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DISTRIBUTION, ECOLOGICAL NICHE MODELLING AND CONSERVATION ASSESSMENT OF THE PERUVIAN NIGHT MONKEY (MAMMALIA: PRIMATES: AOTIDAE: *AOTUS MICONAX* THOMAS, 1927) IN NORTHEASTERN PERU, WITH NOTES ON THE DISTRIBUTIONS OF *AOTUS* SPP.

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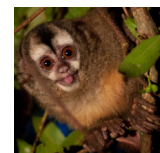
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Abstract: *Aotus miconax* is endemic to Peru and remains one of the least studied of all Neotropical primate taxa. It has an altitudinally restricted distribution and is limited to areas of premontane and montane cloud forest in the countries north. Deforestation in the area is the highest in the country. In many areas deforestation has fragmented remnant populations of *A. miconax* to isolated forest fragments with high hunting pressure. Our aim was to gather information on the current distribution of *A. miconax* and other *Aotus* species in northeastern Peru. Through field surveys we found evidence of the presence of *Aotus* spp. at 44 localities in the departments of Amazonas, Huánuco, La Libertad and San Martín, including 23 visual observations and four aural detections and from secondary evidence at a further 17 sites. *Aotus miconax* was found at sites between 1200–3100 m. Combining GIS and maximum entropy ecological niche modelling we predicted the probable original distribution of *A. miconax*. We also evaluated the current area of occupancy, level of fragmentation and anthropogenic threats faced by this species. The current area of occupancy of *A. miconax* is much reduced and anthropogenic threats to this species are severe and increasing. The current IUCN Red List status (VU) underestimates actual habitat loss and disturbance. Sympatric species which suffer from similar levels of hunting and habitat loss are considered ‘Critically Endangered’ (IUCN 2011) and based on our estimate of ~60% habitat loss, with much of the remaining habitat highly fragmented; we would like to suggest that *A. miconax* be classified as Endangered.

Keywords: *Aotus nancymae*, *Aotus nigriceps*, conservation, maximum entropy, Owl Monkey.



Aotus miconax
Peruvian Night Monkey



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Neotropical Primate Conservation Peru



INTRODUCTION

The Peruvian Night Monkey *Aotus miconax* is one of Peru's eight endemic primate species (Matauschek et al. 2011; Alfaro et al. 2012; Boubli et al. 2012; Wilson et al. 2013; Marsh 2014). *Aotus miconax* was first described by Thomas (1927a) from specimens collected in Amazonas Department with further specimens collected in Huánuco Department (Hershkovitz 1983). This species remains one of the least known of all primates, with few published field observations (Butchart et al. 1995a,b; Cornejo et al. 2008; Shanee & Shanee 2011; Sanchez-Larranega & Shanee 2012) and only one previous behavioural study (Shanee et al. 2013). *Aotus miconax* is listed as Endangered on Appendix II of CITES (2005) and as Vulnerable (IUCN category A2c) on the IUCN Red List of Threatened Species.

The distributions of *Aotus* spp. in northern Peru are poorly understood and no previous distribution survey has been made of *A. miconax*. This species is largely sympatric with *Lagothrix flavicauda* (Shanee 2011) and is limited to areas of pre-montane and montane cloud forest in the departments of Amazonas, Huánuco, La Libertad, Loreto and San Martín (Aquino & Encarnacion 1994; Cornejo et al. 2008) and possibly Pasco. *Aotus miconax* has a marginally wider altitudinal range than *L. flavicauda*, occurring from just below 1,000m (Thomas 1927b; Cornejo et al. 2008) to over 3,100m. in the Santuario Nacional Cordillera de Colan in Amazonas Department (Campbell 2011). This species has been recorded in *Ficus* spp. dominated pre-montane and montane cloud forest and white sand forest (Cornejo et al. 2008; Shanee & Shanee 2011; Shanee et al. 2013).

Deforestation in northern Peru is among the highest in the country (Elgegren 2005), fuelled by high immigration rates and the need for agricultural land and timber extraction (Elgegren 2005; Shanee 2011; Shanee 2012a). The widespread deforestation and habitat fragmentation has, in many areas, forced *A. miconax* into isolated fragments exposing the species to increased parasite load and hunting (Shanee & Shanee 2011; Shanee 2012; Sanchez-Larranega & Shanee 2012; Shanee et al. 2013). There is almost certainly a downward trend in this species population size because of habitat loss.

Geographic Information Systems (GIS) have become an invaluable tool for species distribution modelling (Dunning et al. 1995; Stone et al. 2013). Using data on species presence and absence, combined with information on environmental characteristics, various techniques have been developed for modelling species'

distributions (Guisan et al. 2007; Boubli & Lima 2009; Elith & Graham 2009; Norris et al. 2011). Among these, maximum entropy ecological niche modelling using Maxent program (Phillips et al. 2006) has been shown to perform well compared with other modelling techniques (Elith et al. 2006; Guisan et al. 2007; Elith & Graham 2009; Giovenelli et al. 2010) and has been used in previous studies on a wide range of primate species (Thorn et al. 2008; Boubli & Lima 2009; Willems & Hill 2009; Norris et al. 2011; Peck et al. 2011; Vidal-Garcia & Serio-Silva 2011).

Through field surveys and GIS based distribution modelling we estimated the original distribution of *A. miconax* and evaluated the current ecological and anthropogenic threat to *A. miconax*. Specifically, we aimed to gather up-to-date information on the actual distributions of *A. miconax* and other *Aotus* spp. in northern Peru. With this data we modelled the predicted original and current extent of *A. miconax* distribution using maximum entropy algorithm ecological niche modelling with Maxent and ArcGIS programs (Phillips et al. 2006). We extended this using available data on forest cover and proximity away from human settlement and infrastructure to estimate fragmentation and as proxy measures of anthropogenic threat from hunting (Bodmer et al. 1997; Peyton et al. 1998; Michalski & Peres 2005; Buckingham & Shanee 2009; Shanee et al. 2011).

METHODS

Study sites

We surveyed sites in the pre-montane and montane cloud forest belt in the eastern branches of the Andean Cordillera in northeastern Peru between 05°22'–10°01'S & 78°26'–75°32'W (Fig. 1). We surveyed forested areas at altitudes between 300–3,500 m in the departments of Amazonas, Huánuco, La Libertad and San Martín. During surveys we recorded temperatures between 8–30 °C in the daytime and 3–19 °C at night. Rainfall was variable with monthly averages between ~15mm in the dry season, August to November, and ~1500mm in the wet season, December to May.

Field surveys

We conducted field surveys between March 2009 and March 2013. We chose survey sites based on records from previous surveys (Butchart et al. 1995a; Cornejo et al. 2008; Shanee 2011) and our preliminary GIS analyses of deforestation. Survey sites included

forest fragments, from ~0.5ha to over 50ha and areas of contiguous forest. Some ad hoc observations were also made in gallery forests, stands of individual trees and shade grown crop plantations (Table 1).

We identified species based on pelage and vocalizations. The three night monkey species we expected to encounter, *A. miconax*, *A. nancymaae* and *A. nigriceps*, belong to the red-necked group (together with *A. azarae* and *A. infulatus*) (Hershkovitz 1983; Groves 2001). Although not readily distinguishable, we identified species through direct observation and detailed revision of photographs taken in the field with descriptions given by Groves (2001) and Aquino & Encarnacion (1994). We also compared photographs and accounts given in Rowe & Myers (2012) with our own observations and photographs. Playback of pre-recorded territorial calls (using a portable MP3 player and 1.5 watt speaker) were also used to aid localization and identification of *Aotus* spp. in areas of sympatry with other large nocturnal mammals. This was particularly useful for *A. miconax* through comparison with recordings made during behavioural studies at our main field site at La Esperanza, Amazonas Department (Shanee et al. 2013; unpublished data). Species were never identified based solely on vocalisations. When we were not sure of the species identity we report it here as *Aotus* spp. except in cases for *A. miconax* where based on elevation, geographic location, habitat type and confirmed reports from neighbouring contiguous areas we tentatively identified to species level (Table 1; Images 1–2).

Sympatric nocturnal species of similar size to *Aotus* spp. in our area are *Potos flavus*, *Bassaricyon gabbii*

and *Didelphis* spp. The latter are easily distinguishable from *Aotus* spp., *P. flavus* and *B. gabbii* are more similar and are often considered primates by local people, particularly because of the prehensile tail of *P. flavus*. When collecting secondary data from local informants, species identification was made using photographs and drawings and detailed explanations of pelage, size and ecology. Positive identifications were cross-referenced between informants and we asked further details of behaviour, diet and locomotion to ensure identification (Shanee 2011). We recorded presence of *Aotus* spp. at the generic level from informants, but never inferred species identification based solely on interviews (Shanee 2011). During field visits we interviewed hunters and asked to view captive animals, skins, skulls and miscellaneous body parts of animals hunted in the area. These were used in identification when the locality of the capture could be confirmed. We were always careful not to encourage hunting when asking to see skins, wild caught pets and body parts.

We collected primary data during forest walks along existing trails accompanied by local residents as field guides. Some trails were also made to enter new areas, but this was kept to a minimum to limit forest disturbance (Shanee 2011). We visited field sites during two to seven days, making up to three visits per site (Table 1). The duration of field visits depended on whether or not the presence of *Aotus* spp. could be confirmed or when secondary evidence showed a high possibility of them being found. Because of the non-stratified sampling effort the time and distance spent walking trails varied depending on site-specific limitations, such as patch size and existing access routes resulting in variable survey effort between sites. The location of all sites was



Image 1. *Aotus miconax* Peruvian Night Monkey



Image 2. *Aotus miconax* Peruvian Night Monkey

recorded with a handheld GPS (Garmin GPSMap 60CSx), as were points of visual, audio or incidental (e.g., food residues showing clear bite marks) detection. We never inferred the species presence from bite marks without additional evidence. We also collected data on threats to habitat in areas we visited.

Habitat loss analysis

To model the predicted original distribution of *A. miconax* we used presence-only data in Maxent Program (Phillips et al. 2006; Phillips & Dudík 2008) and ArcGIS 10.1 (ESRI 2012) for analysis and modelling, using 1km resolution environmental layers from BioClim (Hijmans et al. 2005). We selected 13 environmental layers (Table 2) which represent important variables for the presence and maintenance of pre-montane and montane cloud forests and their internal diversity (Webster 1995; Bruijnzeel & Veneklaas 1998; Rapp & Silman 2013). These included bioclimatic variables representative of annual trends, seasonality and limiting factors (Table 2). Also, 30m digital elevation model (DEM) derived from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite and a vegetation layer from the terrestrial conservation assessment (Olson et al. 2001). We resampled all layers to ~90m spatial resolution and clipped these to a calibration area of ~700,000km² that approximated the study area, including most of the Peruvian Andes as well as some lowland Amazonian forest and coastal areas. We used the results of our field studies inputting points of confirmed presence and ran tests using default settings; convergence threshold = 10⁻⁵, maximum iterations = 1000, regularization value β = 10⁻⁴ and use of linear, quadratic, product and binary features (Phillips et al. 2006).

Taking into account a previous study (Shanee et al. 2013) which reported a home range size for a group of *A. miconax* at just over 1ha, we used a regularization multiplier of two to better model the species' use of territory. We set the percentage of test points at 25 and replicate runs using subsamples (Anderson et al. 2002). As ecological niche modelling with Maxent does not take into account geographic boundaries such as major rivers (Gascon et al. 2000), which are particularly important for limiting the distributions of smaller bodied primate species (Ayres & Clutton-Brock 1992), we created a mask based on the Marañon and Huallaga river systems and clipped the Maxent output to within these limits.

Distribution analysis

Canopy cover and vegetation density are important

factors for predicting the presence of *A. miconax* (Campbell 2011). To model the current distribution of *Aotus miconax* we used a forest cover layer at 30m resolution from (<http://earthenginepartners.appspot.com/science-2013-global-forest>) (Hansen et al. 2013). As this data is to the year 2000 we combined it with estimates of forest loss and gain to the year 2012 from the same source. Although quantitative data are given by Campbell (2011) we selected a conservative threshold of 50% forest cover for likely presence of the species based on previous studies of primates and definitions of forested/deforested ecosystems (Johnson et al. 2005; Hartley & Hunter 1998) and removed cells with lower values from the map. We then overlaid this onto the Maxent outputs to get an estimate of possible current area of occupancy.

To better model actual and future habitat disturbance and anthropogenic threat level we made additional analysis of proximity away from human settlements and highways as an index of fragmentation and hunting pressure. Using data layers of the national, regional and local road systems as well as cities, towns and villages provided by governmental authorities. Using this final layer meant that only larger villages (those large enough to have schools) were included in the analysis. Also many additional roads are found in the survey area commissioned by local authorities and have not yet been added to the national road systems database, thus we modelled minimum habitat loss and disturbance. We used a crude maximum estimated extent of anthropogenic disturbance as areas ≤ 5 km from human settlement or highways; this represents an intermediate distance used by previous studies (Peyton et al. 1998; Michalski & Peres 2005; Buckingham & Shanee 2009; Shanee et al. 2011). We also calculated a minimum estimated extent of disturbance as ≤ 1 km away from human settlements and highways. We used this smaller distance as previous studies have shown adaptability in *A. miconax* allowing them to persist close to human settlements in some areas (Shanee & Shanee 2011; Sanchez-Larranega & Shanee 2012; Shanee et al. 2013). All maps were made using three occurrence probability levels (0–19.9%, 20–49.9% and >50%) based on values above the minimum threshold given in the Maxent output.

For comparison between the distributions of *Aotus* spp. we also calculated rough estimates of the distributions of other Owl Monkey species based on freely available shape files (Rowe & Myers 2012) of the estimated distributions.

Fragmentation

To estimate current levels of habitat fragmentation we used ArcGIS to calculate the area of all separate polygon features in the current habitat layer produced from our Maxent outputs. First we removed areas with < 50% forest cover from the Maxent output. To better estimate actual connectivity/fragmentation of *Aotus miconax* sub-populations we aggregated all polygon features (i.e., forest fragments) > than 1.25ha (Shanee et al. 2013) within a buffer of 200m to single polygons. We chose this threshold as an intermediate distance from observations of travel between forest patches by *A. miconax* in fragmented habitat (Shanee & Shanee 2011). We then selected three thresholds representing different conservation units for the species: fragments >1.25ha, based on species home range estimate (Shanee et al. 2013); fragments >50ha to represent an estimate of the area needed to support a minimum viable effective population size to retain reproductive fitness (Franklin 1980) based on the >1.25ha home range estimates (Shanee et al. 2013); and areas >10,000ha to represent large areas with contiguous populations as important conservation units. We then overlaid this with our 1km buffer layer of anthropogenic development to highlight areas of high conservation priority.

RESULTS

Field surveys

We surveyed a total of 88 sites during field surveys representing proximately 530 field nights. We combined results from some field sites for analyses because of their close proximity, leaving a total of 52 separate localities (Table 1). We found evidence of the presence of *Aotus* spp. at 44 localities. We observed wild Night Monkeys 23 times; with an additional four aural encounters. We also found secondary evidence of night monkeys at 44 localities, of these eight were accounts from other researchers active at the site during our surveys and at five sites we found skins or live captive individuals (Table 1). Local informants told us of the presence of *Aotus* spp. at 42 of the sites that we visited. We only found Night Monkeys (*A. miconax*) at one site where local informants had not previously confirmed the species presence.

We recorded *A. miconax* at 31 sites in Amazonas, Huánuco, La Libertad and San Martin (Fig. 1), *A. nancymaae* was registered once, near Tingo Maria, Huánuco Department (Fig. 1) with another two probable records in San Martin, although we were unable to

confirm the species identity. *Aotus nigriceps* was recorded once in north-central San Martin department (Fig. 1) and another probable record at SachaRuna to the east of the Rio Huallaga in San Martin Department (Fig. 1), again we were not able to confidently identify this record to species level. At a further nine sites we recorded the presence of night monkeys but were unable to determine the species (Fig. 1). At seven sites we found no evidence of night monkeys, neither during fieldwork nor from local informants or other researchers.

All sites where we recorded the presence of *A. miconax* were between 1200–3100 m. The majority of records for *A. miconax* were in *Ficus* spp. dominated pre-montane and montane forests. We also recorded the presence of *A. miconax* in other forest types, including; white sand forest, *Podocarpus* spp. dominated cloud forest and *Alzatea verticillata* dominated forest. At three locations we inferred the presence of *A. miconax* from secondary evidence but only at sites where neighbouring contiguous forests had confirmed presence (Table 1). At three sites where we expected to find *A. miconax* populations; Breo, San Antonio and Venceremos (Table 1) we found no evidence of this or other *Aotus* spp.

Levels of deforestation were high throughout the survey area, even in remote areas such as Breo and Simacache in San Martin and nationally protected areas, such as the Bosque Proteccion Alto Mayo. In some areas, most notably Campo Redondo, Churuja and Delta in Amazonas, almost none of the original forest cover remains. At Campo Redondo we found *A. miconax* living in shade tree species (*Inga edulis*) used for coffee (*Coffea* sp.) plantations (Table 1). Hunting was also found to be a problem for all species of night monkey throughout the area. During surveys we recorded seven captive individuals and numerous skins, skulls and stuffed animals (Table 1).

Predicted distribution limits for *A. miconax* are the highlands of La Libertad and the Rio Marañon to the west, the lowlands of the Rio Marañon in Amazonas to the north and the lowlands of Loreto to the north-east, the lowlands of the Rio Huallaga valley to the east. The southern limit of this species distribution could not be determined with confidence. The distributional limits for *A. nancymaae* in this area are the foothills of the Andes above ~1,000m to the west of the Rio Huallaga in Huánuco and San Martin. The distributional limit of *A. nigriceps* in this area appears to be the Rio Huallaga.

Table 1. Records from survey sites, species identification and detection type as well as habitat characteristics.

Location*	Depart-ment	Coordinates	Altitude (m) **	Species present (Probable species)	Forest type/ Quality	Size of Area ***	Survey Effort/No visits	Detection type					
								Direct detection			Secondary detection		
								Visual	Audio	Food residue	Referred to by researcher	Referred to by local	Additional source
Shunte	San Martin	S8°24'40" W76°43'07"	1450	<i>A. miconax</i>	Pre-montane/ Lightly disturbed	Contiguous	4 nights/2 visits	X	X			X	
Tingo de Uchiza	San Martin	S8°28'58" W76°35'37"	1217	<i>A. miconax</i>	Pre-montane	Contiguous	2 nights/1 visit	X	X			X	
Serpentario de Tingo Mario	Huánuco	S9°17'30" W76°00'41"	600	<i>A. nancymaiae</i>	Bamboo	Contiguous/ Fragmented	2 nights/1 visit	X				X	
Centro Rescate Madera Verde	Huánuco	S9°18'42" W76°00'06"	650	<i>Aotus sp.</i>	Tierra Firme lowland rainforest	Contiguous/ Fragmented	2 nights/1 visit	X				X	
Puesto de Control Parque Nacional Tingo Maria	Huánuco	S9°25'11" W75°58'14"	700	X	Tierra Firme lowland rainforest	Contiguous	2 nights/1 visit						
Mono pampa	Huánuco	S9°48'28" W75°45'31"	2920	<i>A. miconax</i>	Montane	Contiguous	1 night/1 visit					X	
Abra Alegria	Huánuco	S9°48'15" W75°44'27"	3000	X	Scrub/ Montane	Contiguous	1 night/1 visit						
Tambo	Huánuco	S9°46'27" W75°44'03"	2200	<i>Aotus sp.</i>	Montane	Contiguous	1 night/1 visit					X	
Pucaplaya	Huánuco	S9°41'03" W75°48'13"	1350	<i>A. miconax</i>	Montane	Contiguous/ Fragmented	1 night/1 visit	X				X	
Miraflores	Huánuco	S9°41'21" W75°50'32"	1000	X	Pre-montane	Contiguous/ Fragmented	1 night/1 visit						
Rio Blanco	Amazonas	S5°34'59" W77°54'51"	1700	<i>A. miconax</i>	Montane/ Moderately disturbed	Contiguous	10 nights/2 visits	X	X			X	
La Esperanza	Amazonas	S5°42'28" W77°54'22"	2000	<i>A. miconax</i>	Montane/ Fragmented	Fragments 0.5–6 ha	Continual field work	X	X			X	Captive individuals
Buenas Aires	Amazonas	S5°43'41" W77°54'45"	1900	<i>A. miconax</i>	Montane/ Fragmented	Fragment 15 ha	Continual field work	X	X			X	Captive individuals
Cabeza del Toro	Amazonas	S5°38'42" W77°54'59"	1800	<i>A. miconax</i>	White Sand/Lightly disturbed	Contiguous	Continual field work	X	X			X	
Olleros	Amazonas	S6°03'13" W77°38'52"	3000	<i>A. miconax</i>	Montane/ Lightly disturbed	Contiguous	2 nights/1 visit					X	
Copallin	Amazonas	S5°38'30" W78°15'03"	2600	<i>A. miconax</i>	Montane/ Lightly disturbed	Contiguous	5 nights/1 visit		X			X	
Nuevo Chichayo	Amazonas	S5°40'50" W78°18'06"	1500	<i>A. miconax</i> *	Montane/ Lightly disturbed	Contiguous	1 night/1 visit					X	
San Martin	Amazonas	S5°56'18" W78°09'57"	1400	<i>A. miconax</i>	Montane/Lightly disturbed	Contiguous	1 night/1 visit					X	Captive individual
San Geronimo	Amazonas	S5°59'38" W78°00'01"	2200	<i>A. miconax</i> *	Montane/ Lightly disturbed	Contiguous	2 nights/1 visit					X	

Location*	Department	Coordinates	Altitude (m)**	Species present (Probable species)	Forest type/ Quality	Size of Area ***	Survey Effort/No visits	Detection type					
								Direct detection			Secondary detection		
								Visual	Audio	Food residue	Referred to by researcher	Referred to by local	Additional source
Leymebamba	San Martin	S6°44'07" W77°40'54"	2000	<i>A. miconax</i>	Montane/ Moderately disturbed	Contiguous	-				X		
La Primavera	San Martin	S6°42'28" W77°13'29"	1700	<i>A. miconax</i>	Pre-montane/ Disturbed	Contiguous	Continual field work	X		X		X	
La Union	Amazonas	S5°41'40" W78°16'42"	1400	<i>A. miconax</i>	Montane/ Disturbed	Contiguous	Continual field work			X		X	Captive individual
Belén	Amazonas	S5°47'19" W78°18'32"	550	<i>Aotus</i> sp.	Dry forest/ Disturbed	Contiguous/ Fragmented	1 night/1 visit			X		X	
Berlin	Amazonas	S5°55'08" W78°24'45"	2200	<i>A. miconax</i>	Montane and <i>Alzatea verticillata</i> /Fragmented	0.5–98 ha	Continual field work	X		X		X	
Las Higueras	Amazonas	S5°38'15" W78°16'48"	1800	<i>A. miconax</i>	Montane/ Disturbed	Contiguous/ Fragmented	2 nights/1 visit			X		X	
San Antonio	Amazonas	S6°15'56" W77°54'55"	2000	X	Montane/ Fragmented	360ha	3 nights/1 visit						
Ocol	Amazonas	S6°09'38" W77°20'04"	2300	<i>A. miconax</i>	Montane/ Fragmented	Contiguous/ Fragmented	3 nights/1 visit	X		X			
Huamanpata	Amazonas	S6°20'48" W77°27'03"	2100	<i>A. miconax</i>	<i>Ceroxylon</i> spp. forest/ Disturbed	Contiguous/ Fragmented	3 nights/1 visit		X	X		X	
Miraflores	Amazonas	S5°41'58" W77°55'36"	2100	<i>A. miconax</i>	Montane/Lightly disturbed	Contiguous	Continual field work	X		X		X	
Venceremos	San Martin	S5°40'18" W77°45'52"	1900	X	Montane/ Lightly disturbed	Contiguous	10 nights/2 visits						
Bagazan	San Martin	S7°14'20" W76°53'25"	900	<i>Aotus</i> sp. (<i>A. nancymae</i>)	Tierra Firme lowland rainforest/ Moderately disturbed	Contiguous	Continual field work	X		X		X	
Simacache	San Martin	S7°02'39" W77°11'59"	500	<i>Aotus</i> sp. (<i>A. nancymae</i>)	Tierra Firme lowland rainforest/ Lightly disturbed	Contiguous	Continual field work	X		X		X	
Shipasbamba	Amazonas	S5°54'35" W77°58'50"	2100	<i>A. miconax</i>	Montane/ Disturbed	Contiguous	2 nights/2 visits	X		X		X	
Poroto	La Libertad	S8°07'02" W77°08'28"	1800	<i>Aotus</i> sp.	Montane/ Disturbed	Contiguous	3 nights/1 visit					X	
Alto Huayabamba	San Martin	S7°19'14" W77°27'39"	2400	<i>Aotus</i> sp.	Montane/ Lightly disturbed	Contiguous	Continual field work					X	
Delta	Amazonas	S5°47'57" W78°34'16"	700	<i>Aotus</i> sp.	Dry forest/ Fragmented	450ha	Continual field work	X				X	
Paitoja	San Martin	S6°21'42" W77°04'52"	1750	<i>Aotus</i> sp.	Pre-montane/ Moderately disturbed	Contiguous	1 night/1 visit					X	

Location*	Department	Coordinates	Altitude (m) **	Species present (Probable species)	Forest type/ Quality	Size of Area ***	Survey Effort/No visits	Detection type					
								Direct detection			Secondary detection		
								Visual	Audio	Food residue	Referred to by researcher	Referred to by local	Additional source
Campo Redondo	Amazonas	S6°13'00" W78°19'47"	1350	<i>A. miconax</i>	Shade coffee plantation	n/a	Continual field work	X				X	
Rio Nieva	Amazonas	S5°34'31" W77°50'54"	1750	<i>A. miconax</i>	Montane/ Lightly disturbed	Contiguous	4 nights/1 vifts	X	X			X	
Cordillera Escalera	San Martin	S6°27'45" W76°17'23"	1250	<i>Aotus</i> sp.	Pre-montane/ Lightly disturbed	Contiguous	Continual field work	X	X			X	
Breo	San Martin	S7°08'41" W77°29'35"	3000	X	Montane/ Primary forest	Contiguous	5 nights/1 visit						
Cordillera de Colan	Amazonas	S5°34'32" W78°14'40"	3100	<i>A. miconax</i>	Scrub/ Montane	Contiguous	Continual field work	X	X		X		
Pucunucho	San Martin	S7°13'46" W76°45'22"	350	X	Secondary forest/ Fragmented	Fragment 23.5ha	Continual field work						
Monzon	Huánuco	S9°15'29" W76°23'36"	1200	<i>Aotus</i> sp.	Pre-montane/ Moderately disturbed	Contiguous	2 nights/1 visit					X	
Gira-Sisa	San Martin	S6°17'34" W76°54'24"	1000	<i>A. nigriceps</i>	Pre-montane/ Disturbed	Contiguous	2 nights/1 visit	X	X			X	
Corosha	Amazonas	S5°47'43" W77°47'12"	2100	<i>A. miconax</i>	Montane/ Lightly disturbed	Contiguous	Continual field work	X	X			X	
Churuja	Amazonas	S6°01'03" S W77°57'20"	1200	<i>A. miconax</i>	Pre-montane/ Fragmented	0.5 – 5 ha	Continual field work					X	Captive individuals
Pomacochas	Amazonas	S5°49'25" W77°58'08"	2100	<i>A. miconax</i>	Montane/ Fragmented	Contiguous/ Fragmented	Continual field work					X	Skins
Jumbilla	Amazonas	S5°54'30" W77°47'54"	2000	<i>A. miconax</i>	Montane/ Fragmented	Contiguous/ Fragmented	2 nights/2 visits					X	Skins
Abra Patricia	Amazonas	S5°41'52" W77°48'38"	2100	<i>A. miconax</i>	Montane/ Moderately disturbed	Contiguous	2 nights/1 visit	X			X	X	
Huiquilla	Amazonas	S6°23'22" W77°59'25"	2600	<i>A. miconax</i>	Montane/ Moderately disturbed	Contiguous	3 nights/1 visit				X	X	
Sacha Runa	San Martin	S6°42' 55" W76°06'09"	1600	X (<i>A. nigriceps</i> at lower elevations)	Montane	Contiguous	5 nights/1 visit					X	

*Determined by elevation, geographic location, habitat type and confirmed reports from neighboring contiguous areas.

** Approximate average of survey site

***n/a = Campo Redondo, the species was not found in forest.

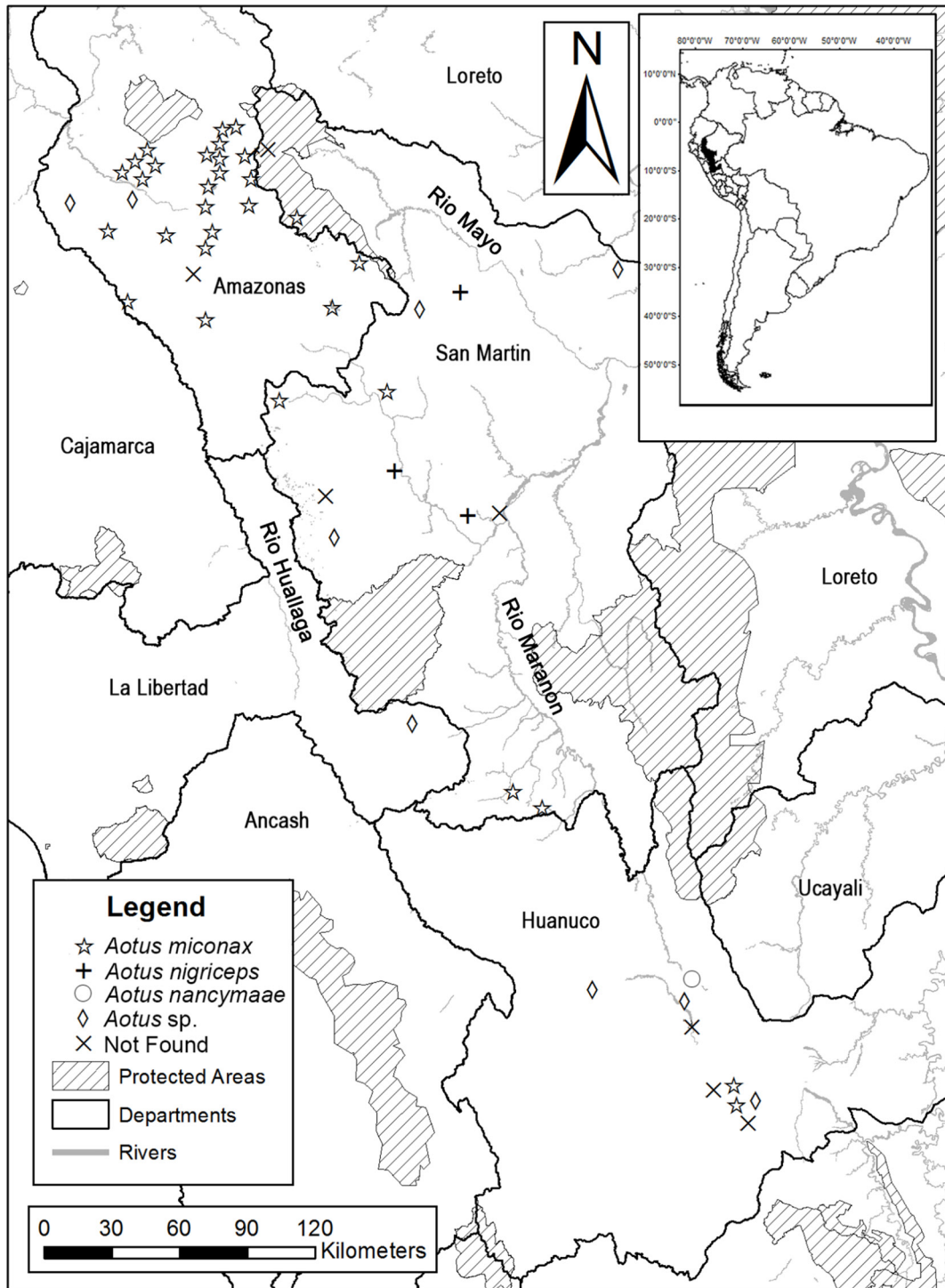


Figure 1. Survey sites showing localities of *Aotus miconax*, *A. nancymaeae*, *A. nigriceps* and *Aotus* spp.

Habitat modelling

The final ecological niche model for *Aotus miconax* using Maxent Program (Phillips et al. 2006) gave a ROC (Receiver Operating Characteristic) curve AUC (Area Under Curve) of 0.986 for training data and 0.978 for test data. Minimum training presence was 0.053, and

its value of statistical significance for presence in the binomial test of omission was 0.067 ($p = 6.182 \cdot 10^{-39}$). Results of the jack knife test showed the environmental variable with highest gain (had the most information when used in isolation) when used alone was precipitation of the wettest quarter. The environmental

Table 2. Selected bioclimatic variables used in ecological niche analysis

BioClim Variable	Variable value	Details
Bio 1	Annual mean temperature	
Bio 2	Mean diurnal temperature range	Mean of monthly Max/Min
Bio 7	Annual temperature range	Max temperature-Min temperature
Bio 8	Mean temperature of wettest quarter	
Bio 9	Mean temperature of driest quarter	
Bio 10	Mean temperature of warmest quarter	
Bio 11	Mean temperature of coldest quarter	
Bio 12	Annual precipitation	
Bio 15	Precipitation seasonality	Coefficient of variation
Bio 16	Precipitation of wettest quarter	
Bio 17	Precipitation of driest quarter	
Bio 18	Precipitation of warmest quarter	
Bio 19	Precipitation of coldest quarter	

variable that decreased gain the most when omitted (had the most information not represented by the other variables) was the vegetation layer (Olson et al. 2001).

When clipped to within known geographical boundaries, and including all cells with training presence ≥ 0.1 , the total original possible extent of occurrence of *A. miconax* was estimated to be 32,993km². This area was reclassified into three levels representing low, medium and good probabilities for the presence of *A. miconax* (0–19.9 %, 20–49.9 % and >50%). Excluding areas of lowest probability the original extent of habitat was estimated to be 25,144km², of which only 6,314km² was in the top category (Fig. 2a). Using data from Hansen et al. (2013) we removed areas with $\leq 50\%$ forest cover (including estimates of forest loss and gain between 2000–2012), extent of available habitat with >50% forest cover for the three probability levels is 27,237, 20,794 and 5,134 km², giving an average estimate of remaining habitat of 17,721, or 53% (Fig. 2b).

Using a minimum estimate of anthropogenic habitat disturbance, $\leq 1\text{km}$ away from areas of human settlement and highways, the estimated area of occupancy available for *A. miconax*, habitat that showed little or no disturbance and where hunting pressure is estimated to be low was 24,854, 18,795 and 4,341km², giving an average estimate, including a lightly disturbed habitat area, of 15,996km², or 48% of the original extent (Fig. 2c). With a maximum estimate of anthropogenic habitat disturbance and hunting, $\leq 5\text{km}$ away from areas

Table 3. Predicted extent of occurrence for *Aotus* spp. based on Rowe & Myers (2012).

Species	Estimated extent of occurrence (km ²)
<i>Aotus brumbacki</i>	514,354
<i>Aotus griseimembra</i>	192,758
<i>Aotus herskovitzi</i>	5,576
<i>Aotus jorgehernandezi</i>	1,196
<i>Aotus lemurinus</i>	57,339
<i>Aotus miconax</i>	27,558
<i>Aotus nancymae</i>	250,597
<i>Aotus nigriceps</i>	1,756,658
<i>Aotus trivirgatus</i>	757,534
<i>Aotus vociferans</i>	1,181,514
<i>Aotus zonalis</i>	188,943

of human settlement and highways, undisturbed habitat remaining for *A. miconax* for the three probability levels is 10,705, 7,884 and 1,202 km², giving an average estimate of undisturbed habitat of 6,627km², or just 20% of the original extent (Fig. 2d). Averaging the three different estimates of habitat loss/disturbance gives an estimate of 13,448 km², or 40%, of remaining habitat.

Estimates of the area of occurrence of *Aotus* spp. using existing distribution maps (Rowe & Myers 2012) varied greatly between species. *A. jorgehernandezi* and *A. herskovitzi* were predicted to have had the smallest historical distributions, 1,000 and 5,000 km² respectively. Whilst *A. nigriceps* and *A. vociferans* had predicted ranges many times larger (Fig. 3 and Table 3). *A. azarai* was not included in analysis as its habitat is naturally fragmented and in many areas restricted to gallery forests (Fernandez-Duque et al. 2001) making predictions from available maps very inaccurate.

Fragmentation

Levels of fragmentation of *Aotus miconax* habitat were extremely high. Our estimate of available habitat included 73,639 fragments, average fragment size was 6.8 ha (min <1, max 62,060ha, ± 324.21). Using our three thresholds (>1.25ha, >50ha and >10,000ha) there were 22,590 fragments, average size 20.7ha (min 1.25, max 62,060, ± 585), 222 fragments, average size 669.8ha (min 50.36, max 62,060, ± 3751) and 7 large areas as possible conservation units >10,000ha, average size 27,907ha (min 11,208, max 62,060, $\pm 17,904$) respectively. Our analysis of connectivity (areas of forest separated by $\leq 200\text{m}$) gave no areas <1.25ha. The total number of fragments was 3,488, of which 3,294 were between 1.25–50 ha in size, average 6.998ha (min 1.25, max 49.9,

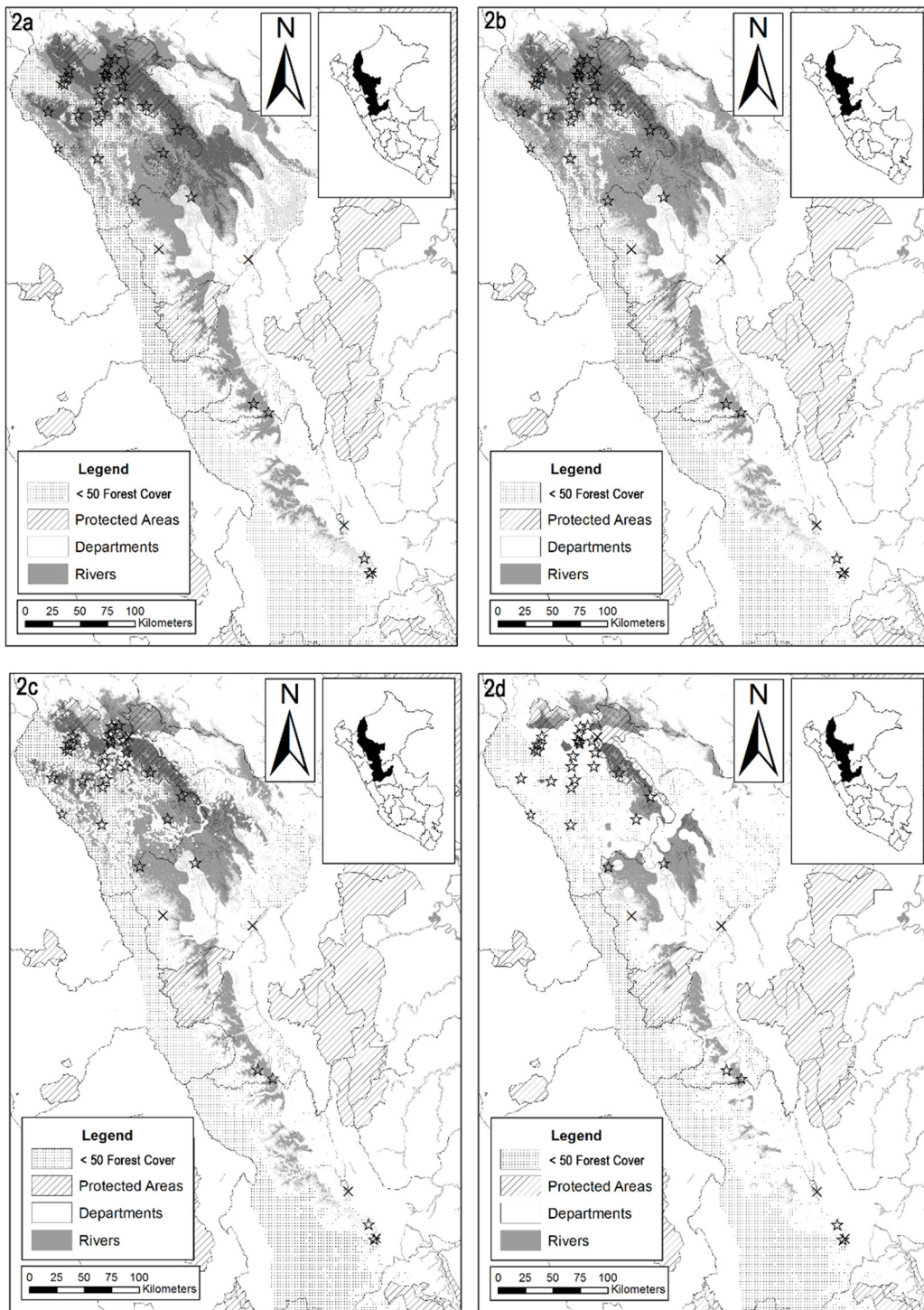


Figure 2. Predicted habitat for *A. miconax* based on maximum entropy ecological niche modelling:
 2a - original extent of *A. miconax* habitat; 2b - estimated current extent of *A. miconax* habitat based on deforestation estimates from the Global Land Cover 2009 assessment; 2c - estimated current extent of *A. miconax* habitat including 1 km buffers around human settlements and highways; 2d - estimated current extent of *A. miconax* habitat including 5km buffers around human settlements and highways.

±7.91). Using the two remaining thresholds there were 190 fragments, average size 256ha (min 50.5, Max 5,287, ±596.98) and four large areas as possible landscape level

conservation units: 180,600, 239,100, 271,600 and one of 2,219,000ha respectively.

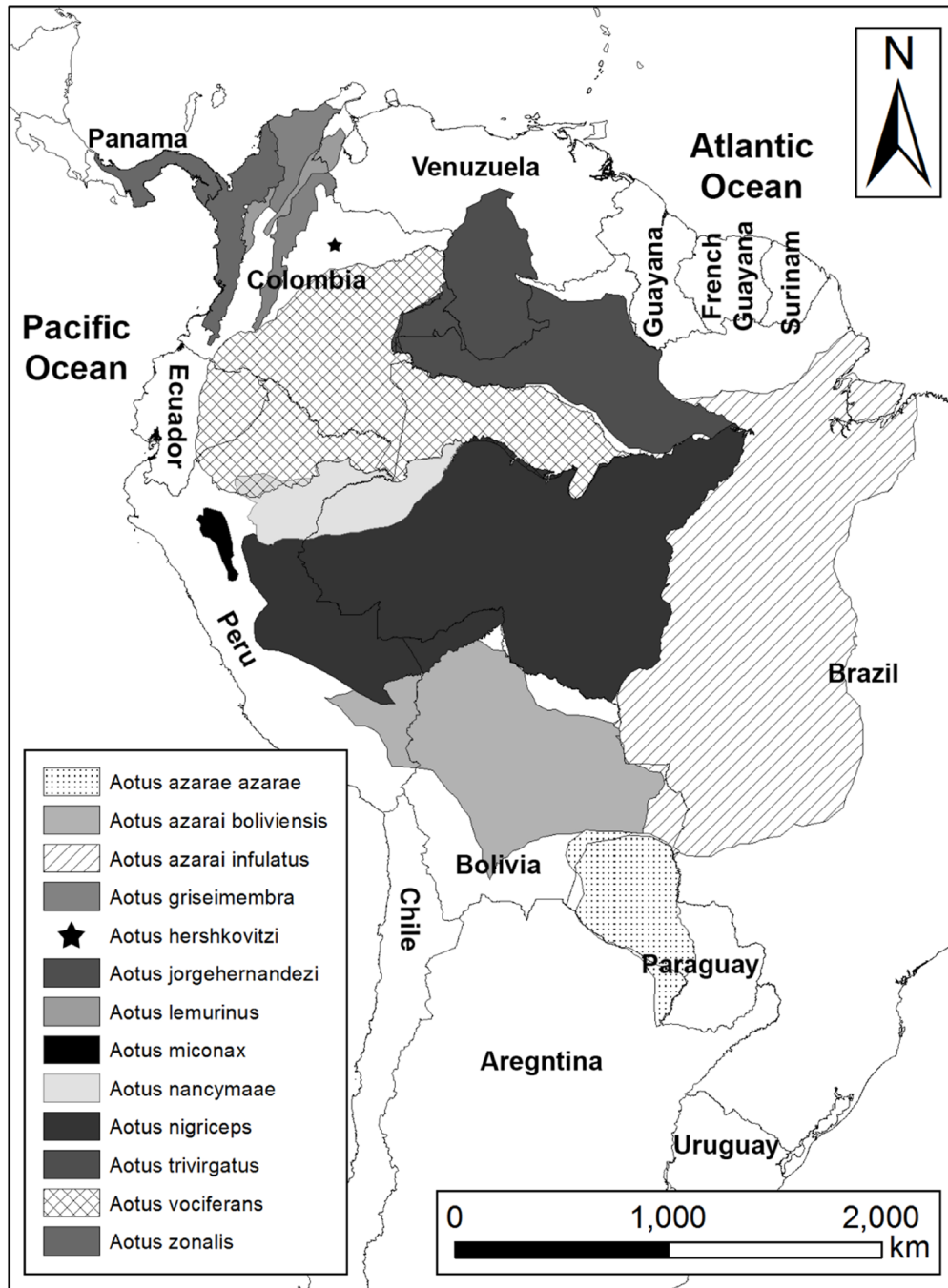


Figure 3. Predicted distributions of *Aotus* taxa based on Rowe & Myers (2012).

DISCUSSION

No previous reliable range estimates or distribution surveys exist for *A. miconax*. This species' endemism and specialized habitat preference to mid and high elevation forest results in naturally restricted distribution and an increased risk from anthropogenic and natural extinction pressures (Pimm et al. 1988; Purvis et al. 2000; Laurance

et al. 2002; Zeigler et al. 2013). The species original extent of occurrence, estimated here at between 25,144–32,993 km² is larger than predictions for Peru's other attitudinally restricted endemic primates, the Yellow-tailed Woolly Monkey *Lagothrix flavicauda* and the San Martin Titi Monkey *Callicebus oenanthe* (Luna 1987; Hershkovitz 1949–1988 cited in Ayers & Clutton-Brock 1992; Buckingham & Shanee 2009; Shanee et

al. 2011), although the methods used to model these distributions was crude (Buckingham & Shanee 2009; Shanee et al. 2011).

The cryptic nature of *Aotus*, their small size and nocturnal habits, make field surveys particularly difficult (Fernandez-Duque 2011). This and the physical similarity between species also make field identification difficult. We made every effort to correctly identify to species level, comparing published accounts and photographs with our field observations. Whenever possible we triangulated identification between field sightings, vocalizations, revision of skins and captive individuals, interviews and proximity to known localities. We were able to identify the majority of our sightings to the species level. However, we were still unable to identify which species of *Aotus* spp. were present at nine of the sites we surveyed (Table 1). It is possible that several of these will also be *A. miconax* (Table 1) although further study is required to confirm this.

We found evidence of *Aotus* spp. at most survey sites. The use of existing trails and surveying fragmented habitat could have reduced the possibility of encountering animals at the other sites (Shanee 2011). However, small body size and nocturnal habits probably make *Aotus* spp. less susceptible to anthropogenic disturbance and we were able to find *Aotus* spp. in many highly disturbed areas and small forest fragments, including coffee plantations. As with previous surveys in this area of Peru (Bóveda-Penalba et al. 2009; Shanee 2011) our choice of survey sites was non-stratified, visiting sites with existing access routes; although some sites were up to two days walk from the nearest road. In most cases the presence of *Aotus* spp. in disturbed habitat would suggest its presence in neighbouring primary forest areas.

Aotus miconax appears to be able to adapt to anthropogenic habitat disturbance (Shanee & Shanee 2011; Sanchez-Larranega & Shanee 2012; Shanee et al. 2013). During our surveys we found the species in many disturbed and fragmented sites (Table 1). Similarly this species seems to utilize a variety of natural habitat types including; *Ficus* spp., *Podocarpus* spp., montane and pre-montane, white sand, palm dominated and *Alzatea verticillata* dominated forests although how much the species utilizes these areas is unknown. At Breo and Venceremos, two largely undisturbed and protected sites, the probable absence of *A. miconax* suggests that some undefined habitat characteristic is important in determining this species micro-level distribution.

We also recorded the presence of *Aotus nancymae* and *A. nigriceps* at two sites in San Martin and Huánuco.

A. nancymae was present at the Serpentario in Tingo Maria (Table 1), an area far to the south of its known distribution (Aquino & Encarnacion 1994; Rowe & Myers 2012). It is probable that our records from other low lying areas, <1,000m, of Huánuco are also *A. nancymae*, as well as records to the west of the Rio Huallaga in San Martin. This extends the known distribution of this species several hundred kilometres to the south along a narrow band of forest between the Rio Huallaga and the Andean foothills. Our record of *A. nigriceps* at Gera-Sisa is also outside of the species know distribution to the east of the Rio Mayo in northern San Martin (Shanee et al. 2013).

The distributions of *Aotus miconax*, *A. nancymae* and *A. nigriceps* are probably limited by physical barriers, less defined ecological barriers and competitive exclusion. *A. miconax* is limited in the west, north and east by the lowlands of the Rio Marañon and Rio Huallaga. We suggest that the Rio Huallaga constitutes the major geographical barrier restricting the distributions of *A. nancymae* and *A. nigriceps* in central San Martin. The southern distribution of *A. miconax* is less well defined; reductions in ecological niche suitability and competitive exclusion with *A. nancymae* and/or *A. nigriceps* are the most likely barriers although the exact limits of the species distribution are still unknown.

We believe that this study is the first predictive model of the distribution of *Aotus miconax*. Our model gave good AUC values, the similarly high values for both test and training data suggest that the model is not overfitted and will have good predictive power (Peterson et al. 2007; Merckx et al. 2011). Ecological niche modelling doesn't consider physical barriers to species distributions. Similarly Maxent has been shown to overestimate distributions, especially with large calibration area (Giovannelli et al. 2010). In our analysis Maxent predicted an ecological niche that included areas as far as northern Ecuador, far outside the species historical distribution (Aquino & Encarnacion 1994). We were able to eliminate this problem by clipping the predicted distribution within known geographical barriers.

The robustness of results from any predictive modelling technique depends largely on the quality and accuracy of data and environmental layers available (Hernandez et al. 2006; Elith & Graham 2009; Giovannelli et al. 2010). Maxent has consistently been shown as one of the most robust ecological modelling algorithms (Elith et al. 2006; Guisen et al. 2007; Elith & Graham 2009; Giovannelli et al. 2010). However, Maxent has been shown to be sensitive to spatial resolution, threshold selection,

calibration area, spatial correlation and accuracy of location data (Elith & Graham 2009; Norris et al. 2011; Bean et al. 2012). Even though the spatial resolution we used ~1ha is very detailed, most environmental layers were resampled from lower spatial resolutions reducing accuracy, however this was necessary to include greater resolution on altitudinal data from the ASTER DEM layer. Even so, at this resolution our model should include all but micro-scale gradients in habitat heterogeneity (Elith & Graham 2009). Our minimum predictive threshold, i.e., those areas with ecological conditions where the species presence was confirmed, was very accurate, training threshold <0.1%. Similarly the accuracy of our location data, coming from our multi-year field surveys and not collections or online databases, was extremely high further increasing the robustness of our model (Bean et al. 2012) and the use of a reduced calibration area will also reduce the possibility of erroneous predictions (Giovannelli et al. 2010).

The predicted historical distribution (maximum extent of occurrence) of *Aotus miconax* we present is one of the smallest of any *Aotus* species, between 25,144–32,993 km². Accurate distribution maps for other *Aotus* spp. are not available. Using information given in Rowe & Myers (2012) we estimate that only *A. jorgehernandezi* and *A. hershkovitzi* had smaller historical distributions, of 1,000 and 5,000 km² respectively. Most other *Aotus* spp., such as *A. nigriceps* and *A. vociferans*, have distributions that are many times larger (Hershkovitz 1983; Rowe & Myers 2012), although our estimates (Table 3) are very crude and don't take into account details of habitat type and availability. Based on our results *A. miconax* now has a much-reduced distribution, extent of occurrence and area of occupancy. Including our analysis of fragmentation, the area of contiguous forests that currently support populations of *A. miconax* are further reduced. Few areas of over 10,000ha, capable of supporting large, sustainable populations, were found further reducing effective population sizes. The area covered by aggregated fragments ≤200m apart was much larger but much of these areas are not suitable as conservation units as they are highly populated.

Deforestation, habitat disturbance and hunting are major threats to all primate species. *Aotus* spp. are similarly threatened by these anthropogenic pressures (Redford & Robinson 1987; Shanee 2012b). Levels of deforestation and habitat disturbance in our area were high, with all sites showing at least low levels of disturbance or hunting (Table 1). Our evaluation of habitat loss show that *A. miconax* should be classified as Endangered on the IUCN Red List (IUCN 2001). Our

estimate of only 53% of total original habitat remaining for the species is based on data that do not give enough detail on fragmentation, with some areas classified as forest but are actually heavily fragmented (Sam Shanee pers. obs.). By including extra data on proximity to human settlement, as a measure of fragmentation, estimates of remaining habitat is further reduced. Our 5km buffer is not a good estimate of fragmentation or habitat loss alone, but can be accurate for estimating areas of high hunting pressure (Peyton et al. 1998; Peres 2001;) and is useful for predicting hotspots of future habitat loss. Conversely, the 1km buffer probably underestimates the effects of proximity to human settlement on forests in all but the least densely populated areas. An intermediate distance would be more accurate in representing actual fragmentation and hunting, resulting in habitat loss over the 50% required by the IUCN Red List categories (IUCN 2001). This will still be an underestimate as our data on human settlement, from the Peruvian Ministry of Education, only includes villages with schools, indicating that the actual number of human settlements, and therefore habitat loss, will be greater. To date the majority of habitat loss has been in peripheral areas of *A. miconax* distribution. During this and previous surveys (Shanee 2011) we found many new roads under construction, some of which are now completed. This opens new areas of forest to logging, hunting and settlement, which will accelerate future habitat loss. There are several protected areas within the range of *A. miconax*, although only small portions of these are suitable habitat for this species. Also, many of these suffer from the same problems as surrounding unprotected areas (INRENA 2008; Shanee 2011; Shanee 2012a).

As in previous studies, we found that *A. miconax* has shown adaptability to anthropogenic habitat disturbance (Cornejo et al. 2008; Shanee & Shanee 2011; Sanchez-Larranega & Shanee 2012; Shanee et al. 2013). This was also true for *A. nancymae* and *A. nigriceps* which we found persisting in disturbed and fragmented areas (Table 1), although we suggest that this is probably true for areas of low hunting pressure only. Hunting has been known to cause localized extinctions of neotropical primate species in fragmented areas, and even in large areas of contiguous forest (Redford & Robinson 1987; Bodmer et al. 1997; Peres & Dolman 2000; Peres 2001; Michalski & Peres 2005). Nocturnal habits, small body size and sub-caudal scent glands make *Aotus* spp. less desirable, and therefore less susceptible, to hunting than larger bodied diurnal primates (Noga Shanee pers. obs.). Even so, we found many cases of hunting of *A.*

miconax, as have previous studies of hunting in the area (Shanee 2012b). Hunting of *Aotus* spp. is likely to increase as populations of more desirable species are reduced in parallel with increasing human populations and expansion of the agricultural frontier (Peres 2001; Remis & Robinson 2012).

Until recently the regions where *Aotus miconax* populations were found remained largely unsettled because of their natural inaccessibility and socio-political unrest (Shanee 2011; Shanee 2012a) from Maoist guerrilla groups, and coca (*Erythroxylum coca*) cultivation (Young 1996; Schjellerup 2000; Shanee 2012a). Even in these areas habitat destruction is now a major threat. Immigration has led to the clearance of many more accessible areas and the expansion of mining and large scale monocultures mean this immigration is now reaching higher into the Andean foothills (Noga Shanee pers. obs.). The patterns of human development and settlement have, as in many areas (Wade et al. 2003), led to the fragmentation of remaining *A. miconax* habitat.

Our results provide much needed information on the distribution of *Aotus* spp. in northeastern Peru and an evaluation of the actual conservation status of *A. miconax*. The current Red List status (Vulnerable A2c IUCN 2012) underestimates actual habitat loss and disturbance. The sympatric *Lagothrix flavicauda* is listed as Critically Endangered (CRA4c) under the same categories and has been considered one of the World's Top 25 Most Endangered Primate Species several times (Mittermeier et al. 2012). Similarly, *Callicebus oenanthe*, which suffers from similar levels of hunting and habitat loss (Shanee et al. 2011; Shanee 2012b) as *A. miconax* is considered CR (IUCN 2011) and as one of the Worlds Top 25 Most Endangered Primate Species for the second time (Schwitzer et al. 2014). Our estimate of up to 62% habitat loss, with much of the remaining habitat highly fragmented and hunted shows that *A. miconax* should be categorized as Endangered under criteria A2ac+A3c+4ac of the IUCN Red List categories (IUCN 2011) based on a decline in area of occupancy.

Further field studies are needed to determine the southern extent of the distribution of *Aotus miconax*. Also, which habitat characteristics determine the micro-level distributions of *Aotus* spp., as well as studies on ecology, population densities and genetic variability. As with all models, ours was limited by the quality of data available. However, we feel it is largely accurate and provides important information from which to base subsequent surveys and conservation actions. With developments in modelling additional modelling

algorithms could be used with finer resolution geographical data when available. Combining this with additional presence and, if possible, absence data would produce more robust models and the use of additional algorithms could increase confidence in predictions. We also highlight the need for further work in karyotyping the various Peruvian *Aotus* spp. which would greatly aid in identification, allowing for better knowledge of diversity and distributions.

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Spanish Abstract: Resumen: *Aotus miconax* es endémico al Perú y una de las especies menos estudiadas de todas las taxas de primates neotropicales. *Aotus miconax* tiene una distribución restringida altitudinalmente y está limitado a áreas premontanas y montanas de bosque nublado. La deforestación en el área es la más alta en el país. En muchas áreas la deforestación ha dejado que poblaciones de *A. miconax* estén persistiendo en fragmentos de bosques aislados y enfrentan una alta presión de caza. Nuestro objetivo es reunir información en la actual distribución de *A. miconax* y otras especies de *Aotus* en el noreste del Perú. A través de entrevistas de campo encontramos evidencia de la presencia de *Aotus* spp. en 44 localidades del departamento de Amazonas, Huánuco, La libertad y San Martín, incluyendo 23 observaciones visuales y cuatro detecciones auditivas y por evidencia secundaria por al menos 17 lugares. *Aotus miconax* estuvo presente entre 1200 y 3100 m.s.n.m. Combinando GIS y un modelo máximo nicho de entropía ecológica predecimos la original distribución de *A. miconax*. También evaluamos el nivel de fragmentación y la amenaza antropogénica que enfrentan estas especies. Nuestro resultado demuestra que la area de ocupancia de *A. miconax* está reducida y las amenazas antropogénicas son severas e incrementando. El último estado de la RedList (VU) menosprecia la actual perdida de hábitat y perturbación. Especies simpátricas las cuales sufren de un nivel similar de caza y pérdida de hábitat están consideradas En Peligro Crítico y basado en nuestra estimación de ~ 60% perdida de hábitat, con más de la restante alta fragmentación de hábitat; recomendamos que *A. miconax* este clasificado como En Peligro.

