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GIS Risk Assessment and GAP Analysis for the Andean Titi Monkey (*Callicebus oenanthe*)

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Abstract: We conducted a predictive GIS (Geographical Information System) analysis to create a realistic Habitat Suitability Model (HSM) and risk analysis throughout the distribution of the Andean titi monkey (*Callicebus oenanthe*) in order to evaluate the effectiveness of the current protected area (PA) network. This was done to help current conservation work and aid in the planning and implementation of future initiatives. Little was known about this species until recently. *Callicebus oenanthe* is listed as Critically Endangered on the *IUCN Red List of Threatened Species.* It is endemic to San Martín region, northeastern Peru. Our results show that the extent of habitat available for this species may be greater than previously thought but that habitat loss in the region is extremely high. GAP analysis indicates that the current protected area network is ineffective in protecting this species, and new reserve areas are urgently needed. We recommend further study into the species' ecology to better understand its needs and to aid in future conservation work.

Key Words: Andean titi monkey, *Callicebus oenanthe,* GIS, deforestation, conservation

Introduction

The Andean titi monkey (*Callicebus oenanthe*) is one of Peru's three endemic primates, together with the yellow-tailed woolly monkey (*Oreonax flavicauda*) and the Peruvian night monkey (*Aotus miconax*). *Callicebus oenanthe* is only found in the San Martín region of northeastern Peru (DeLuycker 2006; Bóveda-Penalba *et al*. 2009). This species is listed on Appendix II of CITES (2011), as Critically Endangered (Categories A2cd) on the IUCN *Red List of Threatened Species* (Veiga *et al*. 2011) and as Vulnerable under Peruvian Law (Decreto Supremo Nº 034-2004-AG). Until recently, very little investigation has been conducted on this species in the wild (Mark 2003; Rowe and Martinez 2003; DeLuycker 2006; Aldrich *et al*. 2008; Bóveda-Penalba *et al.* 2009).

Until 2003, *Callicebus oenanthe* was only known from a handful of sightings and some few museum collections (Bóveda-Penalba *et al.* 2009). Since then further short ecological studies have been conducted (Mark 2003; DeLuycker 2006; Aldrich *et al*. 2008). In 2007, the first long-term survey of this species began (Bóveda-Penalba *et al.* 2009) to determine its actual distribution and conservation status. *Callicebus oenanthe* has an extremely limited geographic range in the Mayo and lower Huallaga river valleys (Bóveda-Penalba *et al.* 2009), part of the Tropical Andes Biodiversity Hotspot (Myers *et al.* 2000). Its preferred habitat is forests below 1,200 m above sea level in northern San Martín (Tello-Alvarado pers. obs.). Previous reports suggested that the species was restricted to the lower elevations of the Alto Mayo valley (DeLuyker 2006), particularly in gallery forests along river margins (Mark 2003). Subsequent study has confirmed the presence of this species in a greater range of habitat types, including palm-dominated forests, hilly areas, and dry forests. Bóveda-Penalba *et al*. (2009) reported that the species was present in seasonally flooded forest, but subsequent investigation shows that this is not true (unpubl. data). This is probably because of competition with *Cebus apella* and *Saimiri sciureus*.

Callicebus oenanthe has been found to be sympatric with *C. discolor* at the lower reaches of the Mayo river valley (Vermeer *et al.* 2011). Small populations of *C. oenanthe* have also been recorded on the eastern bank of the Río Huallaga (Bóveda-Penalba *et al*. 2009). Morphological differences have been reported for *C. oenanthe* populations on either side of the Río Mayo (Mark 2003; Aldrich 2006, DeLuycker 2006) and between populations in the north and south of San Martín

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(Bóveda-Penalba *et al*. 2009). Most *C. oenanthe* have a white mask but differences were found in some groups in the southern end of the species' distribution which have darker coloration on the body and lack the white mask (unpubl. data). These differences appear to be purely morphological as groups of mixed types have been observed as well as a pair of white morphs with dark offspring (unpubl. data).

Callicebus oenanthe is threatened by the widespread loss of its habitat over the last three decades. Deforestation rates in northern San Martín are among the highest in the country (Peru, INEI 2008). Deforestation is fuelled by the need for agricultural land, particularly for rice cultivation, in the plains of the Mayo and middle Huallaga river valleys, and cacao on the lower slopes of the Andean cordillera (DeLuycker 2006). Legal and illegal logging also play a major role. The habitat fragmentation resulting from deforestation is another serious threat to this species (Bóveda-Penalba *et al.* 2009). The original extent of the species' habitat has been estimated at 12,000 km² (Hershkovitz 1949–1988 cited in Ayres and Clutton-Brock 1992). Forest loss in San Martín has been estimated to be at least 40% (Veiga *et al.* 2008), with most of this occurring in the low altitude river valleys. Illegal hunting for the local and national pet trade is an additional threat. We have recorded 16 individuals in illegal captivity since 2007 (unpubl. data).

Although permanent human settlements have existed in this area since colonial times, it wasn't until the 1950s that *C. oenanthe* habitat was severely threatened. Mass immigration began with the construction, and subsequent paving, of the main highway, the *Carretera Marginal de la Selva*, connecting the Peruvian coast with the Amazonian lowlands to the east. The opening of the highway led to massive immigration from the high mountain sierra of Cajamarca and coastal regions such as Piura (Peru, INEI 2011). This immigration continued with the promotion of government-sponsored settlement and agrarian reform (Rengifo-Ruiz 1994). The population of San Martín rose by 131% between 1981 and 1993 (Peru, INEI 2011). This increase is accelerating and has since risen a further 300% between 1993 and 2007 (Peru, INEI 2011).

The fact that *Callicebus oenanthe* is restricted in its altitudinal range and habitat type increases its intrinsic risk of extinction (Purvis *et al.* 2000). This, coupled with anthropogenic pressures, makes the species a priority for conservation. GIS modeling has been used in many studies to determine species distributions and gaps in protected area networks (Aspinall 1993; Mariano *et al.* 2006; Buckingham and Shanee 2009). Here we create the first realistic Habitat Suitability Model (HSM) for the Andean titi monkey, following methods used by Buckingham and Shanee (2009) to assess the yellow-tailed woolly monkey (*Oreonax flavicauda*). We used inductive GIS modeling methodology to predict the original and current extent of habitat for this species as well as to determine 'hotspots' for potential threats. We also carried out a GAP analysis of the current protected area (PA) system in San Martín to assess the extent to which *C. oenanthe* habitat is represented in PAs and to identify optimum areas for the creation of new areas and protected corridors to ensure genetic flow between populations in the future.

Methods

Callicebus oenanthe is endemic to the northern San Martín region of northeastern Peru. It is known to occur in the Mayo river valley and the western side of the middle Huallaga river valley between 5º39' and 7°06'S. The Andean titi monkey has been observed in diverse ecosystems from humid lowland rainforest to dry scrub forest (unpubl. data). It inhabits forests at altitudes of below 1,200 m above sea level. Its range is restricted by rising elevations to the north, northeast and west, partly by the Río Huallaga to the east and the Río Huayabamba to the south.

San Martín has an estimated human population of about 730,000; the most densely populated provinces are in the north of the region (Peru, INEI 2011). The species occurs in the Área de Conservación Municipal Juanjuicillo, Área de Conservación Municipal Paz y Esperanza, Área de Conservación Municipal Almendra and the Área de Conservación Municipal Mishquiyacu-Rumiyacu (Fig. 4). There are also several other small municipal conservation areas in the Alto Mayo Valley. It has also been found in areas bordering the Bosque de Protección Alto Mayo and the Área de Conservación Regional Cordillera Escalera, but its presence in these areas has not been confirmed.

Data collection

Data used in this study include point localities and other field observations, ecological niche data, land use maps and the Digital Elevation Model (DEM90 from the Shuttle Radar Topography Mission) of Peru (<http://www.srtm.usgs.gov>). We used point locality data from previous distribution surveys (Bóveda-Penalba *et al.* 2009) and data collected for this study (unpubl.).

We used ArcGIS 9.3 (ESRI 2008) for analysis and modeling. Land use maps were obtained from the Instituto de Investigación de la Amazonia Peruana (IIAP) (Peru, IIAP 2007, 2008). Distributional limits for the species were set as elevations above 1,200 m above sea alevel to the north and west, the Río Huallaga to the east and the Río Huayabamba to the south and southeast (Fig. 1). All data layers were clipped to the study area. DEM90 in raster format was reclassified to a set of 20 altitudinal classes from 0 to >2,500 m above sea level. Many of the localities for this species are from small forest patches and gallery forests not recognized on the land use maps and were not easily definable in satellite images of the study area. Forest patches and gallery forests were not included in the analysis as they probably do not constitute large areas of remaining habitat and do not provide good GAP areas for reserves. Elevation, river boundaries and vegetation types were combined to produce a map of predicted remaining habitat.

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Distribution and Habitat Suitability Modeling (HSM)

Locality data were converted into decimal degrees and assigned the WGS 84 coordinate system. A kernel density transformation was applied to *C. oenanthe* point data, following Buckingham and Shanee (2009). This was used to determine 'hotspots' with higher densities of *C. oenanthe* sightings. Vegetation types used in habitat suitability modeling were those where *C. oenanthe* presence has been confirmed from field studies. These were *terrazas, bosques subandino, sabanas*, palm-dominated forests, *Ficus*-dominated forests and mixed-association (Peru, IIAP 2007). All habitat types were equally weighted for analysis. Elevation was then divided into two weighted categories: elevations of <700 m were given a 'good' rating; elevations of >700 and <1200 m were given a 'marginal' rating. Areas outside of these elevations were given a null rating. Similarly, land use types outside of the six forest types selected were given a null rating. This was used to create a map of potential remaining habitat of 'marginal' and 'good' rating (Fig. 2).

Ecological Risk Assessment and GAP analysis

ArcGIS 9.3 (ESRI 2008) was used to evaluate levels of threat to areas of suitable habitat highlighted by the HSM. Threats were determined as proximity away from human development (Peyton *et al.* 1998). Urban areas, population centers and road networks were classified as human developments. Areas highlighted by the HSM were classified to one of three threat levels based on proximity to human development (>8 km Low Risk, >3 km and <8 km Medium Risk, <3 km High Risk). A data layer showing mining concessions from the Instituto Geológico Minero y Metalúrgico (Peru, INGEMMET 2011) was then overlaid on the risk assessment layer and areas of mining concessions were removed from the layer. The final risk assessment was overlaid on the HSM layer, and areas of unsuitable habitat and high risk were removed. This was used to create a layer of 'marginal' and 'good' habitat with 'low risk' (Fig. 3).

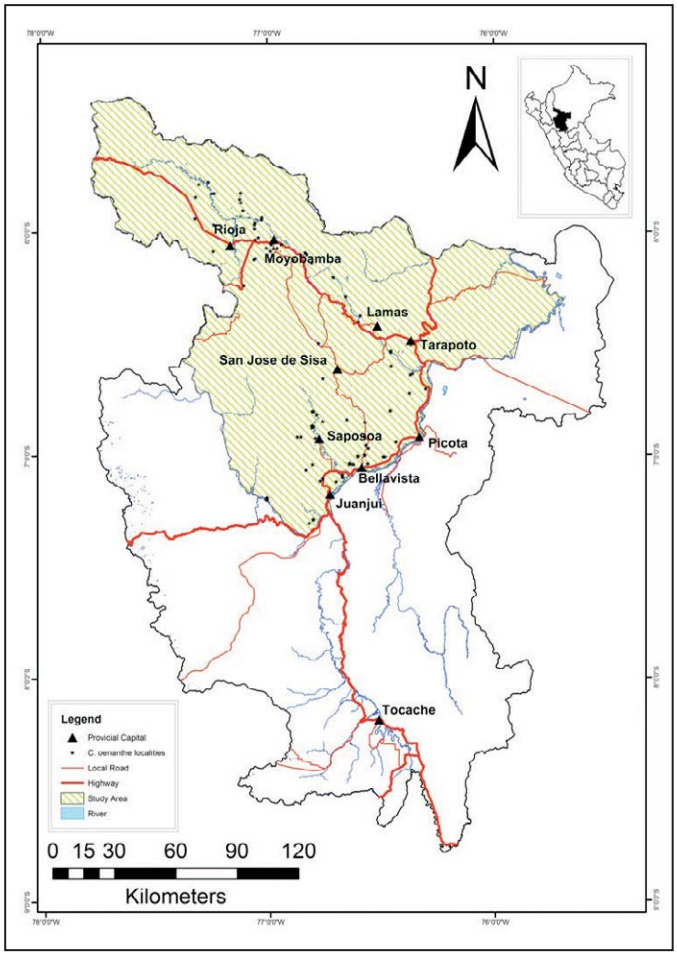


Figure 1. San Martín region. Highlighted are *Callicebus oenanthe* localities and the study area.

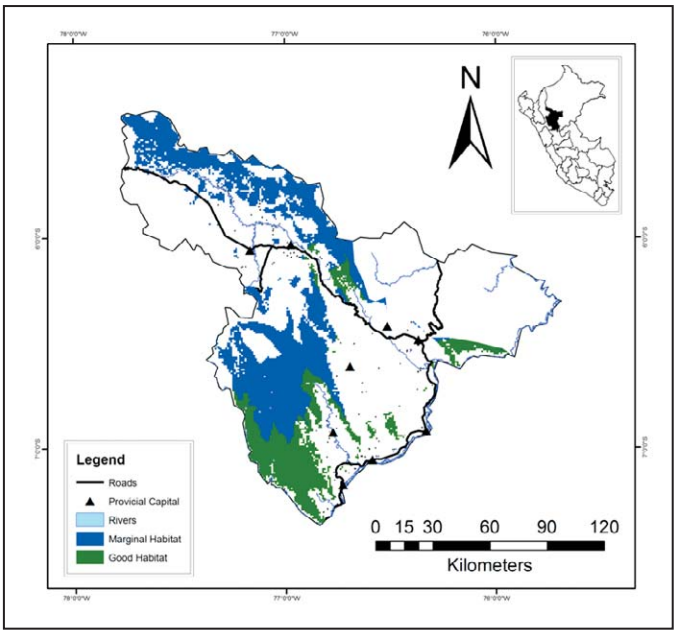


Figure 2. Estimated potential remaining habitat for *Callicebus oenanthe.*

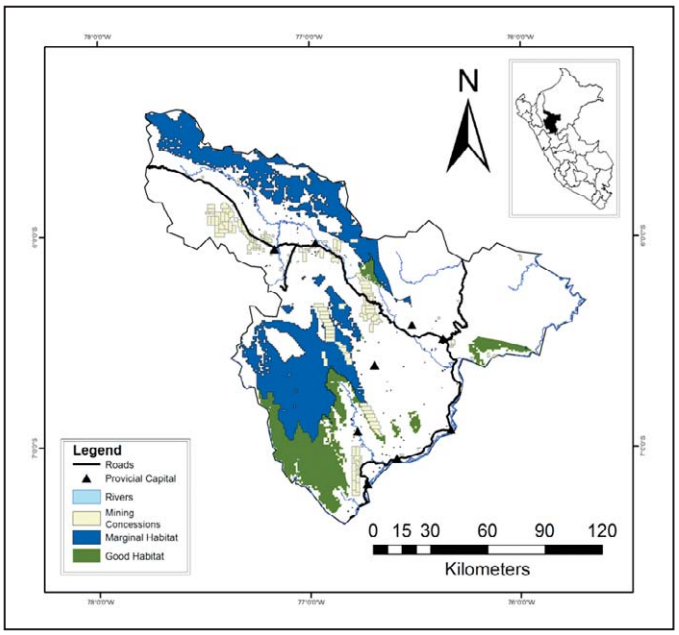


Figure 3. Estimated low risk habitat remaining for *Callicebus oenanthe*, showing mining concessions.

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A PA network layer was overlaid on the HSM and risk analysis layers to highlight areas in need of attention (Fig. 4). Approximate area values were calculated for each suitability category (i.e., marginal and good). This was used to find the area of each suitability class within the existing PA network. A further data layer showing forestry concessions was overlaid on the HSM and risk analysis layers to highlight areas available for protection (Fig. 5). Forestry concessions were not considered high risk as they leave forest cover intact, removing only selected timber species. Finally, a map was generated showing habitat of 'marginal' and 'good' rating with 'no risk' which is available for protection (Fig. 6).

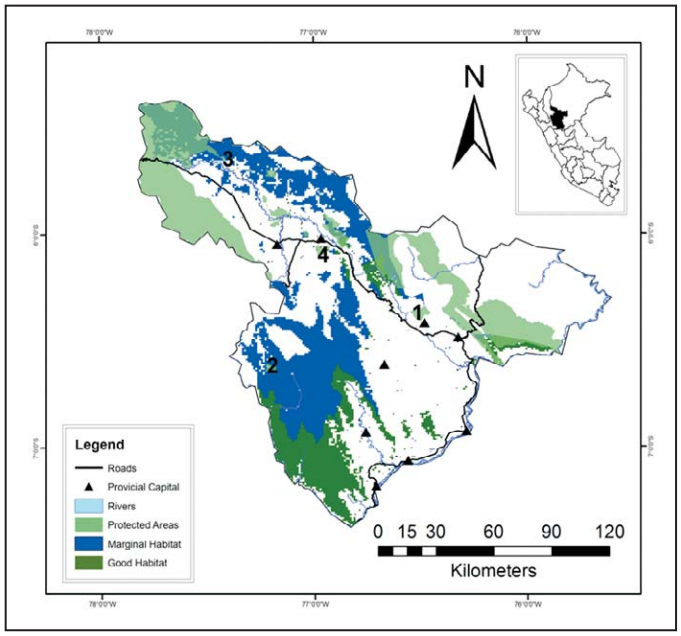


Figure 4. Low risk *Callicebus oenanthe* habitat, showing the existing protected area network. (1: Área de Conservación Municipal Juanjuicillo, 3646.1 ha, 2*:* Área de Conservación Municipal Paz y Esperanza, 1678 ha, 3: Área de Conservación Municipal Almendra, 212.3 ha, 4: the Área de Conservación Municipal Mishquiyacu-Rumiyacu, 856.5 ha)

Results

Habitat Suitability Modeling (HSM)

Total area and percentage of coverage was calculated for all levels of the analysis (Table 1). Based on habitat preferences and suitability modeling from field observation point localities, the estimated original range of *C. oenanthe* covered some 14,686 km². The current estimated extent of 'marginal' and 'good' habitat is only 6,515 km², a loss of 55.6%. The majority of habitat loss has been in the plains of the Mayo and Huallaga river valleys (Fig. 2). Of the remaining estimated habitat, only 1,930 km² is rated 'good'; equivalent to just 13% of the original extension (Table 1).

Risk Analysis

Of the remaining habitat for *C. oenanthe*, 5,710 km² is considered to be 'low risk' or 'no risk' habitat. Only 1,667 km² of this is rated as 'good' habitat (Table 1) with the largest portion in the south end of the species' distribution.

GAP Analysis

Only 14.6% of possible *C. oenanthe* habitat is currently covered by the protected area network, leaving 85% unprotected. Only 7.8% of the habitat rated as 'good' is within the network (Table 1). GAP analysis highlighted large areas of both 'marginal' and 'good' habitat that remain unprotected. It also revealed that much of the remaining habitat for the species is available for protection, although less of the remaining habitat rated as 'good' is available for protection.

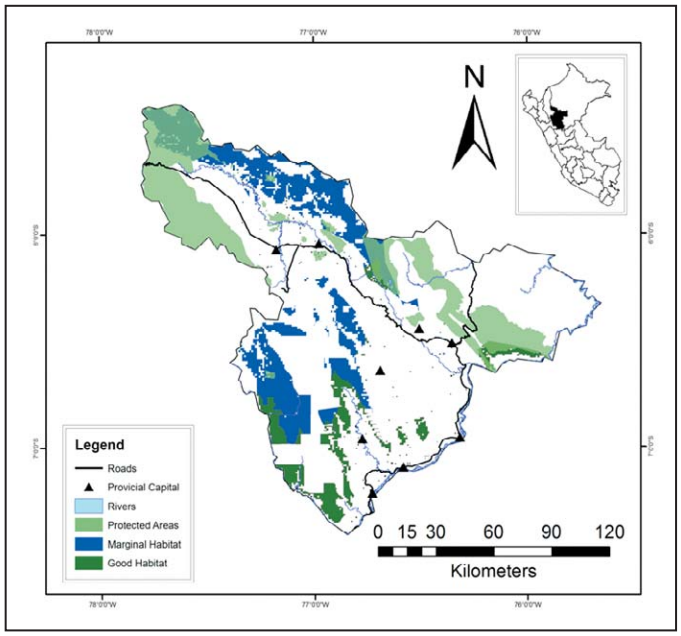


Figure 5. Areas of habitat low risk not covered by logging concessions and that therefore could be considered for protection.

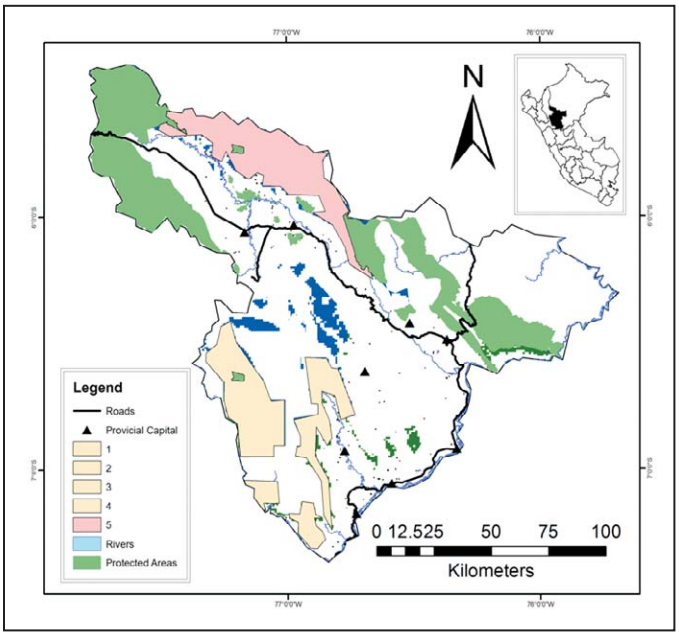


Figure 6. Existing protected areas with suggested GAP reserves and extension areas.

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Four new protected areas and one wildlife corridor area are suggested based on the HSM and the results of the risk assessment (Fig. 6). Together these would protect a further 3,391 km² of remaining habitat, leaving only 2,170 km² or 33% unprotected (Table 1). Potential reserves were chosen as they covered the largest contiguous areas of good and marginal habitat available for protection. A map was created highlighting five areas for new reserves and reserve extensions to complement the existing PA network (Fig. 6).

Discussion

Previously thought to be restricted to the Alto Mayo valley (DeLuyker 2006), an area of only 6,307 km², the actual distribution of *C. oenanthe* is now known to be much larger (Bóveda-Penalba *et al.* 2009). Our calculation of the original extent of the species' distribution — 14,686 km² — is the highest estimate so far, although it is similar to a previous estimate of 12,000 km² by Hershkovitz (1949–1988), cited in Ayres and Clutton-Brock (1992). Unfortunately the parameters used for this estimate are not given.

Although records do exist of the species' presence to the east of the Río Huallaga (Bóveda-Penalba *et al.* 2009), we did not include this area in the analysis as we have the impression that these are small enclave populations that have somehow been able to pass the river (unpubl. data). Such enclave populations have also been observed for other *Callicebus* species (Hershkovitz 1988).

As with most diurnal mammals in the Neotropics, hunting and habitat loss are the main threats faced by this species (Laurance *et al.* 2000). Human population increase and associated deforestation in San Martín are amongst the highest in Peru (Peru, INEI 2011). Immigration has been facilitated by the construction of the main highway connecting this formerly remote region with the coast, furthered by the construction of rural access roads into new areas. Deforestation in the river plains of the ríos Mayo and Huallaga has left a mosaic landscape of small forest patches surrounded by agricultural land. During field surveys (Bóveda-Penalba *et al.* 2009) *C. oenanthe* was encountered in 49 forest patches ranging in size from 0.5 ha to 70 ha (average 6.43 ha ±11.9) (J. C. Tello-Alvarado unpubl. data). This not only reduces the total habitat available to *C. oenanthe* but produces several further negative effects; fragmentation increases the risk of extinction from anthropogenic pressures and independent stochastic events (Reed 2004); fragmentation reduces genetic flow between isolated populations increasing the risk of genetic degeneration through inbreeding (Lande 1998); fragmentation facilitates access for hunters (Peres 2001) and increases intra- and inter-specific competition for resources (Estrada and Coates-Estrada 1996).

The present study was limited by the lack of detailed geographic data on forest patches in the study area. The majority of locality records for this species are within areas classed as deforested (Peru, IIAP 2007). The combined total area of patches previously surveyed (Bóveda-Penalba *et al.* 2009) was 315 ha (J. C. Tello-Alvarado unpubl. data), which represents less than 5% of the remaining habitat. Many of these patches are in areas of 'good' habitat but with a high associated risk because of their proximity to human development.

Density estimates for *C. oenanthe* range from 113 individuals/km² at Tarangue (Aldrich *et al.* 2008), a large isolated patch (about 70 ha) of mostly secondary forest, to 120 individuals/km² at Pucunucho (unpubl. data) an area of secondary forest (about 23 ha) contiguous with more extensive primary forest only through a thin corridor of forest. These density estimates are extremely high compared to other titi monkey species and could be a result of the crowding of individuals into these areas due to habitat loss in surrounding areas (inability to disperse). Such high densities in fragmented forests suggest that protection of forest fragments and connectivity between patches is of high importance for the conservation of this species.

Our study highlights the lack of protection afforded this species by the existing protected area network in San Martín, with only a very small percentage of habitat currently protected (14.6 %), and even less habitat of 'good' quality (7.8%) with low risk (14.8%). The recommendations in this study would afford the Critically Endangered *C. oenanthe* much-needed protection. Areas 1–4 (Fig. 6) could be protected at the national, regional or municipal level or protected privately as conservation concessions (*Concesión para la Conservación*), eco-tourism concessions (*Concesión para Turismo*) or private conservation areas (Área *de Conservación Privada*). Area 5 lies within native community lands and could, therefore, only be protected as a communal reserve under Peruvian law.

Urgent measures are needed to protect habitat for this species, particularly in the southern end of its distribution that

Table 1. Total area habitat predictions and percentage coverage of PA network, potential habitat for protection, and suggested new reserve areas.

	All possible habitat (km²)	Marginal habitat (km²)	Good habitat (km²)
Original extension	14,686.00	8,216.44	6,469.56
Current extension	6,515.75	4,585.68	1,930.07
Low risk habitat	5,710.13	4,042.93	1,667.20
Protected habitat	953.25	802.29	150.95
Low risk protected	842.69	704.27	138.42
Not protected	5,562.50	3,783.39	1,779.12
Low risk not protected	4,867.44	3,338.66	1528.78
% Protected	14.6%	17.5%	7.8%
% Unprotected	85.4%	82.5%	92.2%
% Low risk protected	14.8%	17.4%	8.3%
% Low risk unprotected	85.4%	82.6%	91.7%
Available for protection	4,333.43	3,273.98	1,059.46
GAP reserves	3,391.34	-	-
% Protected with new reserves	66.68%	-	-

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still holds large areas of contiguous habitat rated as 'good' that could be given legal protection (Fig. 4). Currently two initiatives are underway to protect habitat in this area. The NGOs Neotropical Primate Conservation, *Proyecto Mono Tocón* and *Amazónicos para la Amazonia* are working together to protect three areas for the conservation of *C. oenanthe*, all of which are in the southern portion of the species' range. One private conservation area at Pucunucho currently covers about 23 ha of secondary forest but could be extended to protect a forest corridor that connects the area to a large (about 3,000 ha) area of primary habitat. Two conservation concessions are being developed in the province of Mariscal Cáceras. These areas, near the villages of Bagazán and Ricardo Palma, would cover approximately 8,000 ha of 'good' habitat.

Environmental education should be a priority throughout the species' distribution in order to highlight the threats faced and the need to preserve connectivity between patches and in gallery forests. *Proyecto Mono Tocón* has been carrying out education work since 2007, and both Neotropical Primate Conservation and *Amazónicos para la Amazonia* promote educational activities in the area focusing on habitat protection and hunting.

We recommend further investigation on the presence of *C. oenanthe* in areas highlighted by this study as 'marginal' habitat and areas in the far east of the study area and central west areas that are highlighted — previous work in these areas was unable to confirm the species presence but did encounter *C. discolor*. In addition surveys of the species densities in more areas, particularly those with more extensive forest and at different elevations, are needed to determine the natural population density of this species for comparison with densities from previous studies in fragmented and secondary habitat. Also more genetic studies should be made on the northern and southern populations of *C. oenanthe* to better understand the conservation needs of different morphs.

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