velez-Liendo et al. (2013), and combined it with information on natural history and movement data to build a rule-based model. At the population scale, we applied Verboom et al.'s (2001) key patch concept, defining a key patch as a relatively large area supporting a local population in a network, which is persistent under the condition of ≥ 1 immigrant/generation. Finally, we performed a cost-distance analysis (Adriaensen et al. 2003) to determine whether the landscape facilitates or obstructs movement among key populations. Our overall goal was to provide the first nation-wide landscape assessment to determine conservation initiatives, the role of protected areas, and potential corridors for the Andean bear.

Study area

The study area encompassed the eastern slope and inter-Andean valleys of the Bolivian Tropical Andes, covering approximately 240,000 km² (Fig. 1). The western slope includes the Altiplano or Andean plateau, which is considered unsuitable habitat for Andean bears because of its phytogeographical characteristics and climate (Ibish et al. 2003). Geographically, the region can be divided into North and South sections (Ibish et al. 2003). The North spans from north of Titicaca Lake (15°52'S–69°18'W) to the Amboro node (17°48'S–63°46'W), and it is characterized by wide mountain ranges that run west to east and elevational gradients ranging from 300 m to 4,800 m above sea level (asl). The vegetation of the North section is heavily influenced by the humidity of the Atlantic and the Amazon flora (Ibish et al. 2003). The South section is characterized by much lower mountains, running parallel in a north-to-south direction. It spans from the Amboro node to Tariquia (22°04'S–64°46'W), with elevations from 500 m to 2,500 m asl (Ibish et al. 2003). The vegetation in the South is much drier and is strongly influenced by the dry Chaco region and inter-Andean valleys. Despite strong anthropogenic impacts in the region, these valleys are still considered important areas of endemism (Lopez 2003, Larrea-Alcazar and Lopez 2005).

Fig. 1. Andean bear resource-based model output (from Velez-Liendo et al. 2013) in the Bolivian Tropical Andes. Pixel colors represent probability of bear occurrence.

Methods

The Andean bear as a focal species

The Andean bear is an opportunistic carnivore that requires large and relatively undisturbed habitat to gather food, find shelter, mate, and care for its young. Although animal protein can be occasionally included in the bears' diet, their cranio-dental specialization to grind hard and fibrous plants (e.g., bromeliads, palms and bamboo) shows their preference for hard vegetation matter (Sacco and

Valkenburgh 2004, Christiansen 2007, Figueroa and Stucchi 2009). Nevertheless, during the wet season (Oct–Mar), bears feed almost exclusively on fruits from 3 families: Ericaceae (*Gaultheria glauca*, *G. vaccinioides*, *Pernettya prostata*, *Vaccinium floribundum*, *Disterigma* sp.), Lauraceae (*Persea* sp., *Aniba* sp., *Beilschmiedia* sp., *Nectandra cuneatocordata*, *Ocotea* sp.), and Rosaceae (*Prunus brittaniana*, *Hesperomeles ferruginea*, *H. lanuginosa*, *Rubus bullatus*; Eulert 1995, Azurduy 2000, Paisley 2001, Rivade-

neira 2001). This seasonal variation in resource use suggests that Andean bears' diets depend on forest phenology and that their seasonal movements are primarily a response to fruit availability (Velez-Liendo 1999, Paisley 2001).

Home-range and movement-pattern studies of Andean bears have been examined by Paisley (2001) in Bolivia and Castellanos (2008) in Ecuador. Because of differences in terrain between the Bolivian and Ecuadorian studies, we used the 7–9-km² home-range estimate of Paisley (2001), rather than the 59-km² of Castellanos (2008). Nevertheless, both studies showed considerable home-range overlap during certain months of the year. A similar pattern was also observed in American black bears (*Ursus americanus*) when food resource availability was high (Powell 1987). Furthermore, social organization was found in the Ecuadorian study, with a dominant male encompassing the home range of 5 females and other males located at the boundary of the dominant male's territory (Castellanos 2008). Daily movements within their home ranges showed that Bolivian bears travelled a median of 800 m and the longest daily movement was >6 km (Paisley 2001). A subsequent study showed that one bear moved 15 km from the original study site (Rechberger et al. 2001). Information on natal dispersal and female daily movement is unavailable.

Finally, reproductive success in solitary and polygynous large carnivores such as brown bears (*U. arctos*) differs between female and males (Zedrosser 2006). Because parental care is carried out exclusively by the female, reproductive success will depend on the habitat a female can provide to her litter. Thus, it is vital for a female to establish a home range with the best possible food resources as well as shelter for protection and access to adequate dens in which to give birth (Zedrosser 2006). On the other hand, reproductive success in male bears is related to mating success or the number of females a male can inseminate. Therefore, male habitat requirements will be a function of the number of females it can protect from other male bears and successfully breed (Zedrosser 2006). We applied these factors affecting reproductive success, and other relevant information, to build the rule-based model.

A resource-based bear habitat model

In Velez-Liendo et al. (2013), Andean bear habitat was modelled at 1-km resolution (based on the

median daily distance travelled by a bear) by mapping 7 essential resources associated with 3 ecological functions: food (5 plant families: Bromeliaceae, Ericaceae, Poaceae, Lauraceae, and Rosaceae), shelter, and access to water (Fig. 1).

We included an anthropogenic land-use layer to represent habitat fragmentation and barriers to bear movements (Fig. 2). This layer was built based on an unsupervised classification of 4 Landsat ETM mosaics to detect cleared areas (settlements and agricultural fields), and 8 years (2000–2008) of fire activities derived from MODIS Rapid Response System data sets. Fire locations (geo-referenced point-data sets) were acquired via The Fire Information for Resource Management System (<http://maps.geog.umd.edu/firms/default.asp>) using the MODIS active fire locations, and then were transformed into raster format. We merged these layers and superimposed them with the resource-based output, and we reclassified as non-habitat all pixels with land use (i.e., zero probability of bear presence). The final output was the available bear habitat and the base map for this study (Fig. 3).

Model development

Based on bears' biological traits, we developed a bottom-up rule-based model to define habitat patches and key populations and to analyze connectivity. Initially, bear habitat was classified according to female and male habitat requirements. We then used the output to define patches suitable for males and females and to identify key populations according to minimum area requirements and minimum population sizes. Finally, we carried out a cost-distance analysis to determine functional connectivity among key patches in the landscape.

Classifying available bear habitat

We first categorized available bear habitat into 5 classes, differentiating habitat requirements between males and females and identifying potential corridors and unsuitable habitat (Table 1). We reclassified habitats that contained shelter, water, and presence of all food items (Bromeliaceae, Ericaceae, Poaceae, Lauraceae, and Rosaceae) with a probability of bear presence >0.5 (class I) and considered them “female habitat”; we reclassified habitats that contained shelter, water, and Lauraceae, Rosaceae, and Poaceae with a probability between 0.3 and 0.5 (class II) and considered them “male habitat”; we reclassified habitats that contained shelter and water

Fig. 2. Human activity (in black) representing habitat fragmentation and barriers to Andean bear movement, based on a landscape analysis of the Bolivian Tropical Andes. This layer was built based on 3 Landsat ETM mosaics to detect cleared areas, and 8 years of fire activities derived from MODIS data sets.

but little food resources with a probability between 0.2 and 0.3 (class III) and considered them “corridors”; we reclassified habitats that contained little shelter and none of the other resources between 0.1 and 0.2 (class IV) and considered them “marginal”; finally, we reclassified habitat with none of the basic resources with a probability <0.1 (class V) and considered them “unsuitable.” The latter class also included areas with recent signs of human activity, as

explained above. We classified all data using a pixel size of 1 km².

The ruled-based model

We summarized information regarding habitat requirements for females, males, and ultimately key population patches into 3 rules:

Rule 1. Female patch. We defined a female patch as a ≥ 10 -km²-sized class I patch. This corresponds to

Fig. 3. Andean bear habitat layer, derived from a landscape analysis of the Bolivian Tropical Andes, after merging and superimposing the resource-based map with the human activity layer. Pixels in black represent probability of bear occurrence >0.5 ; light gray between 0.3 and 0.5; white between 0.2 and 0.3; medium gray between 0.1 and 0.2, dark gray <0.1 , and white represents human disturbances.

a minimal area of high-quality habitat with food and shelter for reproducing females, based on home range data from Paisley (2001) and Castellanos (2008).

Rule 2. Male patch. We defined a male patch as a female patch large enough for ≥ 2 females or ≥ 2 females' patches linked by a maximum distance of 6 km of habitat class II. The assumption is that

males only settle in areas that are large enough to maintain ≥ 2 females, and that females are within the male's daily movement range.

Rule 3. Key population patch. Initially, we defined a key population as a relatively large local population in a network, which is persistent under the condition of 1 immigrant/generation (Verboom et al. 2001). For long-lived large vertebrates, the standard

Table 1. Summarized habitat requirements used to build a rule-based model for Andean bears within the Bolivian Tropical Andes region: + = must contain; – = may or may not contain; 0 = does not contain.

		Shelter	Water	Food				
				Bromeliaceae	Ericaceae	Poaceae	Lauraceae	Rosaceae
Class I	Female	+	+	+	+	+	+	+
Class II	Male	+	+	—	—	+	+	+
Class III	Corridor	+	+	—	—	—	—	—
Class IV	Marginal	—	0	0	0	0	0	0
Class V	Unsuitable	0	0	0	0	0	0	0

proposed by Verboom et al. (2001) was 20 reproductive units (pairs, territories, families). In this study, a reproductive unit consisted of ≥ 1 male and 2 females and a key patch contained ≥ 20 males and 40 females. A key population patch required a minimum of 400 km² of male patch.

For the application of the rule set on the habitat map, we used ArcView 3.2 (ESRI 1999) with the Spatial Analyst extension. We used FRAGSTATS (McGarigal and Marks 1995) to quantify patch area and between-patch distances. To obtain a map of patches of a minimum area of 10 km² of class I habitat (Rule 1), we extracted pixels from the habitat map and exported them to FRAGSTATS for quantification. Only patches with the minimum area were selected. We then merged female patches with pixels meeting class II thresholds and ran a similar process for Rule 2, but we selected as male patches only patches with ≥ 2 female patches and/or with < 6 km of distance among female patches. Finally, we selected patches with area ≥ 400 km² as key patches.

Connectivity analysis

To assess functional landscape connectivity, we built a cost-distance model applying the Spatial Analyst “cost-distance” extension of ArcView 3.x (ESRI 1999). The model was calculated using a source and a friction layer. The source layer represented habitat patches from which connectivity was calculated, which are the key patches in this study. The friction layer describes the degree of resistance of each element of the landscape to bear movement; in this study, it was represented by 5 habitat classes defined above. We assigned the different classes of the habitat map a resistance value derived from expert knowledge (Schadt et al. 2002, Adriaensen et al. 2003). We assigned raster cells in the friction layer overlapping with key patches the lowest resistance value of 1, considering minimal movement costs within key patches. We

assigned habitat class II (male habitat) the resistance value of 10; we assigned habitat class III (corridor habitat) the resistance value of 50; we assigned habitat class IV (marginal habitat) the resistance value of 150; and we assigned habitat class V or unsuitable habitat the highest resistance value of 500. To represent the potential cost of crossing any anthropogenic area by a bear, we assigned the values of 50 for unpaved roads, 100 for paved roads and highways, and 1,000 for human settlements, agriculture fields, and fire activities; and we ran an additive function in ArcView 3.2 between this anthropogenic cost layer and the bear habitat map. Thus the final resistance value of any anthropogenic disturbance (i.e., a road) depended on the surrounding bear habitat. For example, if an unpaved road crosses a key patch and a corridor patch, the resistance value is 50 when crossing key patch habitat and 100 when crossing corridor habitat.

The outcome of the model is a cost layer or “effective distance” (Ferrerias 2001, Michels et al. 2001, Adriaensen et al. 2003, Verbeylen et al. 2003) where each pixel represents the lowest possible cost of moving from any source to this location through the resistance layer. A cost value of n represents the cost of moving through n cells with the resistance value of 1, or through 1 cell with the resistance value of n (Adriaensen et al. 2003, Driezen et al. 2007). Cost values can easily be converted into equivalents of distance by multiplying the cost by the cell size (here 1 km²; Ferreras 2001). Furthermore, if the maximum dispersal range of the focal species is known, it is possible to set a maximum cost value. Thus, pixels with higher cost values than the maximum established cost can be considered as inaccessible (Adriaensen et al. 2003). We used natal dispersal data from male American black bears (Costello 2010) due to the lack of information on Andean bear dispersal. We used 70, 40, and 10 km as maximum, intermediate, and minimum dispersal distance. Because we considered corridor habitat as

Fig. 4. Potential distribution of female (a) male (b) and key (c) patches for Andean bear in the Bolivian Tropical Andes region.

suitable for movement, we set 3,500 (70 km as max. dispersal distance multiplied by 50 as the resistance value of the corridor habitat) as the maximum cost-distance units in km a bear could travel, and 200 and 500 as intermediate and minimum distances.

The Bolivian Natural Parks system has 22 parks, protecting about 182,716 km². Of these parks, 11 occur in the Bolivian Tropical Andes, comprising about 54,000 km². To evaluate the role of the protected areas in conserving bear habitat, the connectivity map was overlaid on 11 protected areas distributed across the study area. We quantified the proportions of key patches, corridors, and total bear habitat currently under protection.

Sensitivity analysis

We used sensitivity analysis to test how the model responded to changes in the parameters of interest (Jørgensen 1986, Starfield and Bleloch 1986). We focused on the effects of varying female home-range size (Rule 1) and male movement (Rule 2) on the number of key patches. For variation in female home-range size, we used 8 km² (Paisley 2001), 10 km² (Castellanos 2008), and 15 km² as the average home range reported for female bears (Castellanos 2008). Male movement classes were based on the mean (1 km), maximum recorded in 1 day (6 km), and longest (15 km) movement,

respectively, registered for a male bear by Paisley (2001) and Rechberger et al. (2001) in Bolivia.

Results

Key patches

The application of the first rule resulted in 178 patches large enough to sustain ≥ 1 female home range (Fig. 4a) with an average size of 67.7 km² (SD = 153.8). Most of these patches were located in the North and Central sections of the study area, while there were only a few isolated patches in the South section. After application of the second rule, 90 male patches with an average size of 304 km² (SD = 762.9) were identified (Fig. 4b). Most of the southern isolated female patches were connected by habitat class II and considered suitable for male patches as well. Although most male patches were found on the North and Central area, a few male patches in the South may represent strategic locations for conservation initiatives.

After the application of the third rule, the model identified 13 key patches with an average size of 1,624 km²; and those patches were located only in the North and Central sections (Fig. 4c). These patches could presumably support an estimated population of 3,165 adult bears. We considered 9 key patches in the North as small, with an area <2,000 km² and an estimated number of bears ranging from 65 (ID 1) to

Fig. 5. Distribution of the 13 key patches for Andean bears within the Bolivian Tropical Andes region. Key patches were estimated to hold minimum self-sustaining populations of ≥ 20 males and 40 females.

201 (ID 9). Medium-sized key patches (ID 10, 11, and 12) were found in the North and Central section, with areas ranging from 2,000 to 4,000 km² and potentially able to support 364 to 561 bears. Finally, the largest key patch (ID 13) was almost 5,000 km² and could potentially support 741 bears (Fig. 5).

Connectivity analysis

The effective-distance map shows 3 bands corresponding to maximum dispersal distances (through

corridor habitat) of 500, 2,000, and 3,500 km. All key patches are connected by effective distances of ≤ 500 (Fig. 6). Almost all key patches are situated along a chain running from the northwest to the southeast with only narrow gaps between them. An exception is key patch 3, which is found isolated in the north of this chain but is well-connected by the 500 cost buffer. The key patches 11 and 6 are not connected by the 500 buffer, but are connected by a 2,000 buffer. This increase in the cost movement

Fig. 6. Effective distance map for connectivity among key patches of Andean bear habitat within the Bolivian Tropical Andes region. Dark, medium, and light gray areas represent locations that can be reached from the key patches with a total 'cost' (potential cost of crossing any anthropogenic area by a bear) < 500, 2,000, or 3,500 km.

between these 2 key patches is attributed to high human disturbance: a paved road, settlements, agriculture fields, and fire detection along the area.

Furthermore, the effective-distance map shows the dispersal buffer bands expanding toward the South section where no key patches were identified. Nevertheless, the section does contain areas suitable for female and males (Fig. 4a, b) and approximately one-third of these patches can be connected.

Sensitivity analysis

We identified low variation in the number of key patches when modifying female home range and male movement distances (Table 2). However there was considerable variation in the number of female and male patches when modification of female home-range size and male movement occurred. When female home-range size increased from 8 to 15 km², the number of female patches was reduced

Table 2. Results of the Andean bear habitat-model sensitivity analyses on number of female, male, and key patches using varying assumptions on female home-range size and male movement distances within the Bolivian Tropical Andes region.

Female home range (km ²)	No. female patches	Male movement (km)	No. male patches	No. key patches
8	209	1	118	14
		6	104	13
		15	101	13
10	178	1	112	12
		6	100	13
		15	98	13
15	130	1	76	9
		6	69	10
		15	69	10

from 209 to 130, representing few, but larger, female home ranges. Changes in male movement did not modify appreciably the number of key patches. Despite the relatively small change in numbers of key patches, changes observed were in the size and location of key patches. Considering extreme values (i.e., 8-km² F home range and 1-km M movement), 3 additional key patches were identified. Using reciprocal extreme values (i.e., 15-km² F home range and 15-km M movement), 10 key patches were identified as a consequence of merging key patches 7, 9, and 10.

Protected areas

More than 50% of habitat classes I, II, and III were unprotected, primarily as a result of the distribution of classes II and III in the South region, where there are few protected areas (Fig. 7; Table 3). Twelve of the 13 key patches were included at least partially within the limits of a protected area (Fig. 8; Table 4). From a total of 21,113 km² of key patch area, 51% is outside the protected area system. Only one key patch (ID 8) was completely unprotected, and key patch 13 (the largest patch) had only 2% of its area under protection. Five key patches (ID 1, 2, 4, 7, and 9) were entirely protected.

Discussion

We assessed the suitability and potential functional connectivity of remnant habitat patches in the Bolivian Tropical Andes for Andean bears using GIS-based rule models and a comprehensive review of Andean bear biology. We identified 13 key patches interconnected by effective distances of ≤ 500 km, located in the North and Central sections of the study

area, which could potentially support a population of 3,165 adult bears. However, only 49% of key patch area is within the current protected area system.

This study shows the capabilities of ecological modelling and GIS in using limited information on bear biology to address conservation issues. However, it is the role of the expert and criteria based on knowledge of the species that provided the most information in the model. Therefore, it is important to stress the role of understanding the species' ecology and life history to further improve rules used in model development. Although this approach was developed for Andean bears in Bolivia, it could be extended to other locations and species with different habitat requirements and dispersal capabilities.

Resources and rules

Despite incomplete knowledge on the natural history of the Andean bear, additional information from other bear species and large carnivores was used to develop the rule set. In general terms, all species require 3 essential resources to live: food, shelter, and water (Krebs 2008). Nevertheless, use of important resources may vary between males and females of a species. We applied differences in reproductive behavior between female and male bears to build a rule set to reflect these differences when selecting resources. Based on these differences, we used female habitat requirements and home range as the smallest unit of our model. Using estimates of female patch size, the model identified patches suitable for male bears, and ultimately suitable habitat for a key patch. Although our estimates of female home-range size and male movement were based on minimal data from only 2 radiotelemetry studies, the sensitivity analysis showed that neither female home range nor male movement affected significantly the number of key patches. The only implication of selecting different home ranges was observed in the location of the key patches, which could become important when applying conservation initiatives.

Key population patches and connectivity

The 13 key patches we identified were distributed along the North and Central sections of the Bolivian Tropical Andes. Although female and male patches were also identified in the South section, patch sizes and presence of corridor habitat (class II and class III) were too small and limited to sustain 20

Fig. 7. Andean bear habitat and protected areas within the Bolivian Tropical Andes region. Overlap between Andean bear habitat (black represents probability of bear occurrence >0.5 ; light gray between 0.3 and 0.5; white between 0.2 and 0.3; medium gray between 0.1 and 0.2; dark gray <0.1) and protected areas (heavy black lines) within the Bolivian Tropical Andes region.

reproductive units (i.e., 20 M and 40 F bears). Nevertheless, it is important to stress the importance of this region for bear conservation because it represents the southern limit of the Andean bear's continental distribution. Within this context, the sensitivity analysis showed one new key patch in the south when using a small female home range. In

terms of connectivity this new key patch represents the only patch located in the South section, which could become a stepping stone between patches. Furthermore, for a national conservation strategy, this key patch could play a fundamental role when prioritizing areas for conservation and research, particularly regarding home range and movements.

Table 3. Overview of Andean bear habitat classes within the protected area system in Bolivia.

Habitat class	Total area (km ²)	Within parks (km ²)	Percentage
Class I	15,029	7,049	47
Class II	33,457	13,056	39
Class III	30,472	12,619	41
Class IV	27,310	10,989	40
Class V	53,377	8,001	15

The use of corridors as a conservation strategy in fragmented-habitat scenarios has been disputed by several authors (Simberloff *et al.* 1992, Demers *et al.* 1995, Beier and Noss 1998, Rosenberg *et al.* 1998, Brooker *et al.* 1999, Danielson and Hubbard 2000, Mech and Hallett 2001, Nicholls *et al.* 2001, Palomares *et al.* 2001). Our approach differs from other connectivity studies because we assessed functional connectivity by measuring how much it

Fig. 8. Protected areas and key patches of Andean bear habitat within the Bolivian Tropical Andes region. Overlap between key patches and protected areas (heavy black lines) for Andean bears within the Bolivian Tropical Andes region.

Table 4. Key patches (KP) for Andean bears within the Bolivian Tropical Andes region, as identified by the rule-based model.

Key patch ID	Area (km ²)	Estimated <i>N</i> of bears	Key patch area (km ²) under protection	% of KP area protected
1	435	65	435	100
2	458	69	458	100
3	489	73	268	55
4	490	73	490	100
5	643	97	186	29
6	1,040	156	228	22
7	1,087	163	1,087	100
8	1,181	177	0	0
9	1,342	201	1,342	100
10	2,429	364	2,002	82
11	2,836	425	243	9
12	3,740	561	3,481	93
13	4,943	741	118	2
Total	21,113	3,165	10,338	49

will cost for a bear to move among patches based on landscape characteristics. This approach does not select one single “best” path but identifies the area or areas that bears may be more likely to use as corridors. Thus, our model constitutes an advance over the usual cost-distance approach measured by the distance from patches, already criticized by Gaona et al. (1998).

Conservation implications

Conservation of large carnivores, and particularly Andean bears, is challenging because of their low densities and low reproductive rate, and because of limited knowledge of their biology and ecology, but also because they are considered a threat to, and compete for habitat with, humans (Garcia-Rangel 2012). To protect natural habitats or expand protected areas, conservation planners frequently use large carnivores as focal species because the area of habitat required to support viable populations is large enough to protect the habitat of other species (Noss et al. 1996). However, information regarding the biology of large carnivores may be limited, and decisions are often made using incomplete knowledge. Our approach, even with its limitations, provides an example of how available information and modelling could be used to provide a baseline of areas potentially suitable for viable populations of Andean bears. Although the sensitivity analysis showed little variation in the number of key patches, it is the location of these variations that is important when making decisions to ensure the persistence of suitable habitat and landscape connectivity for Andean bears.

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