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Assessing the impact of sustainable logging on arboreal primates: Occupancy modelling of the critically endangered brown-headed spider monkey (*Ateles fusciceps fusiceps*).

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Abstract

Occupancy modelling is a presence/absence survey technique based on fixed point sampling that overcomes many logistical limitations of standard primate survey techniques. Our aim was to identify habitat factors that affect the presence of the critically endangered brown-headed spider monkey (*Ateles fusciceps fusciceps)* in a matrix of sustainably logged and primary forest in Tesoro Escondido (Esmeraldas, NW Ecuador). Using occupancy modelling we quantified occurrence and distribution of *A. f. fusciceps* based on presence/absence surveys undertaken between May-July 2013. Both primary and logged areas were occupied with *Ateles f. fusciceps* and they were detected at 29/71 sites (naïve occupancy estimate=0.41). Tree density and altitude were significant indicators of presence, with primary forest sites and lower altitudes associated with higher detectability. Even replication across sample sites generated the highest detectability, with 5 site repeats found most cost-effective. Occupancy in logged sites is slightly lower than in primary sites suggesting that the spider monkey may be able to persist in this mosaic habitat, however it is likely to be the ratio of primary to selectively logged habitat that determines long term survival as loggers target key fruiting trees also favoured by *A. f. fusciceps* (i.e. *Brosimium utile*). It is suggested that future field studies incorporate occupancy modelling to investigate distribution and impacts of hunting and habitat degradation on remaining populations of *A. f. fusciceps*. Occupancy modelling provides a particularly powerful tool to investigate impacts of habitat degradation and hunting on arboreal mammals in difficult terrain.

Keywords

Ecuador, Chocó, Conservation, Detectability.

Introduction

Primates are increasingly coming in closer contact with humans, and their presence in and close to anthropogenically altered habitats is becoming more common (Estrada and Coates-Estrada, 1996). The need to study primates in such habitats (Baker et al., 2011) and understand how anthropogenic factors such as habitat degradation and loss affects them is of increasing importance for the development of effective conservation action plans. Focusing on studying changes in primate distribution and abundance in response to environmental change provides the scientific understanding needed to underpin effective species-specific conservation action plans, particularly for endangered primates.

The brown-headed spider monkey (*Ateles f. fusciceps*) is endemic to northwest Ecuador (Peck et al, 2011), however an 80% reduction in its historic distribution due to agricultural expansion, logging and hunting (Tirira, 2004) have placed it on the Primates in Peril top 25 most endangered primates list (Mittermeier et al, 2012). It is listed by the IUCN as Critically Endangered, due to an estimated 80% decline in population size over the last 45 years (Cuarón et al, 2008) making the development of effective species action plans imperative to bring this species back from the brink of extinction. Previous work has identified areas of importance for the survival of these spider monkeys in several unprotected areas in NW Ecuador - with a particularly important site at Tesoro Escondido (Esmeraldas Province NW Ecuador), a community of colonist landowners where primary forest still remains and hunting does not currently occur (Moscoso, 2010; Peck et al, 2011).

With commercial logging companies in lands surrounding Tesoro Escondido, and sites of historically logged areas in Tesoro Escondido, we were interested in determining the effects of sustainably logged areas on habitat use by *A. f. fusciceps*. We hypothesized that the spider monkeys would prefer areas of lower elevation (Peck et al. 2011), and that logging would be the strongest predictor of presence in an area as previous studies have shown that spider monkeys prefer mature primary forest (van Roosmalen and Klein, 1988; Aldana et al, 2008), tending to disappear from disturbed forest (Estrada et al, 2004; Aldana et al, 2008; Asensio et al, 2012

Occupancy modelling is a presence/absence survey technique that is based on fixed point sampling. A series of points are visited for a minimum of three repeats (MacKenzie and Royle, 2005) for a set duration of time. Occupancy refers to the number of sites that are being occupied by a species (Guillera-Arroita et al, 2010). However, due to the difficulty in being certain that a point is occupied, the definition also applies to sites that are being used by a species. Modelling occupancy has been used to study several primate species (lemurs; Guillera-Arroita et al, 2010; Keane et al, 2012; gibbons; Gray et al, 2010; Neilson et al, 2013; owl monkeys; Campbell, 2010; Sclater's monkey; Baker et al, 2011). In most of these studies primates occurred in areas that were difficult to study using other survey methods. For instance, Guillera-Arroita and colleagues (2010) studied lemurs in marshy areas by canoe. Occupancy models both occupancy and detectability (MacKenzie et al, 2006). Modelling detectability eliminates false absences that can occur in presence-absence surveys (MacKenzie et al, 2006) when animals are not encountered during the survey period but occupy the survey area. Occupancy modelling is based on a series of assumptions. Sites must be closed to changes in occupancy during the survey season, the species is always identified correctly, and all sites are independent of one another (MacKenzie et al, 2002). The aim of this investigation was to identify which habitat factors affect the presence of *A. f. fusciceps* in Tesoro Escondido using occupancy modelling to aid in the development of a conservation action plan for this critically endangered species.

Methods

Study Site: Tesoro Escondido

Tesoro Escondido is a cooperative of landowners located in the Canande watershed, part of the Cotacachi-Cayapas Ecological Reserve (RECC) buffer zone in Esmeraldas Province, NW

Ecuador (79° 9' 32.37" W 0°27' 21.16"N, Figure 1). The cooperative spans an area of 30 km^2, and all land in Tesoro Escondido is privately owned by 42 families, and houses 10 of these families. The lowland evergreen forests are interspersed with selectively logged forest and deforested areas. Logging is performed for wood extraction, cattle farming and agricultural practices such as cacao farming. Selective logging is also carried out using cables (Figure 2) by the timber company EcoMadera. This is a sustainable timber extraction method in which the trees are extracted from the forest by use of cables instead of the widely used, and more destructive, bulldozers. Logging using cables and a portable sawmill (EcoMadera Forest Conservation, 2013) last took place between 8-9 months ago. Habitat loss and degradation are the primary conservation threats in Tesoro Escondido. Tesoro Escondido was selected as the study site because previous studies have shown that it houses the highest density of *A. f. fusciceps* in NW Ecuador at 8.5 individuals per km^2 (Moscoso, 2010) and 7.5 individuals per km^2 (Peck et al, 2011).

Occupancy Modelling

Occupancy by brown-headed spider monkeys in Tesoro Escondido was modelled using a single-season standard occupancy model. Seventy one occupancy points were distributed amongst 4 pre-existing trails (table 1). At each point, covariates of occupancy were measured; tree density, canopy connectivity, altitude and tree diameter at breast height (DBH). These measurements were taken only once for each point. Points were visited during the months of May-July 2013, the Ecuadorian summer, thereby assuming that the points were closed to changes in occupancy, one of the assumptions of the model (MacKenzie et al, 2006; Guillera-Arroita et al, 2010). Points were visited for 10 minutes during each repeat. We placed survey points every 200 meters along the four trails A, B, C and D to limit overlap between the points, thereby ensuring independence of the occupancy sites (MacKenzie et al, 2006). The trails were flanked by steep declines at several points and therefore the terrain was too difficult to place the points randomly. The nearest tree at each point was flagged to ensure that the same point was visited on subsequent visits. During each visit, records were made of the time of day, the climate, and whether after 10 minutes the point was considered to be occupied. A point was considered occupied by *A. f. fusciceps* if they were seen (visual sighting) or heard (audio) less than 100 m away (to avoid overlap between the points). Due to the difficulty of distinguishing primate bite marks from other mammal species present in the forest, consumed fruits were not included as a way to determine site occupancy.

Covariates were measured to address the assumptions that changes in occupancy and detectability across points can be explained by factors of habitat and weather (Baker et al, 2011). We predicted that canopy cover, altitude, tree density, tree height, tree diameter at breast height (DBH), and logging would affect occupancy, and that weather would influence the probability of detecting spider monkeys at a site. We also modelled other habitat characteristics as measures of detectability as, for example, the removal of trees by logging creates clearances that can enhance vision and increase the chance of spotting the spider monkeys (Figure 2). Because covariates influence one another, in the aforementioned example, models were run using all two x two combinations of covariates.

We measured canopy cover by placing a 1cm x 1cm square grid over the cut off end of a 2 L plastic bottle and counting the number of complete squares through which leaves were visible. Canopy cover was calculated as a percentage of total grid cover. Where possible, only the top levels of the canopy were included in the analysis. The lower levels of the canopy were ignored. We took GPS readings using a Garmin HCx GPS (±3m accuracy) at each occupancy point to measure altitude, with an accuracy of <8 m in a vertical plane. Additionally, at all occupancy points we recorded weather using a 0-5 scale; with 0=heavy rain, 1, little rain, 2=cloudy, 3=partially cloudy, 4=some clouds and clear sky, 5=very sunny. The density of trees was estimated using the point-quarter method (Setchell et al, 2011) around the flagged tree marking the occupancy point. At each quarter point we only recorded trees with a minimum circumference of 15 cm (the minimum size reported as used by *A. f. fusciceps)*. We also estimated tree height and DBH for the four trees at each point. All data were collected with the help of locally trained and employed parabiologists. Parabiologists are members of the local community that were trained in data collection methods. This approach also provides alternative livelihoods and enhances local conservation awareness.

Data Analysis

We first carried out Chi-square tests to determine whether there was a difference between the number of spider monkeys observed in the morning and the afternoon (with significance set at the $p<0.05$ level). Covariates included in analysis were; tree density, DBH, forest type, canopy connectivity, weather and altitude. Forest type refers to areas that showed any signs of logging within a 50m radius of the occupancy point. For instance, the presence of logging cables, sustainably logged areas and secondary forest. It also included areas that had been completely logged such as pastures. We calculated the median for weather at each site for all the visits to the site. We normalised covariate data using the equation $Log^{10}(x +1)$, where x represents the covariate value at the site, before entering the data into the model. The log transformation did not normalize the altitudinal data and therefore we entered the data into the model as non-normal data.

3.3.4 Occupancy modelling

Sites were visited between 5 and 10 times. A detection history (H_i) was created by assigning a 1 to sites that were occupied and a 0 to those that were not (Guillera-Arroita et al, 2010) and the predicted detection history (MacKenzie et al, 2002; MacKenzie et al, 2006) used to devise a probability model with parameters ψ_i and p_i. ψ_i refers to the probability that the spider monkeys are using a site of interest (i), i.e. that the site is occupied. p_i refers to the probability of detecting the spider monkeys at the site, if they use the site of interest (MacKenzie et al, 2002). Detection histories for each occupancy site were combined to create a maximum likelihood model using the program PRESENCE 5 (Bailey and Adams, 2005).

We used the detection histories for *A. f. fusciceps* to run a fixed model in which ψ and *p* were kept constant. We ran this for all replicates, all sites with 10 replicates, and all sites with only 5 replicates. Covariates were then added to the model to determine what factors affect presence of *A. f. fusciceps*. Covariates included: altitude, forest type, tree DBH, tree density, weather, and canopy connectivity. We ran models with covariates for all sites with 5 replicates to ensure that the 71 study sites could all be included in the model, and that a difference in survey effort did not bias results. We determined the best fit model using Akaike Information Criterion (AIC; MacKenzie et al, 2006; Mazerolle, 2006). We selected the top 8 models that were within 4 AIC units difference from the top ranking model (Campbell, 2010; Guillera-Arroita et al, 2010). We tested model fit using

parametric bootstrapping (100 runs) and a Pearson's chi-square test (MacKenzie and Bailey, 2004).

Results

Every occupancy point was visited between 5 and 10 times with a mean of 7.8 visits with survey effort summarised in Table 1. After 99 hours and 30 minutes of surveying, *A. f. fusciceps* was seen on 32 occasions and heard at a distance of <100 m three times. This includes repeated sightings of some groups. The animals were detected at sites between 6:34 in the morning and 15:12 in the afternoon (Figure 3). There was a significant difference between the number of monkeys detected and the number of monkeys that were expected to be observed throughout the day(X^2= 25.847, d.f.=3, $p<0.001$).

Ateles f. fusciceps were detected at 29 out of 71 sites in Tesoro Escondido, giving a naïve occupancy estimate of 0.4085. The model in which occupancy and detectability were kept constant ($\psi(.)p(.)$), gave an occupancy estimate of 1.0 and a detectability estimate of 0.059. An occupancy value of one indicates that all occupancy points should have been occupied or used by the spider monkeys, and that a lower naïve occupancy value means that not all animals were detected. Detectability could have been influenced by forest structure, observer error or time of site visit. When occupancy was modelled for the first 5 site repeats, naïve occupancy fell to 0.32, as spider monkeys were seen or heard only 23 times at 71 occupancy points. Occupancy remained constant at 1 for $\psi(.)p(.)$ and detectability with 5 site repeats was 0.068. This is higher than with a range of 5-10 site repeats. Occupancy was subsequently modelled with 10 site repeats for 29 sites. Naïve occupancy was 0.52, as spider monkeys were seen or heard 20 times. Occupancy for the fixed model came out as 1.0 and detectability was 0.069. Though occupancy values stayed the same when modelling with different site repeats, the detectability increased when keeping site repeats constant across sites and when performing many repeats.

Modelling with Covariates

To test the effect of habitat characteristics on ψ and p, habitat covariates were modelled for 5 site repeats. The top 8 ranked models are presented in table 2. The model in which occupancy was affected by forest type and altitude, whilst keeping detectability constant, came out on top (Table 5). Goodness of fit was tested for the fixed model (X^2=10.28, P=0.69, $\hat{C}$=0.5078), the most parameterized model (N=5) (X^2=11.57, P=0.71, $\hat{C}$=0.5445) and top model (X^2=11.08, P=0.75, $\hat{C}$=0.497). The model was a good fit to the data. Tree density and altitude came out of the model as the most important indicators of spider monkey presence in Tesoro Escondido. Sites of all tree densities and elevations were occupied by *A. f. fusciceps*. Altitude was the main indicator of the probability of detecting *A. f. fusciceps*. With increasing altitude, the ability to detect the spider monkeys decreased. Beyond 600m, detectability dropped to approximately 4 % (Figure 4).

Discussion

Previous studies of the *Ateles fusciceps fusciceps* have focused on determining population densities (Moscoso, 2010; Peck et al, 2011), identifying Tesoro Escondido as having the highest density of spider monkeys in NW Ecuador. This species is difficult to study as it lives in challenging terrain; making traditional line transect surveys more challenging. Additionally, Peck and colleagues (2011) noted that play-back methods may underestimate primate abundance. Recently, occupancy modelling has proven to be a useful technique to study arboreal mammals in difficult terrain (Campbell, 2010; Gray et al, 2010; Neilson et al, 2013). Our aim was to test a novel method to determine the factors that affect habitat use by brown-headed spider monkeys (*Ateles f. fusciceps*) to guide future conservation efforts in the area.

Occupancy modelling revealed that all forest sites in Tesoro Escondido should be occupied by A. *f. fusciceps*. This would make Tesoro Escondido a site of high conservation priority for the future survival of this species. Keane et al (2012), also found occupancy values of 1.0 for *Propithecus diadema* and *Eulemur fulvus*. The model showed that detectability was low across all ranges of site repeats, but was highest when the number of site repeats was the same across all sites. With 5 site repeats occupancy was found to be 1.0 and detectability was 0.068, only slightly lower than with 10 repeats. This would indicate that only 5 repeats per site are needed in future to determine the presence of spider monkeys at sites in and around Tesoro Escondido. By performing 5 instead of 10 repeats, more sites can be visited and it is more cost effective. Occupancy modelling in this way, allows for the long-term monitoring of sites of conservation priority through the comparison of site occupancy across years and the factors that could influence changes in occupancy. Weather was not a good predictor of detectability in Tesoro Escondido with no significant impact on sightings. Instead, increases in altitude lead to a decrease in detectability. The higher altitude sites in Tesoro Escondido often had drops into valleys flanking either side of the trail. This could have reduced the ability to see the spider monkeys as one of the main ways to detect a group was by the noise of branches moving.

Modelling occupancy with covariates showed that altitude was an important indicator of site use by *A. f. fusciceps*. Spider monkeys range from sea level to 1800 m in altitude (Shanee, 2009). The model revealed that the brown-headed spider monkeys were using all the tested sites in Tesoro Escondido within an altitudinal range of 287 m - 634 m above sea level. Shanee (2009) found brown-headed spider monkeys up until 1350 m above sea level. It has been suggested that hunting pressure forces the primates up into higher altitude and less suitable sites (Peck et al, 2011), requiring them to adapt and reduce their group sizes (Shanee, 2009) due to a reduction in the availability of fruit at higher altitudes (Hanya et al, 2003). The presence of *A. f. fusciceps* at low altitude in Tesoro Escondido provides evidence to support the current lack of hunting pressure in the cooperative. However, Tesoro Escondido, made up of mestizos (colonists) borders indigenous communities that continue to hunt *A. f. fusciceps*).

Modelling occupancy of *A. f. fusciceps* showed that tree density was an important indicator of site occupancy. At lower tree densities (fewer trees per hectare), more sites were occupied. Primary forest is characterized by having lower tree densities due to the higher number of large trees. This suggests that *A. f. fusciceps* prefers primary forest which is in line with other members of the *Ateles* genus (Aldana et al, 2008). Plotting the relationship between patch occupancy and tree density shows that spider monkeys in Tesoro Escondido are using selectively logged areas. Both small scale and large scale selective logging are rife in and around Tesoro Escondido. Logging activity changes forest structure by eliminating large trees and with the disappearance of larger trees spider monkeys are forced to adapt. Selective logging also increases sun exposure to small and medium sized trees due to the removal of large trees, thereby increasing fruiting of smaller and mid-sized trees (Johns, 1991; Ganzhorn, 1995). This generates habitat similar to forest edge habitat. This increased fruiting might suggest that ripe-fruit specialists, such as spider monkeys (van Roosmalen and Klein, 1988; DiFiore et al, 2011) would benefit from increased fruit production. However, previous studies found that spider monkeys do not use edge habitats (van Roosmalen and Klein, 1988) as they generally feed on larger trees (Chapman et al, 1995). It is of note that these larger trees tend to be the very hardwood species targeted by logging companies.

Our recent work at Tesoro Escondido has shown that *A. f. fusciceps* have a feeding preference for fruits with higher levels of fats from larger hardwood tree species that are also those targeted and favoured by loggers, in particular *Brosimium utile* (local name Sande) (In prep.). So, although *A. f. fusciceps* is detected as present in selectively logged areas it may simply be using these areas to transit between more productive primary forest sites. The results from occupancy analysis provide an indication that degraded forest still ensures connectivity, but more detailed analysis of activity and feeding behaviour are needed to understand whether selectively logged forest actually contributes to the long term maintenance of the species. The ratio of primary to selectively logged forest is likely to be more critical in maintaining *A. f. fusciceps* within a mixed use forest landscape. Logging also opens up areas to other anthropogenic pressures such as hunting and the primate pet trade, through the building of roads and trails into the forest. Spider monkeys are preferred targets for hunting in the Neotropics (Peres, 2000) due to their large size and pleasant taste (Ramos-Fernandez and Wallace, 2008). They are often the first primates to disappear from forests where they are hunted (Franzen, 2006; Peres, 1990) and the abundance of spider monkeys in hunted areas is lower than in areas without hunting (Peres, 2000; de Thoisy et al, 2005). Tesoro Escondido does not currently experience hunting pressure (Peck et al, 2011) and further research is needed to investigate if the presence of *A. f. fusciceps* in secondary and selectively logged forest can be explained by the absence of hunting pressure. Spider monkeys have been found in disturbed forest (Aldana et al, 2008) within 200m of primary forest (Johns and Skorupa, 1987) and regenerating forest (Chapman et al, 1989). As it stands, the results suggest that as long as there is enough primary forest left in Tesoro Escondido, the spider monkeys may be able to persist in a mosaic habitat and urgent action is recommended to conserve the remaining primary forest habitat.

These results should be extrapolated to other areas, with care. However, as this study has demonstrated, occupancy can be used to investigate the distribution of *A. f. fusciceps* across a site of interest, involving relatively little effort and cost. It is therefore suggested that future conservation efforts incorporate occupancy modelling to investigate where other populations of *A. f. fusciceps* are located, especially when surveying areas in which they are being hunted (Baker et al, 2011) and line transects may not be as applicable due to the difficult terrain (Neilson et al, 2013) and we recommend urgent surveys in and around the Cotacachi-Cayapas Ecological Reserve (RECC, in which the terrain is challenging and hunting occurs) to provide information required to identify protected and connected habitat corridors for this species. The ability to generate information on habitat preferences in addition to estimates of presence and a metric to assess abundance supports the use of occupancy in providing vital information to underpin effective conservation action planning.

References

Aldana, A. M., Beltrán, M., Torres-Neria, J. & Stevenson, P. R. (2008). Habitat characterization and population density of brown spider monkey (*Ateles hybridus*) in Magdalena Valley, Colombia. *Neotropical Primates*, 15, 46-50.

Asensio, N., Lusseau, D., Schaffner, C. M. & Aureli, F. (2012). Spider monkeys use high-quality core areas in a tropical dry forest. *Journal of Zoology*, 287, 250-258.

Bailey, L. & Adams, M. (2005). *Occupancy models to study wildlife. U.S. Geological Survey fact sheet 3096*. USA: USGS.

Baker, L. R., Arnold, T. W., Olubode, O. S., Garshelis, D. L. (2011). Considerations for using occupancy to monitor forest primates: a case study with Sclater's monkey (*Cercopithecus sclateri*). *Population Ecology*, 53, 549-561.

Campbell, N. (2010). The Peruvian night monkey, *Aotus miconax*; a comparative study of occupancy between Cabeza del Toro and Cordillera de Colán, Peru. MSc. thesis, Oxford Brookes University, Oxford.

Chapman, C. A., Chapman, L. & Glander, K. E. (1989). Primate populations in northwestern Costa Rica: potential for recovery. *Neotropical Primates*, 10, 37-44.

Chapman, C. A., Wrangham, R. W. & Chapman, L. J. (1995). Ecological constraints on group size: an analysis of spider monkey and chimpanzee subgroups. *Behavioural Ecological Sociobiology*, 36, 59-70.

Cuarón, A.D., Morales, A., Shedden, A., Rodríguez-Luna, E. & de Grammont, P.C. (2008). *Ateles fusciceps ssp. fusciceps*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 1 September 2013.

De Thoisy, B., Renoux, F. & Julliot, C. (2005). Hunting in northern French Guiana and its impact on primate communities. *Oryx*, 39, 149-157.

Di Fiore, A., Link, A. & Campbell, C. J. (2011). The atelines: behavioural and socioecological diversity in a New World monkey radiation. In: Campbell, C. J., Fuentes, A., MacKinnon, K. C., Bearder, S. K. & Stumpf, R. M. (Ed.), *Primates in Perspective* 2nd ed. (pp. 155-188). New York: Oxofrd University Press.

Estrada, A. & Coates-Estrada, R. (1996). Tropical rain forest fragmentation and wild populations of primates at Los Tuxtlas, Mexico. *International Journal of Primatology*, 17, 759-783.

Estrada, A., Luecke, L., van Belle, S., Barrueta, E. & Rosales Meda, M. (2004). Survey of black howler (*Allouata negra*) and spider (*Ateles geoffroyi*) monkeys in the Mayan sites of Calakmul and Yaxchilan, Mexico and Tikal, Guatemala. *Primates*, 45, 33-39.

Franzen, M. (2006). Evaluating the sustainability of hunting: a comparison of harvest profiles across three Huaorani communities. *Environmental Conservation*, 33, 36-45.

Ganzhorn, J. (1995). Low-level forest disturbance effects on primary production, leaf chemistry, and lemur populations. *Ecology*, 76, 2084-2096.

Gray, T. N. E., Phan, C. & Long, B. (2010). Modelling species distribution at multiple spatial scales: gibbon habitat preferences in a fragmented landscape. *Animal Conservation*, 13, 1-9.

Guillera-Arroita, G., Lahoz-Monfort, J. J., Milner-Gulland, E. J., Young, R. P & Nicholson, E. (2010). Using occupancy as a state variable for monitoring the Critically Endangered Aloatran gentle lemur *Hapalemur aloatrensis*. *Endangered Species Research*, 11, 157-166.

Hanya, G., Noma, N., Agetsuma, N. (2003). Altitudinal and seasonal variation in the diet of Japanese macaques in Yakishima. *Primates*, 44, 51059.

Johns, A. D. (1991). Forest disturbance and Amazonian primates. In: Box, H. O. (Ed.) *Primate Responses to Environmental Change* (pp. 115-135). Cambridge: Chapman and Hall.

Johns, A. D. & Skorupa, J. P. (1987). Responses of rain-forest primates to habitat disturbance: a review. *International Journal of Primatology*, 8, 157-191.

Keane, A., Hobinjatovo, T., Razafimanahaka, H. J., Jenkins, R. K. B. & Jones, J. P. G. (2012). The potential of occupancy modeling as a tool for monitoring wild primate populations. *Animal Conservation*, 15, 457-465.

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Royle, J. A. & Langtimm. C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, 83, 2248-2255.

MacKenzie, D. I. & Royle, A. (2005). Designing occupancy studies: general advice and allocating survey effort. *Journal of Applied Ecology*, 42, 1105-1114.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L. & Hines, J. E. (2006). *Occupancy Estimation and Modeling Inferring Patterns and Dynamics of Species Occurence*. Elsevier Inc., USA. Pp 92-94.

MacKenzie, D. I. & Bailey, L. L. (2004). Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics*, 9, 300-318.

Mazerolle, M. J. (2006). Improving data analysis in herpetology: using Akaike's Information Criterion (AIC) to assess the strength of biological hypotheses. *Amphbia-Reptilia*, 27, 169-180.

Mittermeier, R. A., Schwitzer, C., Rylands, A. B., Taylor, L. A., Chiozza, F., Williamson, E. A. & Wallis, J. (eds.). 2012. *Primates in Peril: The World's 25 Most Endangered Primates 2012–2014*. IUCN/SSC Primate Specialist Group (PSG), International Primatological Society (IPS), Conservation International (CI), and Bristol Conservation and Science Foundation, Bristol, UK. 40pp.

Moscoso Rosero, P. (2010). Estado poblacional del mono araña de cabeza café (*Ateles fusciceps*) en el noroccidente del Ecuador, con notas ecológicas de una relación interespecíca con *Alouatta palliata*. MSc. Thesis. Universidad Católoica del Ecuador, Quito.

Neilson, E., Nijman, V. & Nekaris, K. A. I. (2013). Conservation assessments of arboreal mammals in difficult terrain: occupancy modeling of pileated gibbons (*Hylobates pileatus*). *International Journal of Primatology*, 34, 823-835.

Peck, M., Thorn, J., Mariscal, A., Baird, A., Tirira, D. & Kniveton, D. (2011). Focusing conservation efforts for the Critically Endangered brown-headed spider monkey (*Ateles fusciceps*) using remote sensing, modeling, and playback survey methods. *International Journal of Primatology*, 32, 134-148.

Peres, C. A. (1990). Effects of hunting on western Amazonian primate communities. *Biological Conservation*, 54, 47-59.

Peres, C. A. (2000). Effects of subsistence hunting on vertebrate community structure in Amazonian forests. *Conservation Biology*, 14, 240-253.

Ramos-Fernández, G. & Wallace, R. B. (2008). Spider monkeys conservation in the twenty-first century: recognizing risks and opportunities. In: Campbell, C. J. ed. *Spider monkeys behaviour, ecology and evolution of the genus Ateles* (pp.351-376). Cambridge: Cambridge University Press.

Shanee, S. 2009. Modelling spider monkeys *Ateles* spp. Gray, 1825: ecological responses and conservation implications to increased elevation. *Journal of Threatened Taxa*, 1, 450-456.

Tirira, D. (2004). Estado actual del mono araña de cabeza café (*Ateles fusciceps* Gray, 1866) (Primates: Atelidae) en el Ecuador. Lyonia, 6, 17-24.

Van Roosmalen, G. M. & Klein, L. L., (1988). The Spider Monkeys, Genus *Ateles*. In: Mittermeier, R. A., Rylands, A. B., Coimbra-Filho, A. & Fonseca, G. A. B, ed. 1988. *Ecology and Behaviour of Neotropical Primates Volume 2*. Washington D.C.: World Wildlife Fund, pp. 455-537.

Table 1. Occupancy survey effort and number of survey points on trails at Tesoro Escondido.

Trail	**Length of Trail (km)**	**Number of Points on Trail**	**Survey effort**
Trail A	4.3	21	35 hr 00 min
Trail B	4.3	22	29 hr 10 min
Trail C	2.3	12	10 hr 00 min
Trail D	3.0	16	25 hr 20 min
Total	**13.9**	**71**	**99 hr 30 min**

Table 2. Occupancy models of *A. f. fusciceps* in Tesoro Escondido for the 8 top-ranking models with **AIC**: Akaike Information Criterion, **ΔAIC**: Akaike difference, **AICw**: Akaike weight, **N**: Number of parameters; Model names comprise the covariate that was modelled for the probability of occupancy (Ψ) and the probability of detecting (p) spider monkeys. Covariates of the top models included: presence/ absence of forest disturbance as a result of logging (FOR), altitude (ALT), canopy connectivity (CAN), tree density (DEN), tree diameter at breast height (DBH) and climate (CLI). Models in which covariates were kept constant were denoted by (.).

Model	**AIC**	**ΔAIC**	**AIC w**	**N**	**Ψ**
Ψ(FOR, ALT),*p*(.)	175.26	0	0.0827	4	0.845
Ψ(CAN, DEN),*p*(CAN)	175.85	0.59	0.0615	5	0.873
Ψ(ALT, DEN),*p*(.)	176.09	0.83	0.0546	4	0.859
Ψ(FOR, ALT),*p*(CLI)	177.16	1.9	0.032	5	0.845
Ψ(DEN, DBH),*p*(ALT)	177.18	1.92	0.0317	5	0.901
Ψ(FOR, ALT),*p*(DBH)	177.26	2	0.0304	5	0.845
Ψ(CAN,DEN),*p*(ALT)	177.44	2.18	0.0278	5	0.873
Ψ(ALT,DEN),*p*(DEN)	177.88	2.62	0.0223	5	0.873
Ψ(.),*p*(.)	179.65	4.39	0.0092	2	1.0

Figure 1. Tesoro Escondido, focus of the project location in Esmeraldas Province, NW Ecuador, with light green shaded areas showing remaining forest habitat that require urgent conservation action (Data and map from remote sensing and GIS analysis in Peck et al, 2011).

Figure 2: Top photographs show trail A with primary forest, and bottom ones trail C with primary forest interspersed with logging cables at Tesoro Escondido.

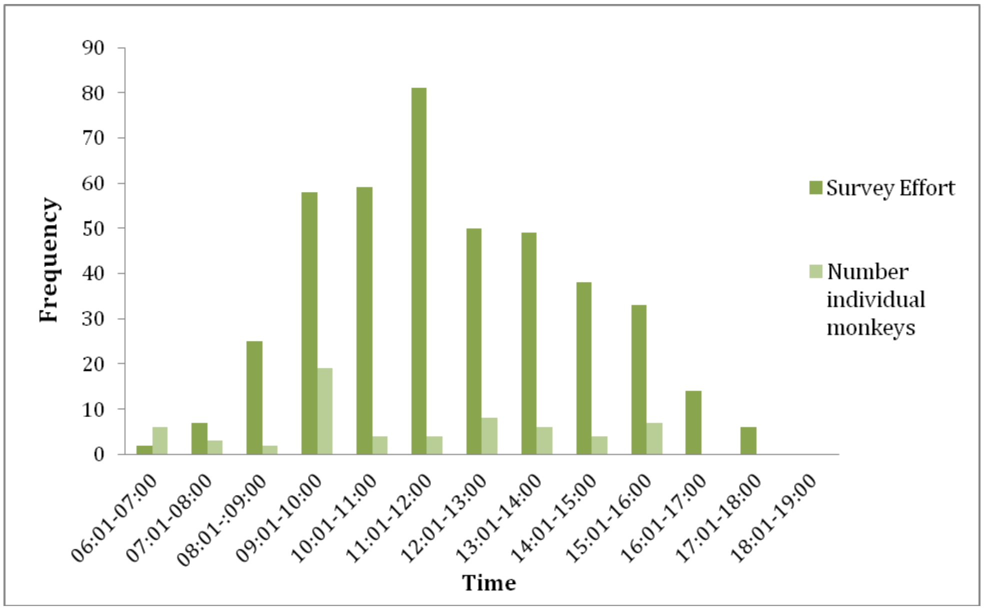

Figure 3. Survey effort in relation to the number of *A. f. fusciceps* observed throughout the day showing survey effort was greatest between 11:00 and 12:00 and the highest number of primates sighted from 9:00 to10:00.

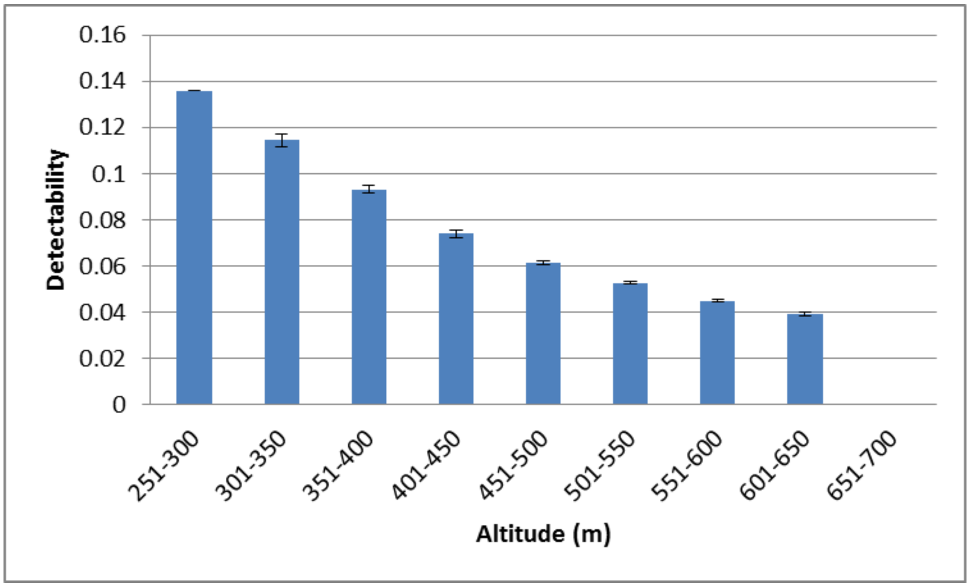

Figure 4. The probability of detection of *Ateles fusciceps fusciceps* in Tesoro Escondido, northwest Ecuador between May-July 2013, in relation to altitude. Error bars represent standard error. Probabilities of detection were taken from the model Ψ(.),*p*(ALT).