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Conservation of brown-headed spider monkeys (*Ateles fusciceps fusciceps*) in NW Ecuador: applying an Agent-Based Model

Citlalli Morelos Juárez

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Declaration

I hereby declare that this thesis has not been and will not be submitted in whole or in part to another University for the award of any other degree.

Signature:

Citlalli Morelos Juárez

UNIVERSITY OF SUSSEX

Citlalli Morelos Juárez

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Summary

Understanding the impacts of landscape fragmentation, degradation and hunting on arboreal species of conservation concern, such as the critically endangered brown-headed spider monkey (*Ateles fusciceps fusciceps*), remains a major challenge in conservation biology. Current research on the population status of this primate and the area it inhabits in the Ecuadorian Chocó is urgently needed to aid in the design of specific and effective conservation strategies. I surveyed the population of *A. f. fusciceps* in the unprotected forest cooperative Tesoro Escondido in the buffer zone of the Cotacachi Cayapas Ecological Reserve during the year 2012-2013. Using the line transect method I estimated a population density of 15.79 individuals/km^2. I found an average subgroup size of 3.42 individuals and a female biased population.

Identifying key food resources for critically endangered species is vital in their conservation, particularly if these resources are also targeted by anthropogenic activities such as logging. The province where *A. f. fusciceps* is found is also heavily dependent on commercial logging with no information available on its impacts on key feeding resources for this primate. I characterised the floristic composition of the habitat of *A. f. fusciceps* and estimated the availability of fruit resources for the annual cycle of 2012-2013 in sixteen 0.1 hectare vegetation plots. I determined feeding preferences for *A. f. fusciceps* using behavioural observations applying the Chesson ε index to identify key feeding tree species. I reviewed regional logging permits to identify species targeted for extraction by the timber industry and calculated extraction volumes in primary forest for key feeding tree species to identify potential

conflict between logging and primate diet. I identified 65 fruiting tree species from 34 families that formed the diet of *A. f. fusciceps*. The Chesson ε index identified twelve species as *preferred species* with further phenological observations identifying seven species as *staple foods* and two palms as potential foods consumed in times of fruit scarcity. Additionally, I found that the lipid rich fruits of *Brosimum utile* make this an important resource for this primate throughout the year. Furthermore, of 65 feeding tree species identified for *A. f. fusciceps*, 35 species are also targeted as sources of timber. Five key feeding species would be depleted under current sustainable management extraction protocols while two other species would be significantly impacted in terms of local abundance.

Hunting pressure on *A. f. fusciceps* has been reported as one of the main causes of its population decline. However, no current research on the extent of this activity or its causes was available. I carried out semi-structured interviews in nine indigenous Chachi villages, as well as two Colono towns, to evaluate the occurrence of hunting activity and to identify drivers, attitudes and behaviour of hunters. In total I interviewed 62 people, 41 Chachis and 21 Colonos. From the Chachi interviewees 93% identified themselves as hunters, with subsistence hunting the main driver for this activity and central to their culture, especially for men. Colonos identified less with this activity (only 38%), and with more varied reasons, such as commerce and conflict. Only Chachis accepted the hunting of spider monkeys, with the main reason given as their taste. Keeping spider monkeys as pets was also a regular activity prior to tougher law enforcement by the Ministry of Environment (MAE). Information on medicinal uses from spider monkeys was also gathered, as well as information of other species hunted in the area. Even though Ecuadorian law recognises the right of indigenous peoples to hunt within their territories, it also forbids hunting critically endangered species. From the interviews it is evident that information and understanding of this law has not been successfully transmitted.

Determining the effects of fragmentation, hunting and habitat degradation on populations viability of this primate is crucial before investing heavily in local sustainable livelihoods and conservation initiatives. A range of fragmentation metrics are available to study habitat fragmentation, yet their relationship to survival of populations of conservation concern remains to be quantified. I applied an agent-based model (ABM), calibrated on field-collected datasets on forest fruit dynamics, behaviour and feeding ecology of *A. f. fusciceps*, to first identify an optimised fragmentation statistic to be used to screen satellite imagery and identify remaining priority conservation areas in unprotected, fragmented forests in NW Ecuador. I then used the ABM to further explore the combined impacts of fragmentation, hunting and logging. Mean Patch Area was the best fragmentation metric predictor of population numbers, I identified a MPA of 174.9 hectares as the cut-off point for the survival of brown-headed spider monkeys given the lowest combinations of logging activity and hunting pressure and I used it to identify priority conservation areas in NW Ecuador.

Implementing conservation strategies in areas where people and nature interact is a challenging task. I designed a step by step framework for the conservation of critically endangered species. Based on my experience with *Ateles fusciceps fusciceps* as a case study, I present the design, assessment and implementation of different community-based strategies.

For my mum Ana Laura Juárez

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Introduction

1.1 Challenges in the conservation of *Ateles fusciceps fusciceps*, a critically endangered primate in the Ecuadorian Chocó

Spider monkeys (genus *Ateles*) belong to the ateline genera alongside *Alouatta, Lagothrix and Brachyteles* and have one of the largest geographical distributions of any primate in the Neotropics. They can be found from Veracruz State in Mexico to northern Bolivia; and in South America from the Pacific Coast in Ecuador to Guyana and Suriname in the northeast (Collins, 2008).

While their geographical distribution is broad, spider monkeys have maintained restricted habitat preferences. They are mostly found in the top canopy layers in low, humid rain forests below 800 meters above sea level (Collins, 2008). Spider monkeys are frugivorous primates, selecting mostly soft and ripe fruits (Wallace, 2005) and displaying a fission-fusion social system with dispersal of females upon maturation (Shimooka *et al.*, 2008). They are easily recognized by their long arms and prehensile tail, with a morphology completely adapted to the upper canopy and to a high-energy lifestyle (Rosenberger *et al.*, 2008).

The Ecuadorian brown-headed spider monkey *Ateles fusciceps fusciceps* is one of the four primates inhabiting NW Ecuador. It can be found in the tropical and subtropical forests of Esmeraldas province (Madden & Albuja, 1989a), within the Tumbes-Chocó-Magdalena biodiversity hotspot identified by Myers *et al.* (2000). As with other biodiversity hotspots, this one is characterized by its high endemism and its accelerated historical and current rates of habitat loss.

Compared to other New World genera, spider monkeys in general are relatively unstudied in the wild; their rapid pace, social system, wide home range and high canopy preference make their study particularly challenging (Campbell, 2008). This is also the case for *A. f. fusciceps*, first studied by Madden & Albuja (1989a) and 14 years later by Mena-Valenzuela (2003), both reporting an alarming decline in their populations.

Research on this spider monkey was followed up by Tirira (2004) showing that the historical distribution of the species had been reduced by 80% in the last 45 years due to deforestation and hunting, with an estimated population of 250 individuals. This situation placed *A. f. fusciceps*, in the category of Critically Endangered (CR) (IUCN Red List 2004) and as one of the 25 most endangered primates in the world, a place unfortunately held to this date (Schwitzer *et al.*, 2015).

Following the aforementioned report, the PRIMENET project was started in 2005 by Dr. Mika Peck from the University of Sussex and the Ecuadorian mastozoologist Diego Tirira, with the objective of developing a sustainable network for primate conservation in NW Ecuador. Research on different aspects of the distribution and ecology of the brown-headed spider monkey was carried out indicating aspects that should be addressed in further work such as the extent of hunting by indigenous, Afroecuadorians and colonist communities, the effect of this activity on the remaining populations, as well as identifying potential conservation strategies to set in place in priority areas (Gavilanez-Endara, 2006; Magnusson, 2006; Shanee, 2006; Baird, 2009; Dowd, 2009; Estevez-Noboa, 2009; Moscoso, 2010; Cueva, 2008).

Moreover, using species-specific landscape modelling, Peck *et al.* (2010) identified 989km^2 of suitable habitat for *A. f. fusciceps* lying in unprotected areas and recommended further research on developing specific and effective conservation strategies and action to bring this primate back from the brink of extinction.

The importance of the persistence of populations of spider monkeys in tropical forests falls mainly to their role as effective seed dispersers (Stevenson *et al.*, 2002). The genus *Ateles* ranks amongst the best known seed dispersers given the fact that they swallow large amounts of seeds from a wide range of sizes and disperse them to areas far from parent trees. Furthermore seedling trials have indicated many of these seeds are not destroyed with rather high numbers reaching the establishment stage (Dew, 2008).

Several studies suggest that the loss of large-bodied frugivores, such as spider monkeys may affect the composition and long term existence of neotropical rainforest diversity, particularly if no other disperser species exists to compensate for missing ecological services (Peres & Van Roosmalen, 2002; Link & Di Fiore, 2006).

Specifically in the case of *A. f. fusciceps*, Calle-Rendón *et al.* (2016) found higher densities and species richness of primate dispersed tree species in a site with significantly higher abundance of brown-headed spider monkeys compared to a structurally similar forest in the same region. This suggests that the maintenance of high levels of tree diversity in Chocoan rainforests is dependent on the conservation of its largest resident primate and flagship species *A. f. fusciceps*, (Figure 1.1).

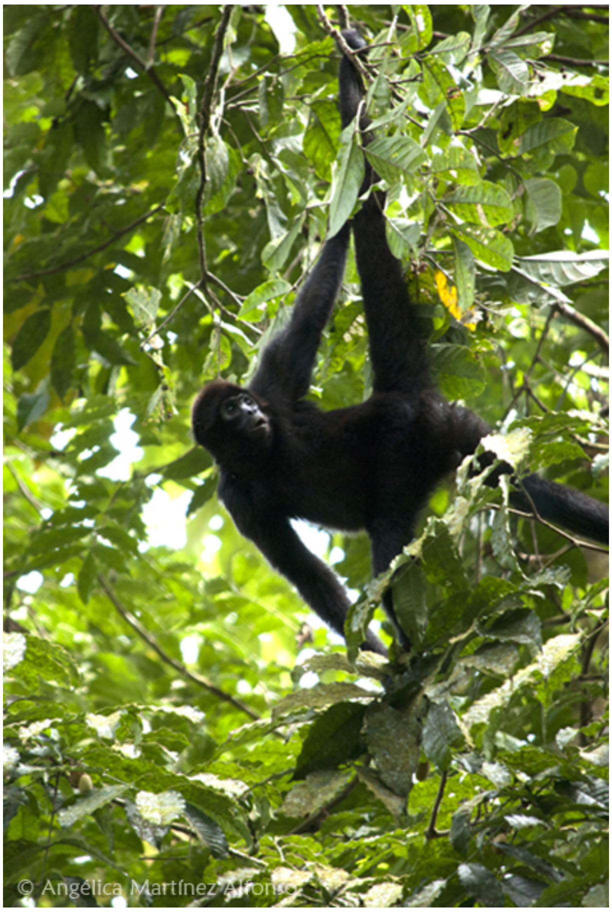

Figure 1.1: The Ecuadorian brown-headed spider monkey *Ateles fusciceps fusciceps*, in Tesoro Escondido, Esmeraldas, Ecuador.

1.1.1 Deforestation and fragmentation of primary forests in NW Ecuador

It is estimated that Ecuador has the highest deforestation rates in South America with the coastal region being the most affected (Mosandl *et al.*, 2008). The main causes of deforestation are logging, wood extraction and agriculture frontier expansion (Sierra, 2001; FAO, 2010).

In particular, habitat loss in the "green province" Esmeraldas, part of the Ecuadorian Chocó, in the NW part of the country is mainly caused by commercial and domestic timber extraction and land conversion to monocrops, such as the African palm. The forestry sector in the area is dominated by a few larger companies that carry out logging operations in primary forests and manage tree plantations (Jestrzemski, 2010). Logging activities in the Ecuadorian Chocó have increased over the past 35 years due to rising local and national demand for timber; around 70% of the Ecuadorian timber destined for domestic use comes from this region (López *et al.*, 2010; Sierra, 2001).

Land conversion in Esmeraldas increased rapidly after the promulgation of Agrarian Reform (between 1963 and 1975) which promoted the redistribution of forest land, previously held by the government, to 'Colonos' (migrants from other provinces) willing to convert the forest into pastures for cattle or crops (Rival, 2003). Additionally, Esmeraldas has become one of the main exporters of monocrop products, such as palm oil and banana with the palm oil business considered to have converted between 60,000 and 100,000 hectares of forest (Buitrón, 2001; Hazlewood, 2010; Lasso, 2012).

Reports suggest that coastal forests in Western Ecuador have been reduced to only 2% of the original coverage area; leading to a rapid reduction in wildlife, especially in forests below 300 m.a.s.l., which are not included within current national protected areas (Critical Ecosystem Partnership Fund, 2005). This has a major impact on *A. f. fusciceps*, as they are mostly found in forest below 700 m.a.s.l (Peck *et al.*, 2010).

Habitat destruction has particularly affected brown-headed spider monkeys, a species with a large home range and need for old growth unfragmented forest with sufficient fruit resources. This has reduced its population densities (Madden & Albuja, 1989b; Tirira, 2004) and restricted the remaining ones to forests either in the Cotacachi Cayapas Ecological Reserve (CCER) or in its buffer zone, where the agricultural frontier advances at a fast pace (Tirira, 2004).

Forest clearance leads to habitat fragmentation, where continuous habitat is broken apart into smaller pieces (fragments) scattered within a matrix of non-habitat

(Arroyo-Rodríguez *et al.*, 2013); this can be extremely detrimental for spider monkeys, who inhabit the canopy and prefer primary and continuous forest (Defler, 2004; Peres, 2001).

Timber extraction in Esmeraldas has never been put into the context of the conservation of a critically endangered species, such as *A. f. fusciceps*. Logging, even under sustainable management, can have serious negative impacts on highly arboreal species, particularly on specialists, such as spider monkeys, however, to date there is no research in the region focusing on this critical issue.

Furthermore, the high rate of deforestation in the region is a reflection of the lack of effective control measures on its causes. Even though there are laws in place regulating deforestation, governments have not successfully enforced these laws, and in some cases, rather than regulating and controlling the industries' activities in the area, have encouraged environmental deterioration (Lasso, 2012).

1.1.2 Hunting pressure on *Ateles fusciceps fusciceps*

Large-bodied primates, such as spider monkeys, are prime targets for hunters in South-American tropical forests (Peres, 1990). In fact, their densities appear consistently low in areas where hunting occurs, with the ateline primates most heavily impacted (Cowlishaw & Dunbar, 2000).

Hunting pressure on brown-headed spider monkeys inside the CCER was first reported by Madden & Albuja (1989b) and then by Mena-Valenzuela (2003). They report a complete elimination of populations of *A. f. fusciceps* in forests close to habited areas in the immediate surroundings of the CCER and a strong impact in areas on the periphery of the reserve.

The last assessment on hunting of spider monkeys in and around the CCER was in 2003 (Mena-Valenzuela, 2003). Therefore, if any strategies are to be planned to bring this primate back from its critical conservation status, it is vital to undertake an evaluation of the current situation of hunting pressure on *A. f. fusciceps*, with emphasis on understanding the cultural context, drivers and attitudes of hunters. It is also important to carry out an assessment of law enforcement in the area with regard to hunting activity. Results from such a study can provide relevant information to local NGOs working in the area and to the Ecuadorian Ministry of

Environment in improving management plans in the CCER and its buffer zone.

1.2 Developing cost-effective, precise and faster methods to identify priority conservation areas

Understanding how primate populations respond to habitat changes is challenging due to the fact that in nature, factors are not isolated; some are interrelated or aggravated by each other (Lacy, 2000). For example, the removal of a few trees via logging may not have a serious impact on primate populations at first, however the roads to access timber may provide access for hunters (Peres, 2001), and/or to people immigrating and extending into the forest (Rimbach *et al.*, 2013).

This may be the case for *A. fusciceps fusciceps* in NW Ecuador, where anthropogenic activities are quickly reducing and fragmenting the habitat and where subsistence hunting by indigenous groups may no longer be sustainable. The critical status of brown-headed spider monkeys is pushing research towards the development of methods that allow cost-effective, precise and faster identification of priority conservation areas, targeting available funding into effective conservation strategies.

One way of evaluating the survival of brown-headed spider monkeys in different scenarios of habitat fragmentation, logging and hunting activity is the use of an agent-based model (ABM); with monkeys interacting as realistically as possible in a real environment with different fragmentation levels and where logging and hunting activity scenarios can be easily modelled based on field data and available literature on the genus.

ABMs are a powerful tool in ecology and in the understanding of the interaction between populations and their environment. They have the potential to provide information over extended time spans in long-living species such as spider monkeys, which would otherwise be more difficult or impossible to obtain through field studies. They can also reduce fieldwork time and costs by aiding in the identification of remaining forests most likely to sustain populations.

Once priority areas are identified, conservation strategies need to be implemented. To improve success in these, several factors need to be taken into account, particularly the local context (Waylen *et al.*, 2010). Addressing issues simultaneously at various scales might prove more successful in the long term (Berkes, 2004) . However, in NW Ecuador, there are no cases focusing on the conservation of an endangered species whilst simultaneously addressing the full range of social issues existing in the area.

1.3 Objective and specific aims

The aim of the present study is to investigate the effect of habitat fragmentation, logging activity and hunting pressure on the survival of *A. f. fusciceps* in NW Ecuador.

The specific objectives are:

- To estimate the population density of *A. f. fusciceps* in the forest cooperative Tesoro Escondido in NW Ecuador
- To characterize the floristic composition of the habitat of *A. f. fusciceps*
- To identify key feeding tree species in the diet of *A. f. fusciceps*
- To evaluate hunting pressure on *A. f. fusciceps* in the buffer zone of the Cotacachi Cayapas Ecological Reserve
- To develop an Agent-Based Model capable of evaluating the effect of habitat fragmentation, logging activity and hunting pressure on the survival of *A. f. fusciceps*
- To identify priority areas of viable habitat for *A. f. fusciceps* in NW Ecuador to focus conservation efforts.
- To develop a stepwise road map for the conservation of critically endangered species, using the case study of *A. f. fusciceps*.

1.4 Thesis structure

This thesis is divided into seven chapters. Chapter 2 provides a review of the current literature on the topics covered in this thesis and serves as a theoretical framework for this project.

Chapters 3, 4 and 5 cover data collection in the field estimating population density of *Ateles fusciceps fusciceps*, studying its habitat and diet and assessing the extent of hunting activity in the region. Chapter 6 presents the development of the agent based model for the brown-headed spider monkey and its application in the conservation of *A. f. fusciceps*. Chapter 7 provides the development of a stepwise road map in the conservation of *A. f. fusciceps* and also serves as a general conclusion presenting perspectives for future research based on the results of the present study.

Literature Review

2.1 Summary

This chapter summarizes the theoretical framework behind the development of an individual-based model for brown-headed spider monkey conservation and the interpretation of its results.

2.2 Individual based modelling: A tool in endangered species conservation

Agent Based Models (ABMs) or Individual Based Models (IBMs) are a step forward towards modelling ecological, social or socio-ecological systems with all the complexity of the real world (Grimm, V. & Railsback, 2005). They provide a way of linking and integrating behavioural ecology and spatial ecology for conservation planning (Semeniuk *et al.*, 2011).

There are various platforms available to develop agent based models, however the free open source Netlogo software (Wilensky, 1999) has become a powerful tool in the last ten years. It is widely used in several research areas, including conservation of endangered species and ecology, mainly because of its relatively simple yet high level language, speed, and approachability for non-programmers. IBMs are able to model spatial variation among individuals, such as in territorial behaviour (Wang & Grimm, 2007), foraging animals in a landscape (Russell *et al.*, 2003) and predator-prey-habitat relationships (Baeza & Estades, 2010). Moreover, IBMs are able to run simulations with fine detail about individuals such as age, sex, knowledge of landscape and even animal cognitive response to the presence of threats and learning processes (Jaeger *et al.*, 2005; Pirotta *et al.*, 2014).

In primates, IBMs have been created to analyse social and foraging behaviour in macaques and chimpanzees (Bryson *et al.*, 2007; Hemelrijk *et al.*, 1999; Boekhorst & Hogeweg, 1994); to model decision-making in baboons (Sellers *et al.*, 2007); and the relationships between group size, grooming and fission on group structure in macaques (Sueur *et al.*, 2011). Specifically, for the genus *Ateles*, an ABM was developed to infer environmental effects on the grouping patterns of (*Ateles geoffroyi*) (Ramos-Fernández *et al.*, 2006). More recently an example of the use of ABMs on the influence of fruit abundance and distribution on the fission-fusion dynamics of spider monkeys was mentioned in Aureli *et al.* (2008).

While the first IBMs in ecology focused on understanding behaviour and decision-making, the current models have a more interdisciplinary approach and are beginning to be used as decision tools in the conservation planning for endangered species, covering many taxa (DeAngelis & Mooij, 2005).

Some of the aspects that have been approached, amongst others, are landscape configurations for endangered carnivores (Kramer-schadt *et al.*, 2004; Cramer & Portier, 2001; Naves *et al.*, 2003); herbivores such as the Chilean huemul deer (López-Alfaro *et al.*, 2012), persistence of the Sumatran tiger population (Imron *et al.*, 2011), life cycles of reintroduced Iguanas (Wolcott & Long, 2012) and effects of interactions with tourism on the behaviour of dolphins (Pirotta *et al.*, 2014).

Particularly regarding primate conservation there are two relevant examples of spatially explicit ABMs: the first one by Bonnell *et al.* (2010) looks at the effect of landscape change on host and parasite dynamics in red colobus monkeys (*Procolobus rufomitratus*); the second one by Wiederholt *et al.* (2010) models the impacts of hunting activity on red howler monkeys (*Alouatta seniculus*), looking for ways to mitigate them.

2.2.1 Population models for *Ateles fusciceps fusciceps*

Since it became evident that brown-headed spider monkeys are on the brink of extinction (Tirira, 2004), efforts to model their distribution, suitable habitat and threats in the NW of Ecuador has intensified.

Dowd (2009) developed a Population Viability Analysis (PVA), which was then incorporated into an environmental assessment to be used in a multi-criteria decision analysis in the conservation of *A. f. fusciceps*. The objective of a PVA is to determine a minimum viable population whose extinction risk is reduced to an acceptable level (Rai, 2003). They are widely used as a prediction tool for persistence of populations. Specific information on this species, for example harvesting rates, were not available at the time of this project, however results indicated a high sensitivity to habitat loss in the context of a mining concession.

Peck *et al.* (2010) developed a species-specific landscape map integrating novel rapid field surveys, satellite images and distribution modelling (MaxEnt). This model identified suitable habitat areas for the brown-headed spider monkey as a conservation priority; in particular areas lying in the unprotected buffer zone of the CCER.

Both models urged a better understanding of the remaining populations of *A. f. fusciceps* , the interaction with their environment and the effects of the threats they currently face.

2.3 Effect of fragmentation on primates

The majority of primates are dependent on forests, therefore one of the major threats to their survival is deforestation. Some, such as spider monkeys (genus *Ateles*), have a strong preference for primary and continuous forests (Defler, 2004) and are therefore particularly affected by habitat loss and fragmentation (Peres, 2001).

Anthropogenic activities (such as timber harvest and agricultural expansion) are a major cause of landscape disruption, and thus of ecological processes within them. It is vital to understand impacts of disruption and their effects on species persistence and maintenance of biodiversity and ecological health (With, 1999). Habitat fragmentation can be described as a landscape-scale process in which continuous habitat is broken apart into smaller pieces (fragments) scattered within a matrix of non-habitat (Arroyo-Rodríguez *et al.*, 2013).

Habitat can be taken out of a landscape in several different ways, resulting in an array of different spatial patterns (Fahrig, 2003). These patterns represent dissimilar degrees of fragmentation and thus may have different implications for the survival of species living in them. A landscape is composed of spatial components such as *patch*, *matrix* and *corridor* (Forman, 1995). A mosaic of patches comprises a landscape; a patch is the basic unit and can be viewed from different perspectives according to the disciplinary approach. From an organism level point of view (for instance spider monkeys) patches can be defined as dynamic environmental units between which quality varies (Wiens, 1976) and that can occur at multiple scales.

The matrix is the most extensive and most connected landscape element type, key in its functioning (Forman & Godron, 1986). An example of a matrix, relevant to the present study, would be a large continuous area of forest (the matrix) within several small disturbance patches (timber harvest or agricultural patches).

The definition of a fragment should be, as suggested by Arroyo-Rodríguez & Mandujano (2009) species-specific, depending on the particular habitat requirements and capacity to disperse. In the case of spider monkeys, who are mostly exclusively arboreal (rarely descending to the ground) with a high preference for closed canopy forests, we could define habitat fragments as forest remnants, isolated by a matrix of unsuitable environment, such as pastures, or croplands.

2.3.1 Analysing the effects of fragmentation

The process of fragmentation causes a number of effects on landscape pattern, the main four being: reduction in habitat amount, increase in number of habitat patches, decrease in sizes of habitat patches, and increase in isolation of patches (Fahrig, 2003).

To analyse these effects there are at least 40 measures of fragmentation (metrics) defined at four levels: 1) cell-level metrics, 2) patch-level metrics, 3) class-level metrics and 4) landscape-level metrics (McGarigal *et al.*, 2012). Each hierarchical level takes a different focus on spatial heterogeneity. In this case, when the primary interest is the amount and change in the spatial configuration of a particular patch type (i.e. primary forest) class-level metrics are the most appropriate choice, as they provide the means to quantify the amount and distribution of each patch type in the landscape (McGarigal *et al.*, 2012).

A useful and straightforward software package to analyse habitat fragmentation is FRAGSTATS (McGarigal *et al.*, 2012). This open software program allows for spatial pattern analysis by quantifying the structure (i.e. composition and configuration) of landscapes. It has previously been used in the study of the relationship of fragmentation on primate populations (Arroyo-Rodríguez *et al.*, 2013).

Depending on the aspect of the landscape pattern they measure, fragmentation metrics can be divided into the following categories (McGarigal, 2014):

Area and Edge metrics

This category deals with metrics quantifying the size of patches and the amount of edge created by these patches. They provide useful information in terms of minimum area and connectivity requirements for a species. They also approach edge-effects, which is one of the well-studied consequences of habitat fragmentation. Edge effects can modify the plant composition and vegetation structure in the fragments affecting important feeding resources for primates by reducing their quantity and quality (Arroyo-Rodríguez & Mandujano, 2006).

Mean Patch Area in particular is the most widely used metric in the study if fragmentation effects on primates. For instance, Michalski & Peres (2005) report it to be the strongest predictor of the occurrence of primates and carnivores in the fragmented Southern Amazonia (Michalski & Peres, 2005).

Core area metrics

Core area is the area within a patch beyond the influence of a certain edge distance and is therefore related to the edge-effect. It appears to be a better predictor of habitat quality than patch area alone (Temple, 1986).

Aggregation and Isolation metrics

These metrics describe the tendency of patch types to be spatially aggregated; a property also described as *texture*. Isolation on the other hand, focuses on the level at which patches are spatially separated from each other. Patch isolation is crucial to the study of spatially structured populations (Kareiva, 1990), as it results in the disruption of movement patterns that can result in the functional isolation of individuals and local populations.

One of the major negative effects of isolation on wild populations is the eventual absence of gene flow, reducing genetic variation, leading to extinction (Hartl *et al.*, 2003). Fragment isolation has previously been found to be negatively correlated to the abundance of howler monkeys *Alouatta palliata* in Mexico (Estrada & Coates-

Estrada, 1996).

Most metrics under this category are based on the Euclidean distance between nearest neighbours (McGarigal & Marks, 1995), which is defined by the accumulated area of neighbouring habitat patches weighted by the nearest neighbour distance. These isolation metrics may however underestimate the effects of isolation as they do not take into account small vegetation remnants that may facilitate movement between fragments thus masking the effects. Actually, area-based isolation metrics, calculating the amount of habitat available within a specified radius have proven to be a more reliable measure of fragment isolation (Bender *et al.*, 2003).

Connectivity can be described as the extent to which a landscape enables ecological flows or functionality (Arroyo-Rodríguez & Mandujano, 2009). This measure is obviously species-specific; in Neotropical primates, connectivity has been studied mainly on howler monkeys (Palacios-Silva & Mandujano, 2007; Alexander *et al.*, 2005). The functional distance between patches must first be determined, this is dependent on the species in focus (With, 1999).

Previous studies on the effect of fragmentation on primates included only four measures of fragmentation (fragment size, fragment isolation, vegetation attributes and forest edge), and usually measured only one of them, mostly fragment size. There are no studies investigating other metrics at the fragment or landscape scale (Arroyo-Rodríguez *et al.*, 2013; Fahrig, 2003). Forest patch area seems to be the most important metric to predict Neotropical primate species presence according to a comprehensive review by Benchimol & Peres (2014). However, literature on this subject strongly advises the use of other metrics, such as number of patches left in the landscape (Arroyo-Rodríguez *et al.*, 2013).

2.3.2 Fragmentation and extinction of primates

Forest primates, spider monkeys amongst them, are thought to be particularly vulnerable to local extinction in fragmented landscapes (Michalski & Peres, 2005). In the conservation of endangered species, it is crucial to understand extinction thresholds, which are used to analyse the minimum proportion, size or habitat amount required for a population to persist in the landscape (Fahrig, 2003). Extinction thresholds are sensitive to reproduction rates and changes in the matrix quality

(Fahrig, 2001, 2003).

Predicting extinction thresholds for endangered species should happen before they are observed, especially in species with long generation times, such as spider monkeys, who would naturally show a slow response to habitat loss detectable only after it is too late (Fahrig, 2001).

The threshold values for primates have not been detailed yet, partly due to the great variability among species. For Neotropical primates, a study on *Alouatta palliata* in three fragmented landscapes demonstrated that both the proportion of occupied fragments and abundance of primates decreases suddenly in landscapes with less than 15% of remaining habitat (Arroyo-Rodríguez *et al.*, 2008). Backing this up with a PVA, Mandujano & Escobedo-Morales (2008) estimate a 60% extinction probability of howler monkeys in fragments smaller than 15 hectares. For three species of primates in Kenya, Cowlishaw & Dunbar (2000) show evidence that fragments of less than 10ha have little probability of being occupied and that extinction rates greatly increase when they inhabit forest fragments of less than 10 ha. Gilbert (2003) points out the need to conserve areas larger than 100 ha for the conservation of six primate populations in the Amazon. In particular, for spider monkeys *Ateles geoffreoyi* an area of 250-500 km^2 was estimated as the requirement for the survival of 500 individuals in Mexico (Estrada & Coates-Estrada, 1996).

In terms of the number of individuals required for a population to persist, the term *Minimum Viable Population* and the 50/500 rule is sometimes referred to. The minimum viable population (MVP) size refers to 'the smallest isolated population having a 99% chance of remaining extant for 1000 years despite demographic, environmental and genetic stochasticity and natural catastrophes (Shaffer, 1981). The concept has been extensively reviewed since the 1980's (see Henriksen, 1997; Rai, 2003). The 50/500 rule, suggested by Soulé (1980) and Franklin (1980) is based on a maximum value of 1% inbreeding per generation. It suggests 50 individuals as the effective population size in the short term (100 years) and 500 for the long term. This rule has been widely criticized for not being applicable to real, wild populations. The main reason being that wild populations are likely to fall into inbreeding depression faster. Therefore, Lande (1995) suggested an estimated number of 5000 individuals to maintain a healthy and viable population over time.

In primates, particularly in *Brachiteles hypoxanthus* (close relatives to spider monkeys) a population of 171 individuals living in an 890 ha forest, was considered viable for the next 100 years by Brito & Grelle (2006) and Strier (2000). Specifically, for *Ateles fusciceps*, a threshold of 250 individuals was proposed by Dowd (2009), predicting that inbreeding would not have an effect on the population in the next 45 years.

It is important to point out that the MVP size (i.e. 500) will vary from species to species, due to inherent variability and demographic constraints, as well as environmental stochasticity (Rai, 2003). For example, research indicates that increasing stress in the environment, such as deforestation, can actually increase the effects of inbreeding, therefore raising the extinction risk (Frankham, 2005).

Working towards the conservation of endangered species it is crucial to look at the relationship between both the inherent demographic and genetic characteristics of the species and the anthropogenic activities threatening its survival.

Population density, subgroup size and demography of brown-headed spider monkeys (*Ateles fusciceps fusciceps*) in an unprotected forest in the Ecuadorian Chocó

3.1 Summary

Ateles fusciceps fusciceps is one of the 25 most endangered primates globally with an estimated population of 250 obtained more than 10 years ago. Current research on the population status of this primate and the area it inhabits in the Ecuadorian Chocó is urgently needed to aid in the design of specific and effective conservation strategies.

I surveyed the population of *A. f. fusciceps*, in the unprotected forest cooperative Tesoro Escondido, located in the buffer zone of the Cotacachi Cayapas Ecological Reserve using the line transect method. I collected data from January to June 2013 along three transects of approximately 4km each within an area of 3000 hectares obtaining an estimated density with DISTANCE software of 15.79 individuals/km^2 using a hazard-rate key function with simple polynomial adjustment and a 5% right truncation.

I found an average subgroup size of 3.42 individuals with an adult:subadult ratio of 1.38:1 and a female to male ratio of 1.91:1, which shows a female biased population.

Given the anthropogenic threats found around Tesoro Escondido, it is possible that this forest cooperative has become a sanctuary for spider monkeys. Further research is urgently required to better undestand the home range and forest connec-

tivity requirements of spider monkeys.

3.2 Introduction

The Ecuadorian Chocó, located in the NW of the country, harbours one of the 25 most endangered primates globally, the critically endangered brown-headed spider monkey *Ateles fusciceps fusciceps* (Schwitzer *et al.*, 2015; Tirira, 2011).

The main threats this primate faces are habitat loss, habitat fragmentation and hunting pressure, all of which have reduced its original distribution in Ecuador by 80% (Tirira, 2004). As other members of the genus *Ateles*, the brown-headed spider monkey's long interbirth interval and marked preference for ripe fruits and continuous old-growth forest, prevent a rapid population recovery to anthropogenic threats and hence make them more prone to extinction.

Unprotected forests around the Cotacachi Cayapas Ecological Reserve (CCER) have been identified as priority conservation areas for *A. f. fusciceps* through species-specific modelling and rapid surveys (Peck *et al.*, 2010). Particularly, the highest densities of this primate have been found in the forest cooperative Tesoro Escondido (Cueva, 2008; Moscoso, 2010). Unfortunately, prior to this project, there have been no long-term studies on the populations of *A. f. fusciceps* in the area. Reliable information on population density and demographics can contribute to a better understanding of the conservation status of this primate and hence aid in the design of more effective strategies for its protection.

There are various methods to estimate primate population densities, however there is no general agreement on which one is most accurate (Marshall *et al.*, 2008). Despite the practical challenges in complying with required assumptions, line transect methods are the most commonly applied techniques for assessing primate population densities (Marshall *et al.*, 2008; Buckland *et al.*, 2010; Peres, 1999). Moreover, as they are widely reported, these methods can be used to compare population densities between different areas.

Data collected in the present study was obtained as part of a broader project developing a spatially explicit agent-based model (ABM) for brown-headed spider monkeys, which incorporates hunting pressure, habitat fragmentation and logging activity as variables affecting populations of spider monkeys, hence determining its effect on the long-term survival of the species.

Obtaining reliable estimates on the population density and demographics of spider monkeys in Tesoro as a study site would provide the means to validate modelled results of densities in the ABM and was therefore the main objective of this study.

3.3 Methods

3.3.1 Study site

The study site is located within the Tesoro Escondido forest cooperative (referred to as 'Tesoro' hereafter) which lies in the buffer zone of the Cotacachi Cayapas Ecological Reserve (RECC) in the Chocó Biogeographic Region in NW Ecuador (0°31N 79°0 W), see Figure 4.1.

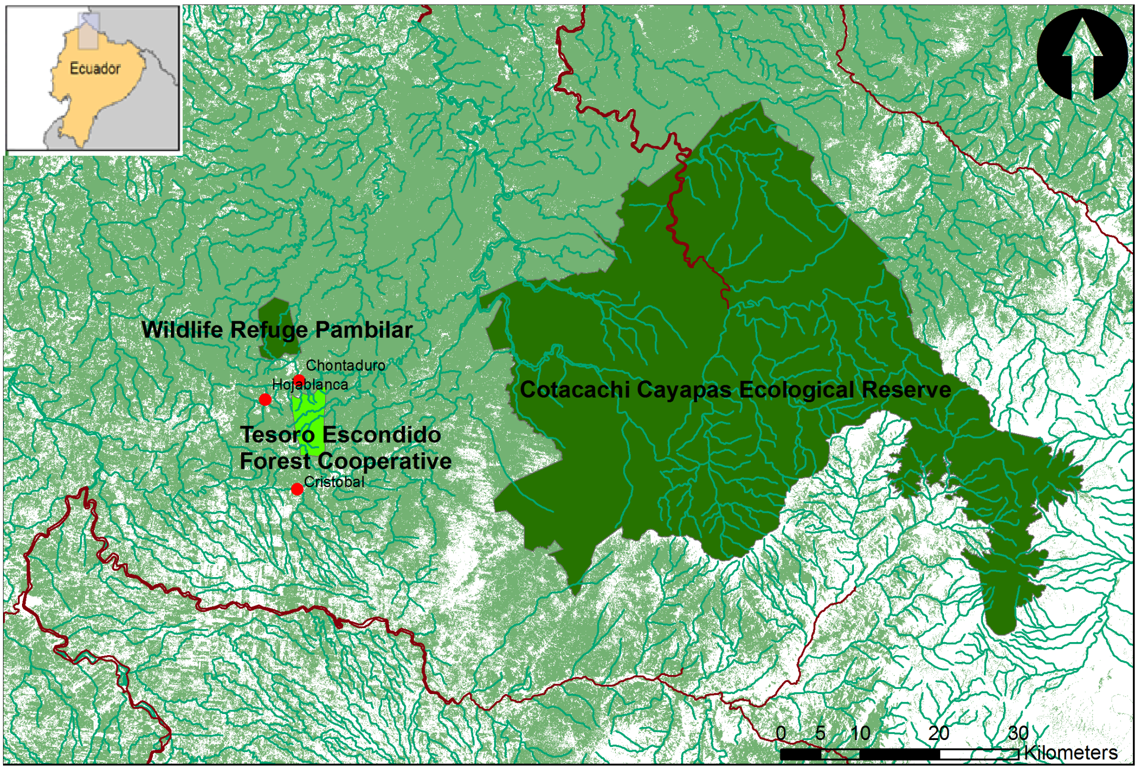

Figure 3.1: Location of the study site Tesoro Escondido in reference to the government protected areas Cotacachi Cayapas Ecological Reserve and Pambilar Wildlife Refuge in NW Ecuador. The three closes towns are represented by red dots. Green layer showing remaining forest in the region was adapted from Hansen *et al.* (2013)

The study area has been classified as evergreen lowland tropical forest by Sierra (1996), restricted in Ecuador to the province of Esmeraldas and north of Manabi.

Precipitation in the area ranges from 4000 to 9000 mm annually, with a mean of 6000 mm (Vargas, 2002; Freire *et al.*, 2005) with two distinct seasons in this area, the rainy season that runs from November until May and a dry season from June to October.

Tesoro covers 3000 hectares of land, of which approximately 6% has been converted into fields for crops and pasture by resident farmers, the rest is primary forest interspersed with a small proportion of secondary forest patches (pers. observation). Altitude in Tesoro ranges from 163 to 687 m.a.s.l.

As a remnant of the Chocó forests, Tesoro is incredibly biodiverse; in terms of primates, there are two more species in addition to *A. f. fusciceps*: Mantled howler monkeys (*Alouatta palliata*) and white-headed capuchins (*Cebus capucinus*) both listed as endangered by the Red List of Endangered Mammals in Ecuador (Tirira, 2011). Other endangered mammals found in Tesoro include jaguars (*Panthera onca*), white-lipped peccaries (*Tayassu pecari*) and pumas (*Puma concolor*).

Tesoro lies within a mosaic of social and economic influences that have an impact on the conservation of its forests. Development in the area is principally driven by oil palm and timber companies as well as agriculture (mainly cacao). The nearest human settlements from the study area are Hoja Blanca to the Northwest (6km), Chontaduro to the North (5km) and Cristóbal Colón to the South (15 km); Chontaduro being the only one with indigenous Chachi inhabitants. Hoja Blanca and Cristobal Colon are inhabited mainly by 'Colonos'. This term refers to people who arrived from other provinces to work the land.

3.3.2 Study design

Prior to the beginning of this study a transect of 4.5 km long (Trail A) was opened, this transect runs from North to South (Figure 3.2). Each 25 m point was marked with a GPS (Garmin eTrex Legend) and flagging tape. After 6 months two other transects of 4.3 km and 3 km respectively (Trail B and Trail D) were opened. Trail D in particular was interesting from the point of view that it extended beyond the borders of Tesoro into lands of another forest cooperative called '10 de Abril' that had not been previously surveyed. When I started the survey, this cooperative was in danger of being converted into a palm oil plantation.

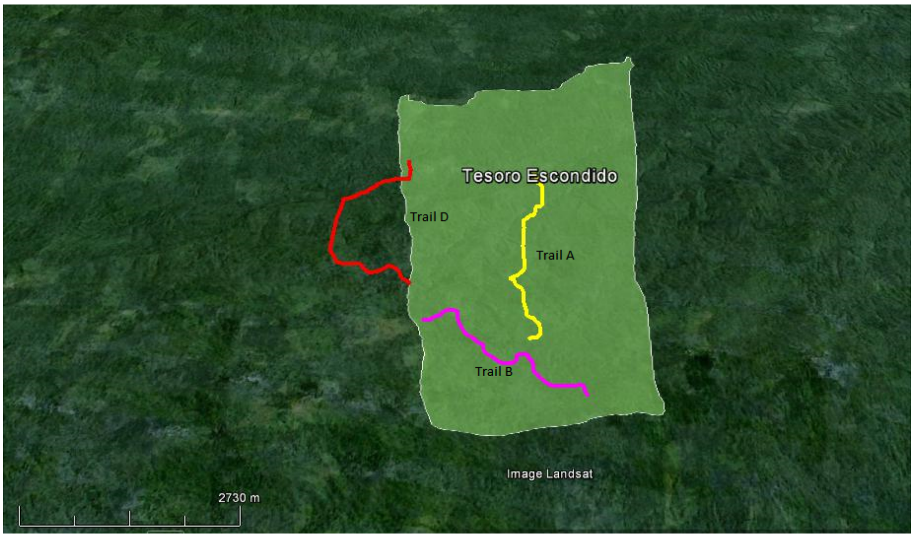

Figure 3.2: Location of the three transects used for population survey of *A. f. fusciceps* in Tesoro Escondido

Trail A was surveyed from July 2012 until June 2013. Trail B and D were surveyed from April 2013 until June 2013. For the census analysis I used data from all three transects from April 2013 until June 2013 for Trail B and D and from January until June 2013 for Trail A. Data from July 2012 to December 2012 for Trail A were not used as spider monkeys were not yet habituated to the presence of researchers. Furthermore, there were interruptions in data collections during September and October 2012.

Data collection for this chapter was conducted with the support of MSc student Denise Spaan alongside local parabiologists Galo Conde, Wagner Encarnación, Yonathan Loor and Nestor Paredes.

3.3.3 Habituation

At the start of this research project the population of spider monkeys in Tesoro Escondido had not been habituated to human presence as there had not been any previous long term studies in the region.

Habituation of the spider monkeys was safe to undertake at this site as there is no hunting of primates by either indigenous or colonists groups within Tesoro. For the habituation the team of researchers, volunteers and parabiologists working in Tesoro in this project followed guidelines by Williamson & Feistner (2003). Data collected in this study will also be used in a comparative study on the habituation process within the genus *Ateles* (Pinacho-Guendulain, B. pers. comm).

3.3.4 Population density of *Ateles fusciceps fusciceps*

I estimated population density of spider monkeys in Tesoro using the line transect sampling method. This method is commonly used to estimate the abundance of wild animal populations (Buckland *et al.*, 2001, 2004). I followed guidelines by Peres (1999) and Buckland *et al.* (2010) focused on surveying primate populations.

When using this method, lines are located randomly in the study site (commonly equally spaced parallel lines). An observer walks along each of these lines recording any animals detected within a perpendicular distance from the line, which is then used to estimate a detection function. This is the probability that an animal is detected, as a function of distance from the line. A density estimate can be then obtained as representative of the entire survey area. (Buckland *et al.*, 2010).

Data were collected from January 2013 to June 2013 for Trail A and April 2013 to June 2013 for Trail B and D. Surveys were conducted every day from 07.00 h to 12.00 h (one way on the Trail) and 13.00 h to 17.00 h (return) at a speed of approximately 1 km/hr stopping every 100 m and waiting for 2 min in silence to detect any sign of spider monkeys. If it was raining heavily, the census was paused until it ceased to a degree where it was possible to continue.

Whenever I detected a group of spider monkeys I recorded the following information: Date, time, number of individuals, reference point on the trail, and perpendicular distance (estimated distance from the transect to the centre of the group). Cluster size represents the size of the travelling or foraging subgroups of spider monkeys (Peres, 1999). Subgroups were defined as all individuals sighted within 150 m (Weghorst, 2007).

I used the free software DISTANCE 6.2 (Thomas *et al.*, 2010) to estimate population density. For the analysis I compared the following models: uniform with cosine and simple polynomial adjustment, hazard-rate with cosine and simple polynomial adjustment, and half-normal with cosine and hermite polynomial adjustments as suggested by Buckland *et al.* (2001) and compared in similar studies with primates by Link *et al.* (2010). I used the mean group size for all the analyses. I then chose the model with the lowest Akaike's information criterion value as suggested in Buckland *et al.* (2004).

3.3.5 Demography

At every sighting I also registered the age and sex category of each individual of the group if possible. I classified the age of individuals as described in Shimooka *et al.* (2008):

- Adults (A): Individuals fully grown, having reached their average size for the species and who exhibit a complete development of secondary sexual characteristics.
- Subadults (SA): Individuals who have reached the average size for the species, but that are still sexually immature.
- Juveniles (J): Individuals no longer carried by their mother however still dependent on her.
- Infants (I): Youngest individuals, unable to move independently, mostly seen carried by their mothers.

The sex of individuals was identified mostly by the presence of the conspicuous clitoris in females, as previously described by Shimooka *et al.* (2008).

3.4 Results

3.4.1 Population density

Table 3.1 summarizes the sampling effort for the three trails, the total number of surveys, total number of observations and the encounter rate.

The best model for the data was the hazard-rate key function with a simple polynomial adjustment with the 5% right truncation to improve model fit as suggested by Buckland *et al.* (2001).

I obtained a density estimate of 4.43 ($\pm$ 0.45; 95% CI: 3.63-5.39) groups/km^2 with an expected group size of 3.56 ($\pm$ 0.14; 95% CI: 3.30-3.85). The estimated population density of brown-headed spider monkeys in Tesoro is 15.79 ind/km^2 ($\pm$1.70; 95% CI: 12.78-19.51).

Figure 3.3 shows the probability of detecting brown-headed spider monkeys on the trails with a cut-off point of 60 meters (performed by the 5% right truncation).

Table 3.1: Summary of population estimates in Tesoro

Trails	**Sampling effort (km)**	**Number of surveys**	**Number of individuals observed**	**Encounter rate (individuals/km surveyed)**
Trails A, B, D	991.7 km	328	244	0.246

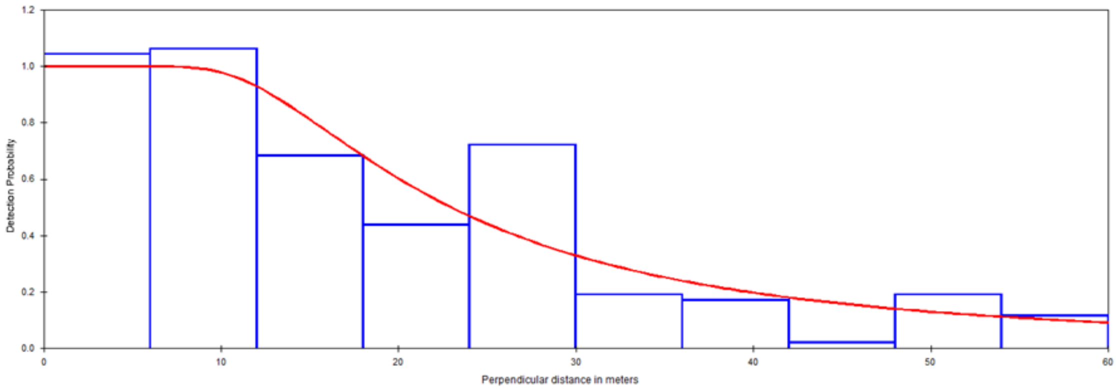

Figure 3.3: Detection curve of the hazard-rate key function with a simple polynomial adjustment with the 5% right truncation showing the probability of detecting spider monkeys on trails.

3.4.2 Demography of *Ateles fusciceps fusciceps* in Tesoro

For the demography analysis I used data from July-December 2012 and from January-July 2013 (Data collection was interrupted during the months of September and October 2012). During 10 months of survey, I encountered 1683 spider monkeys in 466 subgroups. Average subgroup size was 3.42 individuals. The female to male ratio was 1.91:1 whereas the adult to subadult (including juveniles and infants) ratio was 1.38:1. In the case of infants there were a high number of individuals of unknown sex since concealed genitalia makes sexing complicated (as previously mentioned by Weghorst (2007).

Table 3.2 summarizes the composition of spider monkey groups in Tesoro; Figure 3.4 shows the number of individuals observed in subgroups.

Table 3.2: Composition of the population of brown-headed spider monkeys in Tesoro

Age category	Sex	Total individuals
Adults	Males	244
	Females	398
	Females w/inf	191
	Unknown	80
Subadults	Males	106
	Females	114
	Unknown	15
Juveniles	Males	43
	Females	50
	Unknown	36
Infants	Males	28
	Females	53
	Unknown	202
Unknown	Unknown	121

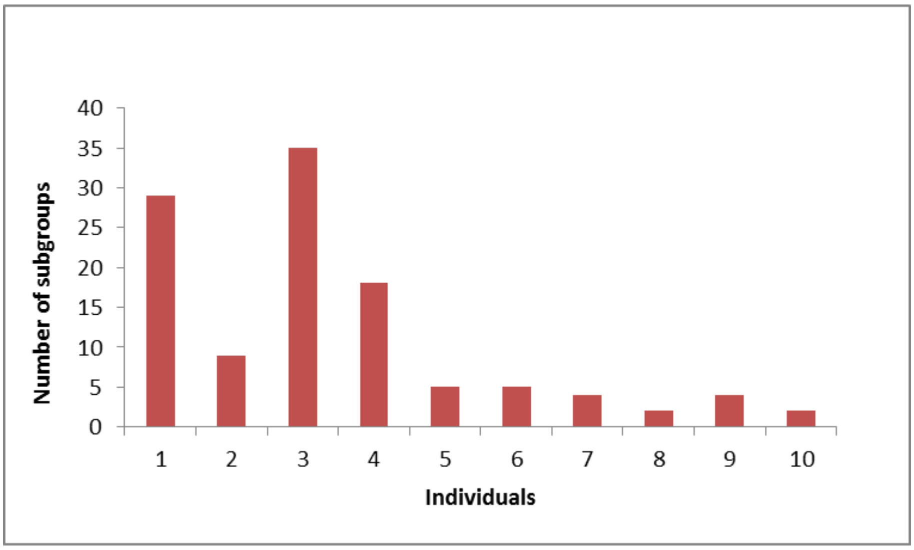

Figure 3.4: Number of individuals observed in subgroups in Tesoro

3.5 Discussion

The estimates of population density in Tesoro obtained are consistent with the ranges of population density reported for the genus *Ateles* (see comprehensive review in Ramos-Fernandez & Wallace (2008)). Furthermore they are also consistent with previous rapid census in the area by Cueva (2008) who reports a population density of 16.6 ind/km^2 and Moscoso (2010) who found a density of 8.9 ind/km^2.

The main limitation of this study was the low number of transects, and the fact that the transects are located in natural paths used by spider monkeys (i.e.

mountain ridge), which could have contributed to an additional overestimation of the population density in the analysis. Nevertheless, estimates obtained using the line transect method provided reliable and comparable results.

The model chosen to estimate the population density (hazard-rate key function with simple polynomial adjustment) is consistent with Buckland *et al.* (2001), who mentions hazard-rate key functions as the most adequate to describe primate populations.

Average subgroup size is consistent as well with reports for the genus (see comprehensive review by Shimooka *et al.* (2008)). However I did find that the adult:subadult ratio (1.38:1) in Tesoro may be different to that generally reported for the species, where normally there are more subadults, juveniles and infants in groups of spider monkeys. Our findings may be partly due to inexperience in identifying subadults at the beginning of the study, where I would see them for only a few minutes before they would disappear. The female:male ratio is consistent with what is reported for the genus showing a female bias, (Shimooka *et al.*, 2008).

My results corroborate the importance of the forest cooperative Tesoro Escondido as a site with the highest spider monkey density recorded in NW Ecuador and hence a conservation priority in the area. It is possible that due to the surrounding threats such as timber extraction, agricultural frontier expansion and hunting activity, Tesoro is acting as a 'sanctuary' for spider monkeys. Future research in the area should include long-term surveys in other unprotected forests in the region in addition to models on connectivity and population genetics.

Diet of the critically endangered brown-headed Spider Monkey *Ateles fusciceps fusciceps* in the Ecuadorian Chocó: Conflict between primates and loggers over fruiting tree species

4.1 Summary

Identifying key food resources for critically endangered species is vital in the design of effective conservation strategies, particularly if these resources are also targeted by anthropogenic activities such as logging. The province of Esmeraldas in NW Ecuador is heavily dependent on commercial logging. It also maintains the only healthy population of the critically endangered brown-headed spider monkey (*Ateles fusciceps fusciceps*). The unprotected forest remnant of Tesoro Escondido, in the buffer zone of the Cotacachi Cayapas Ecological Reserve, is home to an estimated 130 individuals of a global population of approximately 250. There is an urgent need for information to develop effective conservation action plans for the species, in particular the impact of logging activity on key feeding resources. I characterised the floristic composition of the habitat of *A. f. fusciceps* and estimated the availability of fruit resources for the annual cycle of 2012-2013 in sixteen 0.1 hectare vegetation plots. I determined feeding preferences for *A. f. fusciceps* using behavioural observations applying the Chesson ε index to identify key feeding tree species. I reviewed regional logging permits to identify species targeted for extraction by the timber industry and calculated extraction volumes in primary forest for key feeding tree species to identify potential conflict between logging and primate

diet. I identified 65 fruiting tree species from 34 families that formed the diet of *A. f. fusciceps*. The Chesson ε index identified twelve species as *preferred species* with further phenological observations identifying seven species as *staple foods* and two palms as potential foods consumed in times of fruit scarcity. Additionally, high densities of the lipid rich fruits of *Brosimum utile* make this an important resource for this primate throughout the year. Of 65 feeding tree species identified for *A. f. fusciceps*, 35 species are also targeted as sources of timber. Five key feeding species would be depleted under current sustainable management extraction protocols while two other species would be significantly impacted in terms of local abundance. Given the critically endangered status of *A. f. fusciceps* remaining primary forest in NW Ecuador requires urgent protection, including thorough revision of current logging protocols to ensure long term survival of the species.

4.2 Introduction

The brown-headed spider monkey *Ateles fusciceps fusciceps* is one of the 25 most endangered primates globally (Schwitzer *et al.*, 2015), it is considered critically endangered (IUCN Red List 2015, 2015) with an estimated remaining population of 250 individuals (Tirira, 2004). They can be found in the tropical and subtropical forests of Esmeraldas province (NW Ecuador) within the Tumbes-Chocó-Magdalena biodiversity hotspot (Myers *et al.*, 2000). As with other biodiversity hotspots, this forest ecosystem is characterized by its high levels of endemism and accelerated historical and current rates of habitat loss. The main threats faced by the brown-headed spider monkey are habitat loss and hunting, both of which have caused a reduction of 80% in population size over the last 45 years (Tirira, 2004).

Habitat loss in Esmeraldas is mainly a result of commercial and domestic timber extraction and land conversion to monocrops, such as the African palm. Esmeraldas has become one of the principal exporters of monocrop products, such as palm oil and banana. The palm oil business is considered to have converted between 60,000 and 100,000 hectares of forest in that province (Buitrón, 2001). Regional reports suggest that coastal forests in Western Ecuador have been reduced to 2% of the original coverage, leading to a rapid reduction in wildlife, especially in forests below 300 m.a.s.l., which are not included within current national protected areas (Critical

Ecosystem Partnership Fund, 2005).

Habitat loss in particular has affected populations of *A. f. fusciceps*. The species requires a large home range of old growth unfragmented forest with sufficient fruit resources and forest loss has drastically reduced its population densities (Madden & Albuja (1989b); Tirira (2004)). Moreover, in NW Ecuador the remaining suitable habitat of 989km^2 lies in unprotected areas (Peck *et al.*, 2010).

Primates of the genus *Ateles* are forest dwelling, frugivorous and heavily dependent on ripe fruits; between 75% and 90% of their diet is based on fruit (Wallace, 2005; Di Fiore *et al.*, 2008). They also feed on new leaves (preferring the leaves of trees from families Cecropiaceae, Menispermaceae, Malvaceae, Passifloraceae and Fabaceae) and consume flowers, insects and seeds in lower proportions. The genus *Ateles* is considered a ripe fruit specialist, with a high preference for fruits with elevated nutritional content (such as proteins and lipids) over nutritionally poorer yet more abundant food resources (Dew, 2005; Stevenson, 2000a).

In disturbed and fragmented habitat the availability of some plant species is reduced, leading to significant impacts on nutrition, physiology and stress to spider monkeys (Pozo-Montuy & Serio-Silva, 2006). Temporal and spatial variation in the availability of fruit has also been reported to have major repercussions on the distribution, grouping, sociality and reproduction of primates (van Schaik *et al.*, 1993). For instance, it has been observed that reproduction coincides with times of maximal fruit production (Knott, 1998), most probably to maximize survival of newborns (Di Fiore *et al.*, 2008). It is important to note that the high degree of fission-fusion shown by spider monkeys is also thought to be related to resource availability (Di Fiore *et al.*, 2008).

Spider monkeys play a vital role in the maintenance of the diversity of the forest in terms of ecosystem function as seed dispersers (Stevenson, 2000b), especially in NW Ecuador, where *A. f. fusciceps* is the only arboreal disperser of large seeded fruit trees and hence plays a critical role in tree diversity in these forests (Calle-Rendón *et al.*, 2016). Reduction in abundance of spider monkeys may also impact the ecological sustainability of selectively logged forests (Link & Di Fiore, 2006). NW Ecuador, particularly Esmeraldas province, relies economically on activities associated with commercial logging (Stallings & Sierra, 1998; Sierra, 2001); it is also the province where the only healthy population of *A. f. fusciceps* has been found (Moscoso, 2010). The relationship between species targeted by commercial timber extraction and key resources for spider monkeys has been previously reported by Felton *et al.* (2010) in a reduced impact logging (RIL) concession in Bolivia, however, this is the first study in NW Ecuador investigating conflict over key resources between logging activity and spider monkeys.

Identifying key food resources for this endangered primate is vital for their effective conservation. Furthermore establishing whether competition exists between *A. f. fusciceps* and the timber industry over these resources would enable more effective design of forest management plans to ensure species survival. In this study our objectives were to: 1) Characterize the floristic composition of the habitat of *A. f. fusciceps*; 2) Estimate the availability of fruit resources for brown-headed spider monkeys throughout an annual cycle; 3) Identify key feeding tree species and 4) Based on legal regional logging permits, identify conflict between feeding requirements of *A. f. fusciceps* and logging activity.

4.3 Methods

4.3.1 Study site

The study site is located within the Tesoro Escondido forest cooperative (referred to as 'Tesoro' hereafter) which lies in the buffer zone of the Cotacachi Cayapas Ecological Reserve in the Chocó Biogeographic Region in NW Ecuador (0°31N 79°0 W). This study site was chosen as it harbours the highest density of *A.f.fusciceps* in NW Ecuador (Cueva, 2008; Moscoso, 2010).

The study area has been classified as evergreen lowland tropical forest by Sierra (1996). This type of vegetation is restricted in Ecuador to Esmeraldas Province and areas north of Manabi (Sierra, 1999). It is characterised by the presence of trees taller than 30 metres and dominated by species of the families Myristicaceae, Arecaceae (Palmaceae), Moraceae, Fabaceae and Meliaceae.

Mean annual precipitation in the Chocó ecoregion is 6000 mm, ranging from 4000 to 9000 mm annually (Vázquez & Freile, 2005; Vargas, 2002) with two distinct seasons. The rainy season runs from November until May and the dry season from

June to October. Altitude in Tesoro ranges from 163 to 687 m.a.s.l. The nearest human settlements to the study area are Hoja Blanca to the Northwest (6 km), Chontaduro to the North (5km) and Cristóbal Colón to the South (15 km), whereas the nearest protected areas are El Pambilar Wildlife Refuge to the North (8 km) and the CCER to the Northeast (30 km) (see Figure 4.1).

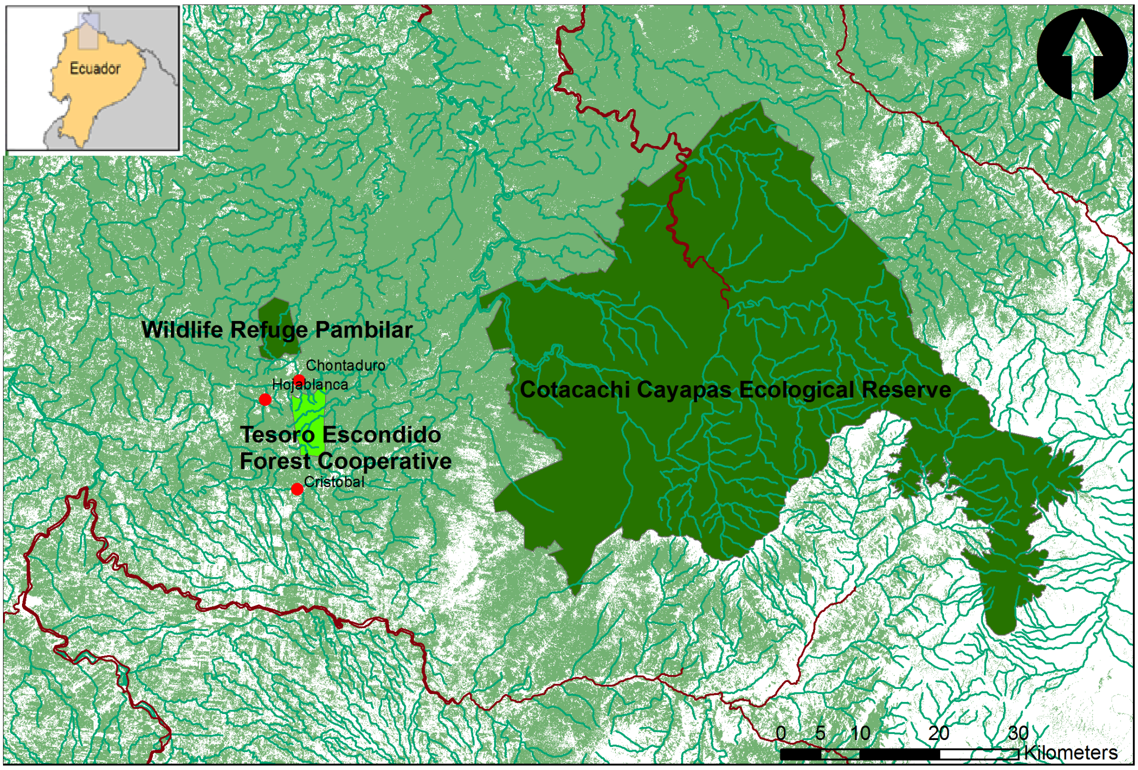

Figure 4.1: Location of the study site Tesoro Escondido in reference to the government protected areas Cotacachi Cayapas Ecological Reserve and Pambilar Wildlife Refuge in NW Ecuador. The three closes towns are represented by red dots. Green layer showing remaining forest in the region was adapted from Hansen *et al.* (2013)

Tesoro encompasses around 3000 hectares of unprotected land, of which approximately 6% has been converted into fields for crops and pasture by resident farmers. The remainder is primary forest interspersed with small secondary forest patches (pers. obs.).

As a remnant of the Chocó forests, Tesoro is incredibly biodiverse (Myers *et al.*, 2000), however it also lies within a mosaic of social and economic influences which impact on the conservation of its forests. The agricultural frontier advances towards primary forests mainly through establishment of cacao plantations and expansion of pastures, moreover pressure from extractive companies in the area is further reducing and fragmenting primary forests at a rapid pace.

Commercial timber extraction is principally undertaken by two companies: Endesa-Botrosa S.A and Verde Canandé. The timber company Endesa-Botrosa S.A. operates in lands around Tesoro in the Canandé Watershed. It legally owns at least 25 thousand hectares of primary forest, and 600 hectares are in Tesoro itself. Verde Canandé is a smaller timber company also operating around Tesoro, established as a community based business, with the aim of practicing low impact timber harvest and implementing sustainable forestry. This company owns around 500 hectares.

All data for this chapter was collected with the support of BSc. Andrea Tapia, MSc Bayron Calle, and local parabiologists Nestor Paredes, Galo Conde and Yonathan Loor.

4.3.2 Study design

Prior to sampling I opened a 4.5 km transect (trail A) in a North to South direction at Tesoro. I mapped the transect by taking GPS points (Garmin eTrex Legend) at 25 m intervals and marking each point with flagging tape. I used this transect principally for primate population and behavioural surveys.

As no phenological studies for this particular forest exist and there is no dietary information for *A. f. fusciceps* , I applied the Area Based Method as suggested by Marshall & Wich (2013). This method provides phenological data for potential food species, allowing further analysis for feeding selectivity. It monitors all plant stems that meet a basic criterion (i.e. Diameter at Breast Height (DBH) >10cm) within a delineated area (plot), throughout the focal species range (Marshall & Wich, 2013).

I established 16 rectangular plots (Marshall & Wich, 2013) of 10m x 100m every 250 m on either side of the existing transect. Stems were included within the plot if more than half of the stem area fell inside the plot.

In each plot all trees with a DBH greater than 10 cm were tagged and identified on site to species level by a local expert where possible. For each tagged tree I measured DBH and estimated its height. For trees whose identification was not possible on site, samples were collected following standard protocols (Rodriguez & Rojas, 2006) for further identification at the National Herbarium in Quito. Lianas were not included in the phenology surveys.

Each month from July 2012 to July 2013 the crowns of all individual trees were inspected with binoculars, to detect the presence of flowers and fruits. As I was unfamiliar with the fruits I did not make any distinction between ripe and immature fruits.

4.3.3 Fruit availability

I calculated a monthly index of fruit availability for spider monkeys in Tesoro using the basal area of trees. Basal area is considered to be an accurate index of fruit crop size (Peters *et al.*, 1988), and has been previously used by Felton *et al.* (2008) to estimate food availability in a study on Peruvian spider monkeys (*Ateles chamek*). I included all trees from the vegetation plots as I did not know *a priori* which species formed part of the diet of *A. f. fusciceps.* I also included trees that were recorded as feeding trees during behavioural field observations of spider monkeys but were not present in the plots.

For trees I calculated the index as follows:

Monthly Tree index (index T):

$$\text{IndexT} = \sum_i (pi \times BAi) \times 100 \tag{4.1}$$

where pi is the proportion of surveyed individuals of species i that were observed carrying fruits or flowers each month, and BAi is the basal area per hectare of species i.

I also calculated an index for palms. In this case I did not use the basal area for the calculation since palm trunks do not grow incrementally and are therefore not a good indicator of fruit crop size. Instead I used their densities, as described in Felton *et al.* (2008).

Monthly Palm Index (Index P):

$$\text{IndexP} = \sum_i (pi \times di) \times 100 \tag{4.2}$$

where pi is the proportion of surveyed individuals of palms observed carrying fruits or flowers each month and di is the density of palms.

4.3.4 Feeding tree species for *A. f. fusciceps* in Tesoro

Activity budget data were collected by following and observing groups of spider monkeys both on and off Trail A. I carried out 10 minute instantaneous group sampling (adapted from Altmann (1974) to record subgroup numbers, composition and activity. When an individual or a subgroup of spider monkeys was observed feeding on a tree for more than five minutes the species of tree (if known) and the plant part (flower or fruit) was recorded. The tree was tagged, DBH measured and a geographic positioning system (GPS) waypoint was taken. I used a correlation test (Spearman's correlation coefficient) to determine whether the size of trees (DBH) was related to the time spent feeding by spider monkeys. Fruit samples of feeding trees were collected, dried and bromatological analysis was undertaken in the Food Laboratory at the Universidad San Francisco de Quito (USFQ), to determine their caloric value. Values obtained were: percentage of water by using the Halogen Lamp Method, crude protein by the Kjeldahl Method (Barreto *et al.*, 1990) and lipids by the Soxhlet Method (Soxhlet, 1879).

4.3.5 Preference index

I calculated a selectivity index (Chesson ε index) to determine food species preference for *A. f. fusciceps.* This index compares the proportion of a given tree species in the diet with the relative availability of the trees in the environment. It allows ranking of tree species in order of frequency in the diet. Its main advantage is that it is unaffected by changes in relative tree species abundance (Chesson, 1983).

This index is based on Manlys α selection index, applicable in situations where the feeding activity is assumed not to deplete the plant species, as is the case with spider monkeys. Chesson's ε (Chesson, 1983) ranges from -1 to +1. Negative values represent fruits that are 'avoided' (according to Chesson, 'avoidance' refers to those species appearing less frequently in the diet than their availability in the environment allows). An index value of 0 suggests no selective feeding on that particular plant species. This index has previously been used in the study of food selection by primates (i.e. Harrison (2009); Rivera & Calmé (2005) and is calculated as follows:

$$\varepsilon = (m\alpha - 1)/((m-2)\alpha + 1, \tag{4.3}$$

where m is the total number of fruit species in the diet; α is calculated as follows:

$$\alpha = \frac{ri/pi}{\sum_i (ri/pi)} \tag{4.4}$$

where ri is the percentage of time primates spend feeding on species i throughout the year and pi is the relative abundance of species i in the environment (based on basal area/ha from vegetation plots). Due to the small number of observations of feeding activity on leaves and flowers, they were not included in the analysis.

4.3.6 Identifying conflict over keystone feeding trees

I requested access to permits granted for timber extraction from the Ecuadorian Ministry of Environment (MAE) for the Esmeraldas Province from the past four years (2010-2014) for each tree species. This information is available to the public upon official request. They contain the specific location of extraction with coordinates, type of extraction programme (i.e. native trees, sustainable extraction, plantation) name of the company (or person) responsible for the plot, the duration of the permit (mostly between 90 and 365 days), the tree species (with scientific and common names), the size of the land in hectares, the volumes approved to be extracted and the volumes that were actually extracted and mobilized.

I filtered the information to obtain volumes approved for extraction only for the species that I identified as key species for spider monkeys (see Chesson index results) as well as staple fruit trees (trees that were consumed throughout the year). For these species I chose the highest volume per hectare that was approved for extraction based on their sustainable extraction protocols.

I calculated the volumes of key fruit species from the vegetation plots and subtracted the maximum volume per hectare. I then compared the original available volume of key fruit species per hectare in our plots with that following the hypothetical extraction of the maximum volume approved for each species to identify potential conflict between logging and diet.

4.4 Results

4.4.1 Floristic composition of the forest in Tesoro

The vegetation plots covered a total area of 1.6ha and contained 621 individual trees with DBH >10cm. I identified 101 individual species of trees belonging to 68 genera and 37 families. Of the 621 trees, 57 of them could not be identified to species level, this was due to difficulty in obtaining adequate samples.

The dominant family with 135 individuals was Palmaceae, 76 belonging to the genus *Iriartea* species *Iriartea deltoidea* and 59 to the genus Wettinia species *Wettinia quinaria*. The second most common family was Moraceae with 65 individuals. Most belonged to the genus *Brosimum* (dominated by *Brosimum utile*). The complete list of species in Tesoro is presented at the end of this chapter.

4.4.2 Phenology

The highest number of trees carrying fruits was observed in the month of July, with almost 25% of trees in the plots carrying fruit. A second peak was observed in the month of May. December and January showed the lowest level of fruiting trees in the plots (Figure 4.2).

There is a clear fruiting peak in the months of July and August and a decrease in the amount of available fruit in the months of December and January. Conversely, the availability of fruits from palms shows that there is an increased availability of fruits in November and a lower abundance in July (See Figure 4.3), however palms provided ripe fruit almost continuously throughout the year.

Seven species of trees carried fruit for at least 10 months of the year; (*Brosimum utile, Hortia brasiliana, Trema integerrima, Virola sebifera, Protium ecuadorense, Jacaratia spinosa, Pouruma chocoana*. In addition, at least 8 species from the genus *Inga* and the two palms *Iriartea deltoidea* and *Wettinia quinaria* also carried fruit for most of the year. Of these, four species bore fruit throughout the year (*Brosimum utile, Hortia brasiliana, Trema integerrima* and *Virola sebifera*). All of these continuously fruiting species were seen to be part of the diet of *A. f. fusciceps* hence I refer to them as *staple foods*.

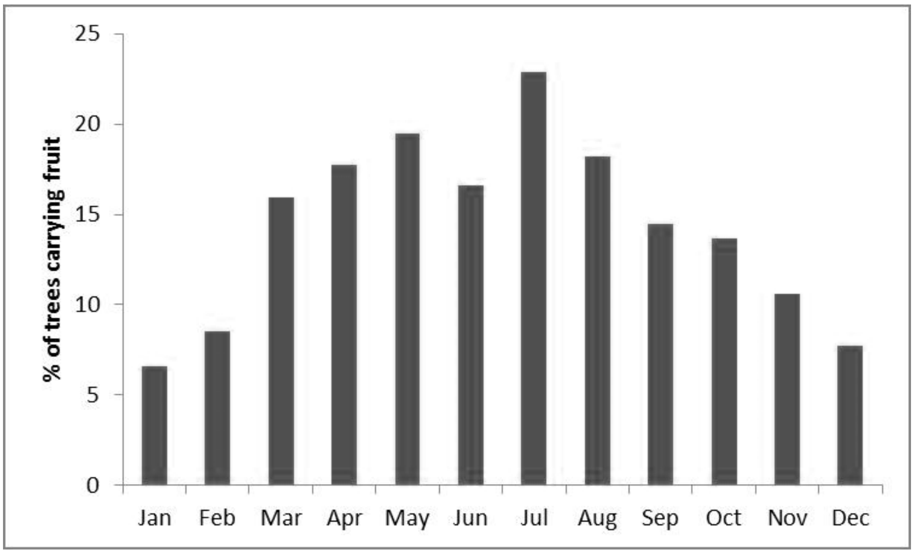

Figure 4.2: Percentage of fruiting trees per month in Tesoro, July 2012 to July 2013.

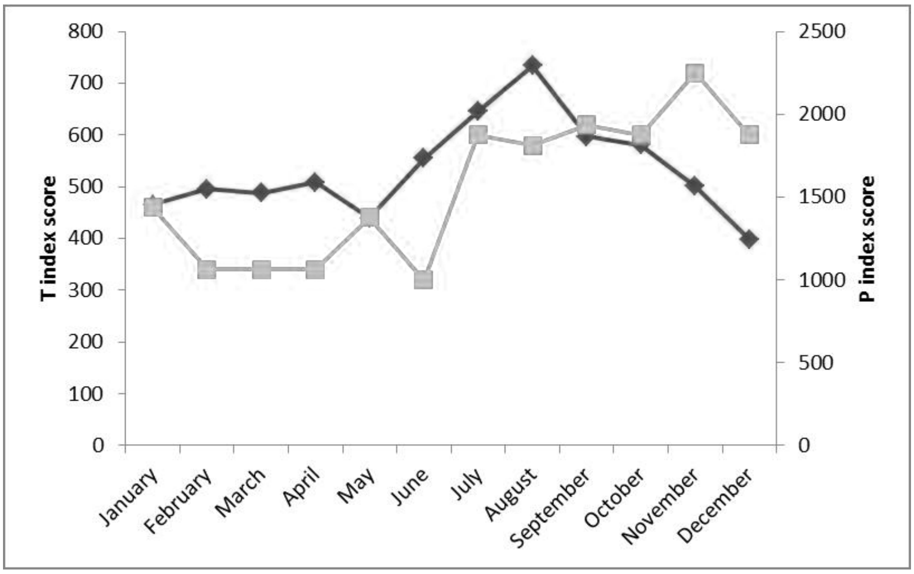

Figure 4.3: Monthly availability of fruit resources from trees in Tesoro Escondido, July 2012 to July 2013 shown in light grey compared to available fruits from trees shown in dark grey. I included 78 species from vegetation plots and feeding trees

4.4.3 Feeding trees of *Ateles fusciceps fusciceps* in Tesoro Escondido

Between July 2012 and December 2013, I tagged 296 different feeding trees. 65 feeding trees were identified to species level. Feeding trees belong to at least 34 families and 51 genera (See end of chapter for a complete list of feeding trees). Palmaceae was the dominant family with 42 trees (all of them belonging to the species *Iriartea deltoidea*), followed by Moraceae with 35 trees; 15 of which were *B.utile* and third, Myristicaceae (35 trees). The highest number of feeding tree species used by spider monkeys were in the months of August and July (Figure 4.4). The mean DBH for all species of feeding trees was 55.5 cm (Figure 4.5). There was a positive correlation between the size of feeding trees (DBH) and time (in minutes) spent feeding on them ($r = 0.24$, $n = 244$, $p < 0.001$) (Figure 4.6). In total 14 species of trees accounted for 80% of the total time spent feeding by spider monkeys: *Iriartea deltoidea; Hortia brasiliana; Pouruma chocoana; Brosimum utile; Inga.sp.; Nectandra guadaripo; Clarisia biflora; Garcinia madruno; Solanum sp.; Minquartia guianensis; Calocarpum sapota; Virola dixonii; Ziziphus cinnamomum* and *Matisia sp.*). In *ad libitum* observations, spider monkeys were also seen feeding on lianas, flowers, new leaves, seeds and bark. I also observed them drinking water from bromeliads. No predation on other animals was observed.

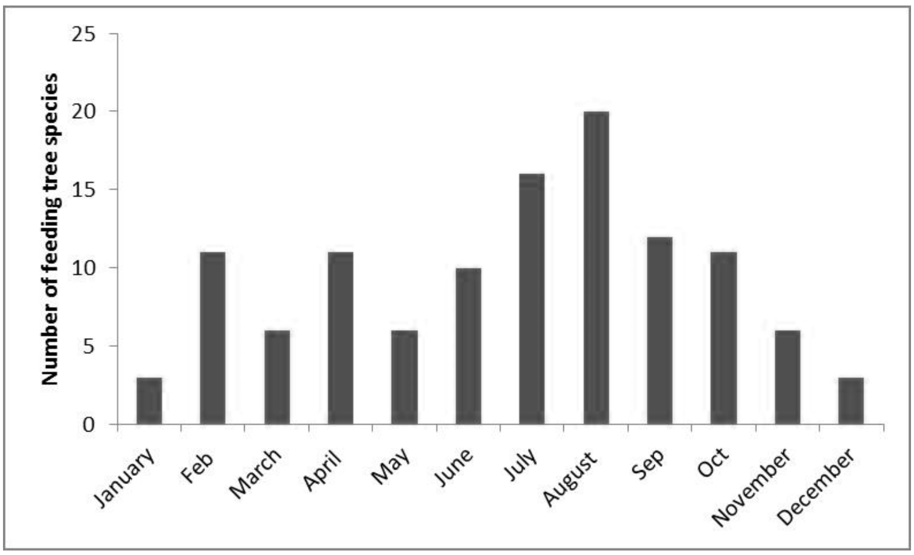

Figure 4.4: Number of feeding trees used per month by spider monkeys in Tesoro throughout the year

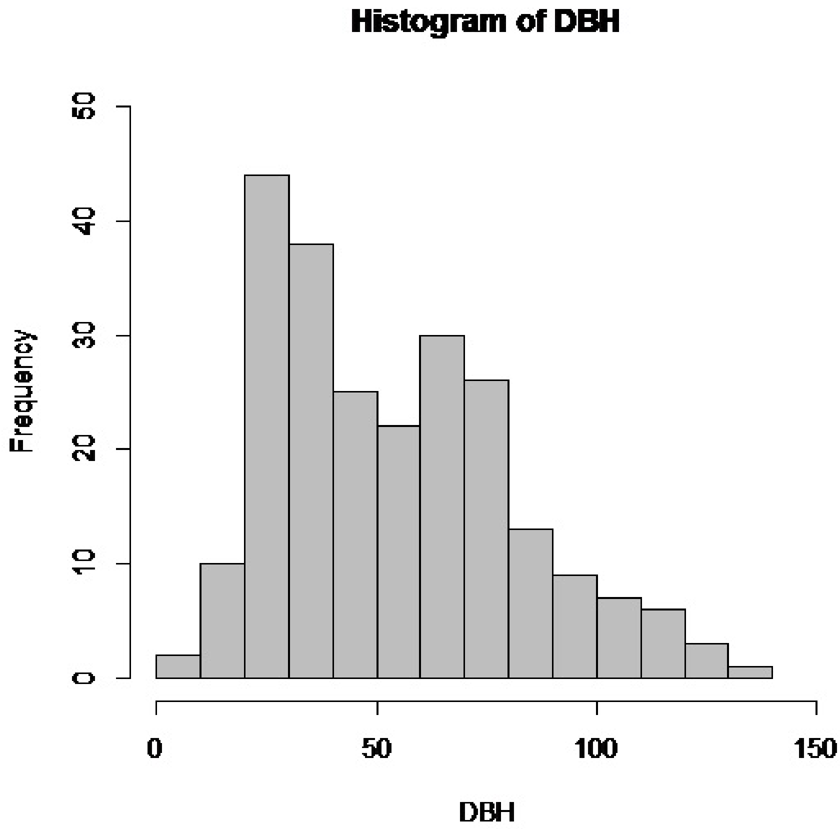

Figure 4.5: Frequency distribution of DBHs of feeding trees (palms not included) in Tesoro

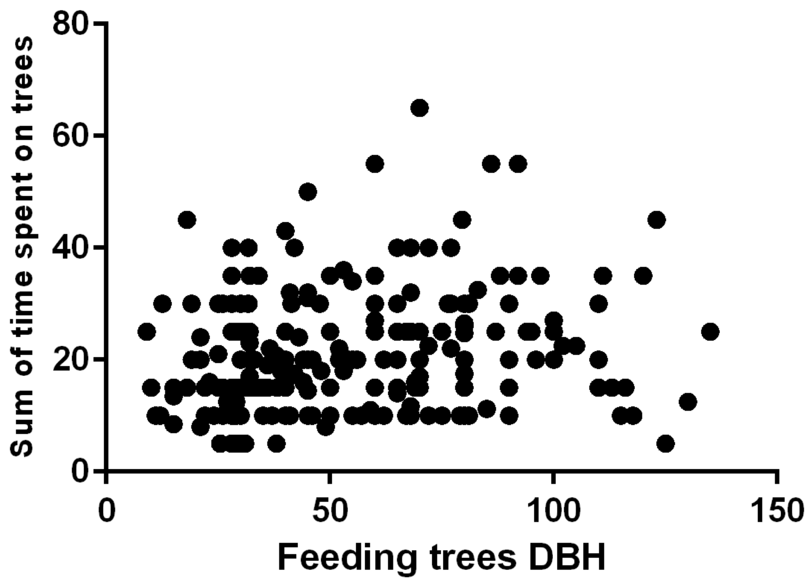

Figure 4.6: Scatterplot of time spent feeding by spider monkeys and tree sizes (DBH)

4.4.4 Feeding preference

Fruit from at least 59 species of tree were seen to be consumed by spider monkeys in Tesoro during the study. The Chesson ε index identified twelve as *preferred species* (see Figure 4.7). Bromatological analysis was carried out on 13 of these tree species (see Table 4.1). Results showed that species belonging to the genus *Inga* and species *Cleidion casteneifolium* provided the highest percentages of protein, whereas *Garcinia madruno* and *Brosimum utile* ranked higher in terms of percentage of lipids. Finally *Iriartea deltoidea* and *Solanum sp.* contributed higher percentages of carbohydrates.

Table 4.1: Nutritional value of 13 species of fruit in Tesoro Escondido

Species	Protein %	Lipid %	Carbohydrate %
Inga sp.	13.59	0.39	78.44
Hortia brasiliana	3.33	0.33	27.90
Garcinia madruno	2.95	12.35	77.50
Calocarpum sapota	2.82	4.08	24.05
Ficus insipida	10.91	2.39	69.68
Ireartea daltoidea	1.25	0.43	92.57
Matisia soegengi	3.99	2.14	81.27
Brosimum utile	7.89	9.90	75.5
Clarisia biflora	1.54	1.31	13.33
Solanum sp.	5.72	1.90	84.30
Cleidion.castaneifolium	10.52	8.32	69.55
Isertia.sp.	8.20	1.09	80.64
Ziziphus cinnamomum	9.49	6.30	77.34

4.4.5 Selective logging in Tesoro

Logging permits obtained from the Ecuadorian Ministry of Environment (MAE) comprised data from 2010 to 2014. I requested data on extraction permits for individual tree species, of which 211 permits were granted for 81 different sites in Esmeraldas. Timber extraction was carried out under 8 different types of management programme: Sustainable management, simplified management, plantations, natural regeneration, pioneer species, relict trees, legal conversion and balsa plantations (For a detailed explanation of these management programs see MAE (2004). Permits were granted for a total of 133 species.

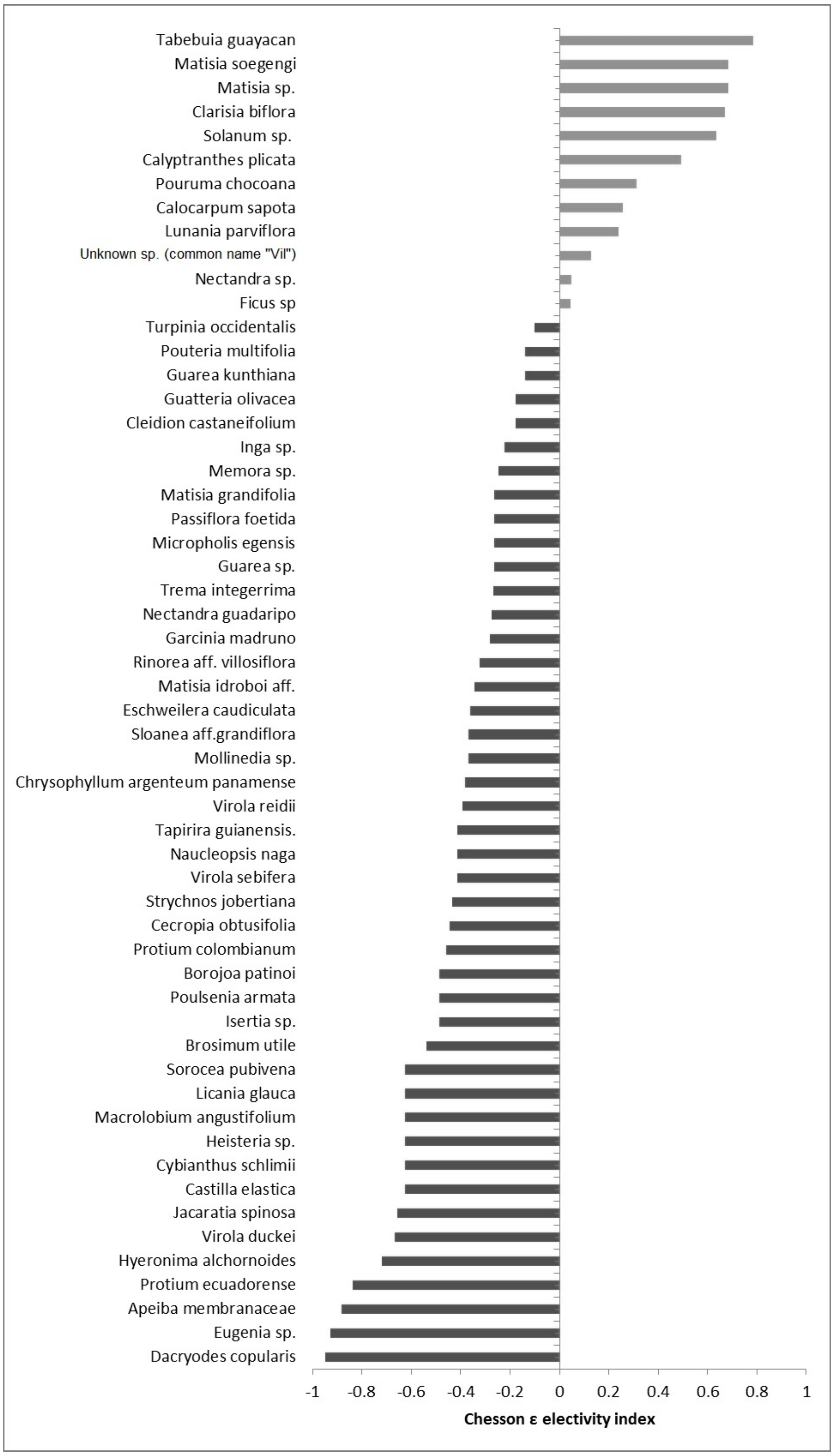

Figure 4.7: Chesson ε index values for the tree species used as food sources by *Ateles fusciceps fusciceps* in Tesoro Escondido. The higher the preference for a particular species, the higher the value (maximum value is 1). Complete avoidance is denoted by -1, while 0 represents random selection.

Of 59 feeding tree species identified in Tesoro, 35 species are also targeted as sources of timber, including *preferred fruits* and *staple fruits.* Of the 16 key species shown in Figure 4.8, five tree species would be depleted under current sustainable management extraction protocols (over 100% extraction allowed for *Virola spp, Pouruma minor, Matisia spp., Trema integerrima, Minquartia guianensis*). Two other species would be significantly impacted in terms of local abundance (69% reduction in abundance for *Ficus spp* and 90% reduction for *Protium ecuadorense*).

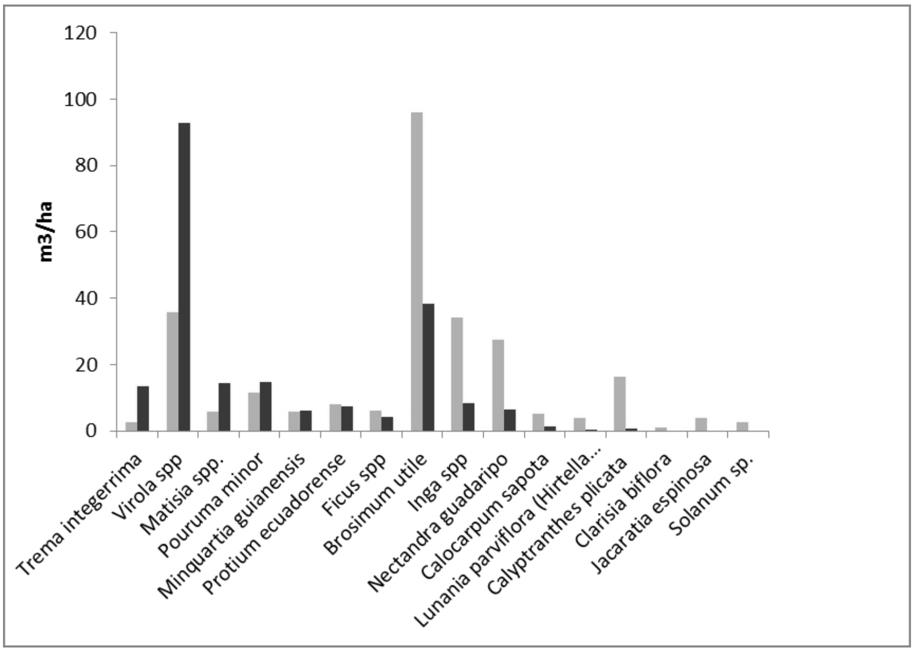

Figure 4.8: Volumes of key species for *Ateles fusciceps fusciceps* ; in light grey existing volume in Tesoro, in dark grey maximum volume approved for extraction in permits by the Ecuadorian Ministry of Environment.

4.5 Discussion

The results of our study in Tesoro Escondido, NW Ecuador, provide the first data set on dietary preference for the critically endangered brown-headed spider monkey.

Results of vegetation surveyed in Tesoro are consistent with other studies in the Chocó and in Esmeraldas Province (evergreen lowland tropical forest) (Sierra, 1999). I found at least 100 species (DBH >=10cm) in 1.6 ha, similar diversity to results from previous studies in the region (Valencia *et al.*, 1988; Palacios *et al.*, 1994; Tirado, 1994). The families Moraceae, Palmaceae and Fabaceae were dominant, however Meliaceae and Myristicaceae were underrepresented in Tesoro compared to studies by Sierra (1999). This study also registered species that had not been reported for the genus, mainly due to the unique nature of the area and the lack of studies in NW Ecuador, for instance *Pouruma chocoana*, native to the tropical forests of Ecuador (Jorgensen & Leon, 1999).

The area-based method, used for the vegetation plots, provided a good description of habitat and fruit availability, however this particular methodology is not focused principally on feeding tree species, which tend to be rare (Marshall & Wrangham, 2007). The hybrid method (combining the area-based method and survey of feeding trees found outside plots) would have provided more information on the specific phenology of feeding trees. I recommend future work to collect phenological data of identified feeding trees outside the existing vegetation plot network. The area surveyed by the vegetation plots provides valuable information, however in forests as diverse as the Chocó, the data fails to describe the full extent of plant diversity.

The pattern of fruit availability observed is similar to that seen at a site with similar rainfall patterns in Bolivia (Felton *et al.*, 2008). Data collection in December and January was carried out under heavy rainfall which potentially diminished the ability of observers in the field, and could account in part for the low T Index value seen for these months. On the other hand it is interesting to note that the availability of the Palmaceae family was high during these months. This suggests a role of palms as possible fall-back fruits for *A. f. fusciceps* in Tesoro when other sources of fruits are reduced.

If the percentage of trees carrying fruit and the T index per month are compared, a high percentage of trees in May carrying fruit is evident. However, we also observe a low T index value. The reason for this lies in the fact that the T index is calculated using the basal area, which derives from the diameter of trees. For May, there were a higher number of small fruiting trees (i.e. with a small DBH) resulting in a low overall T index value.

The analysis highlighted potential staple foods for *A. f. fusciceps* , in particular tree species fruiting throughout the year (*Brosimum utile, Hortia brasiliana, Trema integerrima and Virola dixonii*). Of these species *Trema integerrima* is not considered an important food resource for spider monkeys in Tesoro, based on both time spent feeding and the Chesson index. On the other hand, *A. f. fusciceps* did spend a significant percentage of their total time feeding on *Brosimum utile, Hortia brasiliana* and *Virola dixonii*. Furthermore, these three food species provide high levels of important crucial nutrients throughout the year.

My results corroborate the use of the genus *Brosimum* in the diet of *Ateles*, previously reported in other studies (Di Fiore *et al.*, 2008). My data confirms the importance of *Brosimum utile* in the diet of *A. f. fusciceps* that was initially observed in a two month pilot study, where Tapia (2014) reported a higher feeding effort (number of bites per fruit) for *B.utile* compared to 28 other species. This study concludes that *A. f. fusciceps* strongly favours this tree species. Furthermore, fruits from *B.utile* show a very high lipid content, which has been reported as a factor influencing dietary preferences, especially in times of ripe fruit scarcity and during reproduction (van Schaik *et al.*, 1993; Dew, 2005). It is interesting to note that I did not find *B.utile* amongst preferred food resources according to the Chesson index analysis. This is principally due its high abundance in Tesoro; the strength of the Chesson index is that it is a good method for identifying frequently used species that are at lower abundance. The importance of *B.utile* lies in the fact that it provides a high lipid food resource throughout the year for *A. f. fusciceps* , and hence we consider it a *staple food*. The Chesson index was however useful at identifying a key species in Tesoro: *Virola dixonii*, a high lipid food resource available throughout the year.

All the reported feeding data describes ripe fruit, however in *ad libitum* observations spider monkeys in Tesoro were also seen to feed on unripe fruits, leaves (mostly new leaves) and flowers (i.e. flowers from *Licania glauca*). I also observed them drinking water from bromeliads, which has been previously reported by Campbell *et al.* (2005) and by (Santorelli *et al.*, 2011) for *Ateles geoffroyi*. I never saw them descending to the ground, however I did find a potential salt lick and suggest placement of camera traps at this site to further investigate possible terrestrial behaviour (Blake *et al.*, 2010).

A limitation of this study was the fact that brown-headed spider monkeys were not habituated at the beginning of the field season, hence collecting data on activity took more time than expected. In order to habituate primates, researchers need to be able to follow groups or individuals throughout the day. However in areas of extreme topography, such as in Tesoro, this becomes nearly impossible. Even with this limitation, I managed to collect data on their diet and analyse food preferences. Comparing my results with data from long-term studies with habituated groups (Di Fiore *et al.*, 2008), I can conclude that this study provides a realistic overview of the dietary and feeding preferences of this species.

The positive correlation observed between time spent feeding and tree size (DBH) shows the preference of spider monkeys for larger trees which tend to carry larger volumes of fruit. The importance of this correlation in the context of a timber extraction area is that trees targeted by loggers, based on minimum harvesting diameters, are always larger than 40cm-60cm DBH (depending on species) (MAE, 2004). Spider monkeys are key seed dispersers and vital in the regeneration of the forest (Stevenson, 2001; Calle, 2013), in fact in my *ad libitum* observations spider monkeys would swallow entire fruits and defecate them intact. I only observed spider monkeys spit out the seeds of *I.deltoidea*, which has been previously reported by Link & Di Fiore (2006). I suggest further research on the role of *Ateles fusciceps fusciceps* as a keystone seed disperser in the Esmeraldas province.

This study is the first to analyse timber extraction regulations in the context of the conservation of the critically endangered *A. f. fusciceps* , whose main requirement for survival is primary continuous primary forests. My findings suggest that key tree species for *A. f. fusciceps* are also highly preferred as timber species, particularly *Brosimum utile* and *Virola spp (Virola dixonii).* They both rank in the highest number of granted permits and in the highest volumes approved for extraction. Even though spider monkeys can be flexible in terms of their feeding preferences, the loss of staple foods, especially nutrient-rich ones, are likely to have detrimental effects on primate populations, (See review by Cowlishaw & Dunbar (2000)).

Logging, even under sustainable forest management (SFM), has been shown to have serious negative impacts, both directly and indirectly on animal biodiversity (Zimmerman & Kormos, 2012) and on primates specifically (Peres, 2001; Rimbach *et al.*, 2013). Secondary impacts include road building, colonization and hunting (Zimmerman & Kormos, 2012).

Moreover, extensive research indicate that current government SFM protocols for tropical forests (minimum cutting cycle, minimum DBH limit, harvest intensity) are inadequate and guarantee commercial depletion and even extirpation of most timber species within three cutting cycles (see review by Zimmerman & Kormos (2012)). Recommendations by various studies suggest that shifting from industrial logging to small-scale community timber and non-timber forest management options, can result in the protection of tropical forest ecosystems that simultaneously promote sustainable livelihoods (Zimmerman & Kormos, 2012; Bray *et al.*, 2003).

Recommendations by the Ecuadorian Ministry of Environment suggest establishment of permanent protection zones in areas where the presence of endangered flora or fauna has been confirmed (MAE, 2004). Nevertheless, current management plans by local timber companies do not present a comprehensive survey of endangered fauna or flora in the area (Morales-Castillo, 2005). Furthermore Ecuadorian forestry law for sustainable forest management programmes, stipulates the need for protection of trees used by endangered fauna. In this context our results provide valuable information that can be used to enforce this law and to expand it to other forest management programmes.

Given the above, I recommend the following to ensure long-term viability of the remaining populations of *A. f. fusciceps*:

- The Ecuadorian Ministry of Environment should carry out surveys to determine the presence of *A. f. fusciceps* and act accordingly by ensuring these areas are gazetted as areas of permanent protection.

- However, if permits are already in place the Ecuadorian Ministry of Environment should carry out a review of timber extraction protocols to minimise impacts to *A. f. fusciceps*.This review should ensure protection of keystone food tree species identified in this study for *A. f. fusciceps*.

- Connectivity of the remaining forests in the region should also be considered by adapting current extraction protocols to protect keystone feeding species for *A. f. fusciceps*.

List of tree species found in TE in 1.6ha of vegetation plots

FAMILY	**GENUS**	**SPECIES**	**LOCAL NAME**
ACHARIACEAE	Carpotroche	*Carpotroche platyptera*	NA
ANACARDIACEAE	Tapirira	*Tapirira guianensis*	NA
ANNONACEAE	Annona	*Annona quinduensis*	NA
ANNONACEAE	Guatteria	*Guatteria duodecima*	NA
ANNONACEAE	Guatteria	*Guatteria microcarpa aff.*	NA
ANNONACEAE	Xylopia	*Xylopia cuspidata*	NA
ASTROCARPUS	Astrocarpus	*Astrocarpus chambira*	Mocura
BIGNONIACEAE	Tabebuia	*Tabebuia guayacan*	Guayacan
BOMBACACEAE	Matisia	*Matisia soegengii*	Zapote de monte
BOMBACACEAE	Matisia	*Matisia sp.*	zapotillo
BURSERACEAE	Dacryodes	*Dacryodes chimantenis*	NA
BURSERACEAE	Dacryodes	*Dacryodes copularis*	copal
BURSERACEAE	Protium	*Protium colombianum*	anime
BURSERACEAE	Protium	*Protium ecuadorense*	Copalillo
BURSERACEAE	Protium	*Protium puncticulatum*	NA
BURSERACEAE	Tetragastris	*Tetragastris panamensis*	NA
BURSERACEAE	Tetragastris	*Tetragastris varians*	NA
CAESALPINIACEAE	Andira	*Andira inermis*	Chontillo
CARICACEAE	Jacaratia	*Jacaratia spinosa*	Papayuelo
CECROPIACEAE	Cecropia	*Cecropia obtusifolia*	guarumo
CECROPIACEAE	Pouruma	*Pouruma chocoana*	Uva
CHRYSOBALANACEAE	Hirtella	*Hirtella mutisii*	Carbonero
CHRYSOBALANACEAE	Licania	*Licania celiae*	NA
CHRYSOBALANACEAE	Licania	*Licania longicuspidata aff.*	NA
CHRYSOBALANACEAE	Licania	*Licania macrocarpa*	Huevo de potro

Cont... List of tree species found in TE in 1.6ha of vegetation plots.

FAMILY	**GENUS**	**SPECIES**	**LOCAL NAME**
CLUSIACEAE	Chrysochlamys	*Chrysochlamys membranacea*	NA
CLUSIACEAE	Garcinia	*Garcinia.madruno*	Madrono
ESTERCULIACEA	Theobroma	*Theobroma gileri*	Cacao de monte
EUPHORBIACEAE	Alchorneopsis	*Alchorneopsis floribunda*	NA
EUPHORBIACEAE	Amanoa	*Amanoa anomata*	Piedrita
EUPHORBIACEAE	Hyeronima	*Hyeronima alchornoides*	mascarey
EUPHORBIACEAE	Sapium	*Sapium caudatum*	vil
FABACEAE	Cynometra	*Cynometra bauhiniifolia*	NA
FABACEAE	Erythrina	*Erythrina poeppigiana*	Mambla
FABACEAE	Inga	*Inga carinata*	guabo de lora
FABACEAE	Inga	*Inga involucrata aff.*	guava
FABACEAE	Inga	*Inga involucrataaff.*	guaba
FABACEAE	Inga	*Inga marginata*	guabilla
FABACEAE	Inga	*Inga sp.*	Guabo
FABACEAE	Inga	*Inga spectabilis*	guabo machete
FABACEAE	Senna	*Senna sp.*	NA
LAURACEAE	Nectandra	*Nectandra guadaripo*	Guadaripo
LAURACEAE	Nectandra	*Nectandra purpurea*	Jigua negra
LAURACEAE	Nectandra	*Nectandra reticulata*	Aguacatillo
LAURACEAE	Nectandra	*Nectandra tomentosa cf.*	NA
LECYTHIDACEAE	Eschweilera	*Eschweilera caudiculata*	NA
LECYTHIDACEAE	Eschweilera	*Eschweilera caudiculata*	NA
LECYTHIDACEAE	Eschweilera	*Eschweilera pittieri*	NA
LECYTHIDACEAE	Eschweilera	*Eschweilera rimbachii*	NA
LEG-MIMOSACEAE	Zygia	*Zygia arborea*	Dormilon
MALPIGHIACEAE	Ectopopterys	*Ectopoterys soejartoi*	NA
MALVACEAE	Matisia	*Matisia idroboi aff.*	Poma rosa
MELASTOMATACEAE	Miconia	*Miconia sp.*	NA

Cont... List of tree species found in TE in 1.6ha of vegetation plots.

FAMILY	**GENUS**	**SPECIES**	**LOCAL NAME**
MELIACEAE	Carapa	*Carapa.guianensis*	tangar
MELIACEAE	Guarea	*Guarea kunthiana*	Colorado Manzano
MELIACEAE	Trichilia	*Trichilia pallida*	NA
MELIACEAE	Trichilia	*Trichilia poeppigii*	Pialde hembra
MORACEAE	Brosimum	*Brosimum utile*	Sande
MORACEAE	Clarisia	*Clarisia biflora*	sande macho
MORACEAE	Ficus	*Ficus insipida*	Higueron/matapalo
MORACEAE	Ficus	*Ficus macbridei aff.*	NA
MORACEAE	Naucleopsis	*Naucleopsis ulei puberula*	NA
MORACEAE	Sorocea	*Sorocea jaramilloi*	NA
MORACEAE	Sorocea	*Sorocea pubivena oligotricha*	Quinde
MYRISTICACEAE	Otoba	*Otoba gracilipes*	NA
MYRISTICACEAE	Otoba	*Otoba novogranatensis*	Sangre de gallina
MYRISTICACEAE	Virola	*Virola duckei*	Coco
MYRISTICACEAE	Virola	*Virola obovata*	NA
MYRISTICACEAE	Virola	*Virola pavonis*	NA
MYRISTICACEAE	Virola	*Virola sebifera*	Characoco
MYRTACEAE	Eugenia	*Eugenia concava*	NA
MYRTACEAE	Eugenia	*Eugenia feijoi*	NA
NA	NA	*NA*	caniquillo
NYCTAGINACEAE	Neea	*Neea divaricata*	NA
OLACACEAE	Minquartia	*Minquartia guianensis*	guayacan pechiche
PALMACEAE	Ireartea	*Ireartea deltoidea*	Pambil
PALMACEAE	Wettinia	*Wettinia quinaria*	Vsola
PHYLLANTHACEAE	Hyeronima	*Hyeronima oblonga*	NA

Cont... List of tree species found in TE in 1.6ha of vegetation plots.

FAMILY	**GENUS**	**SPECIES**	**LOCAL NAME**
RHAMNACEAE	Ziziphus	*Ziziphus cinnamomum*	vara negra
RUBIACEAE	Agouticarpa	*Agouticarpa williamsii*	guangare/matapalo
RUBIACEAE	Faramea	*Faramea parvibractea*	NA
RUBIACEAE	Hillia	*Hillia killipii*	NA
RUBIACEAE	Psychotria	*Psychotria allenii*	NA
RUBIACEAE	Psychotria	*Psychotria esmeraldana aff.*	NA
RUTACEAE	Hortia	*Hortia brasiliana*	limoncillo
SALICACEAE	Banara	*Banara guianensis*	NA
SALICACEAE	Casearia	*Casearia fasciculata*	NA
SALICACEAE	Casearia	*Casearia fasciculata*	NA
SALICACEAE	Tetrathylacium	*Tetrathylacium macrophyllum*	Punta de lanza
SAPOTACEAE	Calocarpum	*Calocarpum sapota*	Mamey
SAPOTACEAE	Chrisophillum	*Chrisophillum argenteum*	Caimitillo
SAPOTACEAE	Pouteria	*Pouteria multifolia*	Caimito
SAPOTACEAE	Pouteria	*Pouteria sp.*	NA
SIPARUNACEAE	Siparuna	*Siparuna sp.*	NA
TILIACEAE	Apeiba	*Apeiba membranaceae*	Peine de mono
ULMACEAE	Celtis	*Celtis schipii*	gallinazo
ULMACEAE	Trema	*Trema integerrima*	sapn blanco de palomo
URTICACEAE	Coussapoa	*Coussapoa contorta*	NA
VIOLACEAE	Gloeospermum	*Gloeospermum equatoriense*	NA
VIOLACEAE	Leonia	*Leonia crassa*	NA
VOCHYSIACEAE	Vochysia	*Vochysia ferruginea*	gomilla
VOCHYSIACEAE	Vochysia	*Vochysia macrophylla*	laguno

Feeding trees for Ateles fusciceps fusciceps in Tesoro (2012-2013)	
Family	**Species**
TILIACEAE	*Apeiba.membranaceae*
RUBIACEAE	*Borojoa patinoi*
MORACEAE	*Brosimum utile*
SAPOTACEAE	*Calocarpum sapota*
RUTACEAE	*Hortia.brasiliana*
MORACEAE	*Castilla elastica*
CECROPIACEAE	*Cecropia obtusifolia*
SAPOTACEAE	*Chrysophyllum.argenteum. panamense*
MORACEAE	*Clarisia biflora*
EUPHORBIACEAE	*Cleidion castaneifolium*
PRIMULACEAE	*Cybianthus schlimii*
BURSERACEAE	*Dacryodes copularis*
LECYTHIDACEAE	*Eschweilera caudiculata*
MYRTACEAE	*Eugenia sp.*
MORACEAE	*Ficus insipida*
MORACEAE	*Ficus pertusa*
MORACEAE	*Ficus tonduzii*
CLUSIACEAE	*Garcinia.madruno*
MELIACEAE	*Guarea kunthiana*
MELIACEAE	*Guarea sp.*
ANNONACEAE	*Guatteria olivacea*
OLACACEA	*Heisteria sp.*
HUMIRACEAE	*Humiriastrum proserum*
EUPHORBIACEAE	*Hyeronima alchornoides*
FABACEAE	*Inga carinata*
FABACEAE	*Inga involucrata aff.*
FABACEAE	*Inga marginata*
FABACEAE	*Inga sp.*
FABACEAE	*Inga spectabilis*
PALMACEAE	*Ireartea deltoidea*
RUBIACEAE	*Isertia sp.*
CARICACEAE	*Jacaratia spinosa*
CHRYSOBALANACEAE	*Licania glauca*
RHAMNACEAE	*Ziziphus cinnamomum*

Cont...Feeding trees for Ateles fusciceps fusciceps in Tesoro (2012-2013)	
Family	**Species**
BOMBACACEAE	*Matisia idroboi aff.*
BOMBACACEAE	*Matisia soegengii*
BIGNONIACEAE	*Memora sp.*
SAPOTACEAE	*Micropholis egensis*
OLACACEA	*Minquartia guianensis*
MONIMIACEAE	*Mollinedia sp.*
MORACEAE	*Naucleopsis naga*
LAURACEAE	*Nectandra guadaripo*
LAURACEAE	*Nectandra sp.*
PASSIFLORACEAE	*Passiflora foetida*
MORACEAE	*Poulsenia armata*
CECROPIACEAE	*Pourum bicolor*
SAPOTACEAE	*Pouteria multifolia*
BURSERACEAE	*Protium colombianum*
BURSERACEAE	*Protium ecuadorense*
VIOLACEAE	*Rinorea aff. villosiflora*
ELEAEOCARPACEAE	*Sloanea aff. grandiflora*
ELEAEOCARPACEAE	*Sloanea grandiflora*
SOLANACEAE	*Solanum sp.*
MORACEAE	*Sorocea pubivena*
MYRTACEAE	*Sp. Guayabilla*
LOGANIACEAE	*Strychnos jobertiana*
ANACARDIACEAE	*Tapirira guianensis*
BIGNONIACEAE	*Tabebuia guayacan*
STAPHYLEACEAE	*Turpinia occidentalis*
MYRISTICACEAE	*Virola duckei*
MYRISTICACEAE	*Virola reidii*
MYRISTICACEAE	*Virola sebifera (dixonii)*

Evaluation of hunting pressure on the critically endangered brown-headed spider monkey *Ateles fusciceps fusciceps* in NW Ecuador

5.1 Summary

Hunting pressure on the critically endangered brown-headed spider monkey has been reported as one of the main causes of its population decline. However, no current research on the extent of this activity or its causes was available. This information is key in the conservation of this critically endangered primate. I carried out semi-structured interviews in nine indigenous Chachi villages, as well as two Colono towns, to evaluate the occurrence of hunting activity and to identify drivers, attitudes and behaviour of hunters. In total I interviewed 62 people, 41 Chachis and 21 Colonos. From the Chachi interviewees 93% identified themselves as hunters, with subsistence hunting the main driver for this activity and central to their culture, especially for men. Colonos identified less with this activity (only 38%), and with more varied reasons, such as commerce and conflict. Only Chachis accepted the hunting of spider monkeys, with the main reason given as their taste. Keeping spider monkeys as pets was also a regular activity prior to tougher law enforcement by the Ministry of Environment (MAE). Information on medicinal uses from spider monkeys was also gathered, as well as information of other species hunted in the area. Even though Ecuadorian law recognises the right of indigenous peoples to hunt within their territories, it also forbids hunting critically endangered species. From the interviews it is evident that information and understanding of this law has not been successfully transmitted. I recommend better understanding of Chachi culture be integrated in environmental workshops run both by the MAE and by local NGOs.

5.2 Introduction

Large-bodied primates, such as spider monkeys, are prime targets for hunters in South-American tropical forests (Peres, 1990). In fact their densities appear consistently low in areas where hunting occurs, with the ateline primates most heavily impacted (Cowlishaw & Dunbar, 2000).

In Ecuador, the most endangered primate is *Ateles fusciceps fusciceps*, with an estimated population left of 250 individuals. The main threats to this primate are hunting, habitat loss and habitat fragmentation, which have reduced their population by 80% in the last 45 years (Tirira, 2004). Consequently, *A. f. fusciceps*, has been placed among the 25 most endangered primates in the world under the critically endangered category (Schwitzer *et al.*, 2015).

Hunting pressure on brown-headed spider monkeys inside the Cotacachi Cayapas Ecological Reserve (CCER) was first reported by Madden & Albuja (1989b) and then by Mena-Valenzuela (2003). They report a complete elimination of populations of *A. f. fusciceps* in forests close to inhabited areas in the immediate surroundings of the CCER and a strong impact in areas on the periphery of the reserve. Madden & Albuja (1989b) mention that action and environmental projects in the Management Plan for the CCER had not yet been yet initiated or their impacts were hardly noticeable. Previous studies also mention hunting pressure on brown-headed spider monkeys by Colono communities in the southern section of the CCER (Shanee, 2006) and on the western side (**?**).

Peck *et al.* (2010) identified conservation priority areas for the brown-headed spider monkey in unprotected forests around the CCER, however to date there is no updated information available on hunting activity in the area. This information is critical for the conservation of this endangered primate.

Data collected in this study was obtained as part of a broader project to develop a spatially explicit agent-based model for brown-headed spider monkeys, which incorporates hunting pressure as a variable affecting populations of spider monkeys, with the aim of determining its effect on the long-term survival of *A. f. fusciceps*.

Semi-structured interview questions were designed to gather data needed to calibrate the model. Questions also aimed at gaining a better understanding of the drivers and behaviour of Chachi and Colono hunters and hence contributing to the design of more effective conservation strategies in the area.

The objectives of this study are:

- To evaluate hunting pressure on *A. f. fusciceps* by Colonos and indigenous Chachi in the buffer zone of the CCER.
- To identify drivers, attitudes and behaviour of hunters in the buffer zone of the CCER

5.3 Methods

5.3.1 Focused semi-structured interviews

This technique is used to collect qualitative data by setting up a situation (the interview) that allows a respondent time to talk about their opinions on a particular subject. It allows gathering of in-depth information through a series of open-ended questions, with additional follow-up questions in order to extract more detailed and contextual data (Bryman, 2008; Piercy, 1998).

There are many strengths in the use of this method, such as a high validity as people are able to talk about a certain topic in detail, for themselves, with little direction from the interviewer. The interviewer can also probe areas suggested by the respondent's answers, gathering information that had either not occurred to the interviewer or of which the interviewer had no prior knowledge. It is a well suited method for the exploration of attitudes, values, beliefs and motives and it also provides the opportunity to evaluate the validity of the respondent's answers by observing non-verbal indicators. This is especially useful when discussing sensitive issues (Barriball & While, 1994).

This method has been previously used in the assessment of hunting activity and primate conservation (Maldonado Rodriguez, 2010; Peres, 2000).

5.3.2 Study site and inhabitants

This study was conducted within the western buffer zone of the Cotacachi Cayapas Ecological Reserve. This area of Ecuador belongs to the biodiversity hotspot

Tumbes-Chocó-Magdalena identified by Myers *et al.* (2000) as one of the 25 most important places for biodiversity globally due to high endemism and its accelerated historical and current rates of habitat loss.

The buffer zone of the CCER is inhabited by indigenous Chachis, Afroecuadorian and Colono communities. The Chachi and AfroEcuadorian have occupied this region for over 300 years, their subsistence depends mostly on garden-scale (plantain-based 'chacras') supplemented by products obtained from the forest, rivers, as well as commerce involving crops (cacao) and timber (Suarez *et al.*, 1995; Medina, 1992). The rivers in this area act as a transportation system, for exchange, a place to bathe, socialize, wash clothes, and as a source of food (Hazlewood (2004), pers.observation).

The Chachis function as single-family households. They traditionally farm individual plots and maintain communal forests for hunting and extraction activities (McIlvaine-Newsad, 2000).

'Colono' is a term used for immigrants from other Ecuadorian provinces who arrived in the area less than 60 years ago. Agriculture is their main subsistence, however isolated communities which still lie in the vicinity of forested areas also depend on forest products, such as meat (pers. observation).

Chachi and Colono communities

I evaluated hunting activity on *A. f. fusciceps* in towns inhabited by Colonos and Chachis. (see questionnaire in Appendix 1).

The first set of interviews were conducted on the river route from Borbón towards the town of San Miguel (distance approx. 40km). Chachi communities on this route are larger and more developed, with higher rates of commercial exchange with Borbón. The town San Miguel can be considered as the centre for commerce and where one of the CCER park guard lives. This town has mixed inhabitants (Chachi and AfroEcuadorian). The villages visited on this route were: Guaudal and Zapallo.

The route I followed for the second trip was along the river leaving from the town Chontaduro towards the CCER (see Figure 5.1). The questions for the semi-structured interviews were first discussed at length with the Chachi teacher (Evaristo Candelejo) in Chontaduro who provided valuable input and whom I knew from my fieldwork in the area. I was accompanied on the trip by his brother (Agner

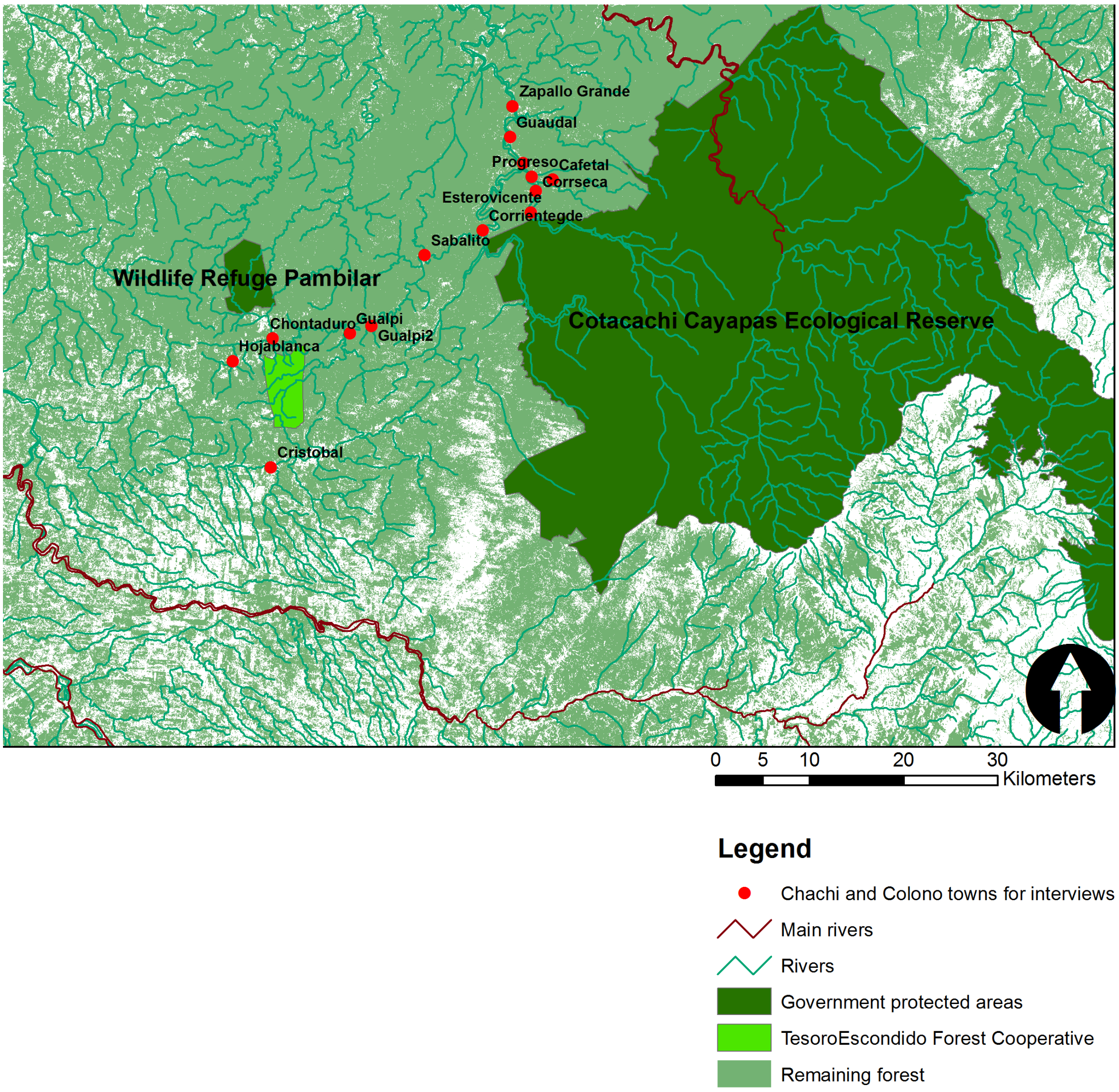

Figure 5.1: Indigenous Chachi and Colono towns where interviews on hunting activity were undertaken in the buffer zone of the Cotacachi Cayapas Ecological Reserve. Remaining forest layer was adapted from Hansen2013

Candelejo) who acted as a translator.

Chachis speak Spanish, as they learn it at school together with their local language 'Cha'palaa', however, Agner and Evaristo thought it was best to conduct the interview in Cha'palaa as a way of generating increased trust among the interviewees. Both brothers are quite respected in the Chachi community as Evaristo is the local teacher and director of the school as was his father before him. He is interested in developing projects for the conservation of the forests that involve Chachi communities, and was always helpful in providing information on the attitudes and culture of the Chachi people.

The interview was tested in Chontaduro for further improvement and Agner practiced it with his father (a former hunter) who also provided useful input on the structure of the questions.

On this route I conducted interviews in the villages of Gualpí2, Sabalito, Corriente Grande, Progreso, Corriente Seca, Estero Vicente and Cafetal. The last two being only one or two km away from the CCER.

In every Chachi community I introduced myself to the local teacher or the person with highest authority and explained our purpose. I asked to meet with hunters who could share information about brown-headed spider monkeys and who would regularly go hunting. Each interview lasted around 30 minutes. Hunters would direct me to speak with other hunters in the same community, identifying the 'best' or more regular hunters. The attitude was always open and welcoming.

I chose Colonos towns based on three reasons: i) vicinity to forested areas where previous studies (Moscoso, 2010; Tirira, 2004) had indicated presence of brown-headed spider monkeys ii) local information of hunting activity occurring in the area and iii) vicinity to the national protected areas El Pambilar Wildlife Refuge (referred to as Pambilar hereafter) and CCER. The towns in which I conducted the interviews were: Hoja Blanca and Cristóbal Colón.

Hoja Blanca is a town located in the Canandé watershed where most of its inhabitants are farmers who arrived from different parts of the country, mainly Manabí around 40-50 years ago looking for a place to settle and work the land, which at the time was still forest.

Almost all families own between 1-10 ha of land, some of them still owning forested land. Agriculture is centred on the production of cacao, fruits and vegetables for local use and more recently oil palm. Agricultural expansion towards the remaining forested area is taking effect at a fast rate, mainly through the expansion of cacao fields and oil palm (pers. obs.).

Hoja Blanca is a strategic location for the development of projects both for the conservation of the forest and for extractive activities. It is a convenient entry point from the southeast to the forest cooperatives Tesoro Escondido and 10 Abril (where the highest density of brown-headed-spider monkeys in NW Ecuador has been reported by **?**Moscoso (2010). It is also an entry point to the Chachi town of

Chontaduro to the northeast and to lands and operation camps belonging to the timber company Botrosa S.A. to the west. Timber is extracted via a main road which in the near future will connect the Chachi town Gualpí and Hoja Blanca.

As the town is still surrounded by forest the presence of local fauna can be observed or heard. In the case of primates there is a local group of howler monkeys (*Alouatta palliata*) which can be observed no further than two kilometers from the town and brown-headed spider monkeys *A. f. fusciceps* can be occasionally heard, though further away. Capuchin monkeys *Cebus capucinus* are also regularly observed along the road from Hoja Blanca to Botrosa's operation camps. Along this road there is a weekly market 'La Punta' (approximately 5 km away from Hoja Blanca) where people from smaller neighbouring towns gather to sell their products, bushmeat being one of them. Furthermore, bushmeat dishes can be easily found in local diners.

Cristobal Colon is a town located on the banks of the Canande river, approximately 30km east of the CCER. It is still surrounded by primary forest, where brown-headed spider monkeys are regularly observed. Inhabitants of this town are dedicated to agriculture and working at the local timber company. After spending time in this area and realising that hunting was a regular activity for some of the men, my interviews were directed to establishing if hunting extended to spider monkeys as well. In the case of Hoja Blanca and Cristobal the interviews were conducted after I had lived there for some time and people trusted me. I interviewed hunters I knew and men whom I was told were regular hunters.

Interviews were carried out under informed consent and following all ethical considerations (Protocol approved by the ethics committee of the University of Sussex UK and Universidad San Francisco de Quito, Ecuador). I recorded the interviews under consent from each person interviewed and transcribed them with input of the translator and another researcher present during the interviews. The recordings will be returned to the Chachi teacher Evaristo as agreed.

5.4 Results and Discussion

5.4.1 Semi-structured interviews

Carrying out semi-structured interviews to gather information on hunting activity provided, fist of all, an in-depth understanding of the culture and attitudes towards hunting activity and conservation by the Chachi culture. Having a Chachi friend as a translator and as interview ensured the interviewees to feel comfortable and safe, especially when answering delicate questions.

Semi-structured interviews, not only gave me the choice of wording each questions according to the interviewees in each community, but also allowed the use of probes, which can be an invaluable tool for ensuring reliability of the data, as suggested by Barriball & While (1994). Probing allowed me to clarify issues raised by the respondents, such as the communities opinion of the government park guards' role. It also gave me the opportunity to explore sensitive issues such as the illegality of hunting activity inside the CCER, selling of wild meat or keeping monkeys as pets. My conversations with hunters using this method also enabled me to explore and clarify inconsistencies in some answers, and to help respondents recall information for questions involving memory, such as numbers of monkeys hunted per year. The advantages of semi-structured interviews and probing have been previously explored in Barriball & While (1994). A weakness of this method is that it is time consuming and expensive, also it is not very reliable as it is difficult to exactly repeat an interview and samples tend to be small. However, in trying to understand hunting activity in the area, this method proved effective.

5.4.2 Identity in Chachis and Colono hunters

I interviewed a total of 62 people, 41 in Chachi villages and 21 in towns inhabited by Colonos (see Figure 5.2).

All the interviewees were male, as I targeted hunters, but there are notes in the interview transcripts of input given by women present, especially for the medicinal uses of *A. f. fusciceps*.

Of 41 Chachis interviewed, 93% (38) identified themselves as hunters although all of them had a principal income from agriculture or in the timber business. Three

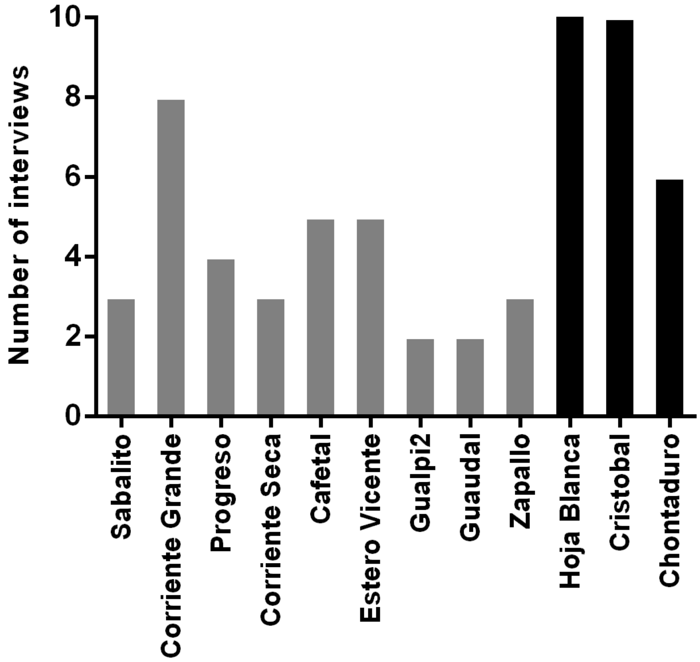

Figure 5.2: Number of interviews in Chachi and Colono towns. Grey indicates Chachi, black indicates Colono.

Chachis (7%) (in the communities of Guaudal, Zapallo and Chontaduro) did not identify themselves as hunters, but rather as farmers. They all accepted they used to hunt 5 to 10 years ago (Figure 5.3).

Hunting is an activity taught to all young boys, so in essence all Chachi men can be considered hunters, however for the purpose of this research I refer to 'hunters' as Chachis who identified themselves or identified other men as such rather than just knowing how to hunt or shoot.

Of the 21 people interviewed in Colono towns, 38% identified themselves as 'hunters' however all of them said they knew how to shoot. The principal activity of all the people interviewed in these towns is agriculture or working for the local timber companies. In both Chachi and Colono areas the age of the hunters that were interviewed ranged from 20 to 45 years old. All of them mentioned having learnt to hunt at an early age, from 9 years old to the eldest 17 years old. The one who learnt at 17 years old taught himself whereas the others were taught by either their father or an older male member of the family in the case of the Chachis and also by friends in the case of Colonos. They all agreed that hunting is an activity

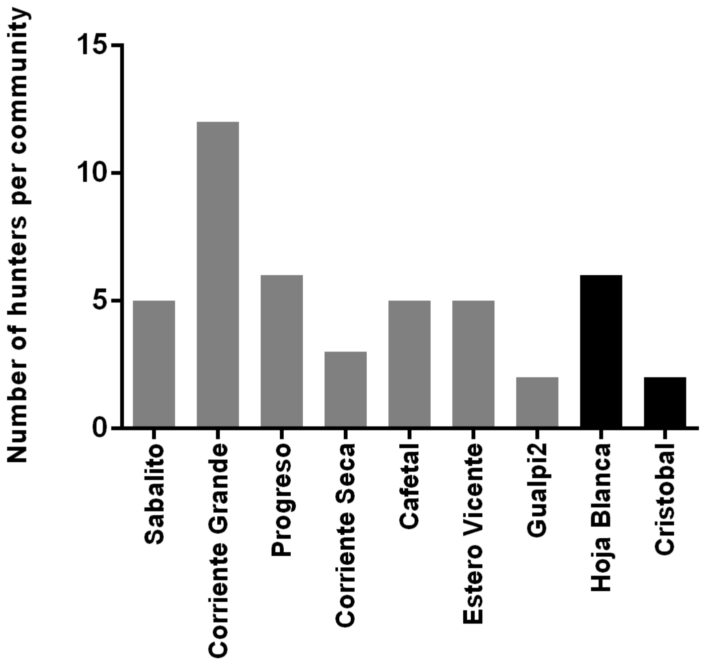

Figure 5.3: Number of hunters in Chachi and *Colono* communities.

reserved for men; women do not hunt, however in the case of the Chachis, women do fish.

5.4.3 Main species hunted by Chachis and Colonos

The species hunted varied between Chachis and Colonos as can be observed in Table 5.1.

In the case of primates, none of the Colonos who were interviewed acknowledged the hunting of primates of any of the three species present in the region. However all the hunters in Hoja Blanca had knowledge of the fact that the meat from the howler monkey is more 'greasy'. This may be due to the vicinity of the Chachi town Chontaduro, and from the Chachi influence in the area (stories, etc). During my stay in the area and visit to the market 'La Punta' I could not establish whether Colonos hunt spider monkeys. However I gathered valuable information on hunting activity for other species, which I include in the following section as it might help to inform conservation strategies in the area (see Chapter 7).

Table 5.1: Main species hunted by Chachis and Colonos in the buffer zone of the Cotacachi Cayapas Ecological Reserve (common names in Spanish). ND=No data available; Conflict=Conflict with crops, livestock or chicken; ND= Use was not defined; CR= Critically endangered; VU=Vulnerable; LC=Least Concern; NT=Near-threatened; DD= Data deficient.

Scientific name	**Common name**	**Purpose of hunting by Chachis**	**Purpose of hunting by Colonos**	**IUCN Red List 2015**	**Red List Ecuador 2011**
Ateles fusciceps fusciceps	brown-headed spider monkey	Subsistence	No	CR	CR
Alouatta palliata	howler monkey	Subsistence	No	LC	EN
Cebus capucinus	white-headed capuchin	Subsistence	No	LC	EN
Penelope obscura	dusky-legged guan	Subsistence	Subsistence	LC	LC
Cuniculus paca	lowland paca	Subsistence	Subsistence/Commerce	LC	NT
Dasyprocta punctata	Central American agouti	Subsistence	Subsistence/Commerce	LC	LC
Tayassu pecari	white-lipped peccary	Subsistence/commerce	Subsistence/Commerce	VU	EN
Puma concolor	puma	ND	Conflict	LC	VU
Panthera onca	jaguar	ND	Conflict	NT	CR
Mazama americana	red brocket	Subsistence	Commerce	DD	NT
Puma yagouaroundi	jaguarundi	ND	Conflict	LC	NT
Didelphis marsupialis	common opossum	Subsistence	Conflict	LC	LC
Leopardus pardalis	ocelot	Conflict	Conflict	LC	NT
Pecari tajacu	collared peccary	Subsistence/commerce	Subsistence/Commerce	LC	LC
Bradypus variegatus	brown-throated sloth	Subsistence	Not defined	LC	LC
Microsciurus mimulus	western dwarf squirrel	Conflict	Conflict	LC	NT
Dasypus novemcinctus	nine-banded armadillo	Subsistence	Medicine	LC	LC
Tamandua mexicana	northern tamandua	ND	Subsistence/Not defined	LC	VU

5.4.4 Drivers of hunting activity by Chachis and Colonos

The main drivers for hunting activity are shown in Table 5.1 In the case of Chachis the principal driver for hunting mentioned is subsistence. All of the hunters said they would stop hunting if they had a secure job, as they would not have time to go hunting. This may be true however during the interviews 90% of the hunters mentioned that they like going hunting.

In the case of Colonos the reasons were more varied. There are more cases of hunting species due to conflict where wild species destroy or are perceived to destroy crops or eat livestock or chickens. Killing the animal can (and in most cases does) take place as a mitigation strategy, even before the conflict has occurred (pers. observation). In the case of pumas and jaguars the meat is not wasted but consumed and the skin is set on display in the house of the hunter as a kind of trophy (pers.observation). All of the hunters interviewed enjoyed hunting, 5 of them (the younger ones) said they would sometimes hunt just for fun.

During interviews with Chachis only once was it mentioned that the meat is sold, in the case of wild pig meat (*Tayassu pecari*). Spider monkeys are too scarce and there is not enough meat to be sold. Moreover when a hunter brings prey back to his community, the meat is shared amongst the whole community.

In the case of Colonos, in Hoja Blanca, there are more cases where meat is sold in the market, this is especially so for pacas (*Paca cuniculus*). Hunters also sell the meat to local diners/restaurants in Hoja Blanca. In Cristobal this is not the case and the hunters who were interviewed would rarely hunt in their 'fincas' (farms), and then usually only for pacas.

5.4.5 Hunting brown-headed spider monkeys

From the semi-structured interviews with the Chachi hunters I conclude that the main focal area for hunting of spider monkeys is inside the CCER as they cannot be found in other forests surrounding the Reserve. However, in Estero Vicente and Cafetal all the hunters mentioned that they have found spider monkeys outside the CCER, in community forests, which is realistic as they are the two villages closest to the CCER. Two hunters (father and son) in Gualpi2 mentioned the possibility of hunting spider monkeys close to the village. This is relevant as Gualpi2 is one of the furthest villages from CCER in our study, however it is closer to El Pambilar Wildlife Refuge, where spider monkeys are also found.

Hunting activity by Chachis close to this protected area had been previously reported by a former park guard and hunters in Chontaduro.

Hunters usually go hunting accompanied by friends or family. Usually a hunting party ranges from 2 to 4 hunters, who leave early before 7am and return before dark, never staying overnight in the forest (unless the rare possibility of getting lost occurs; only one hunter mentioned this happening to him). The best time to find spider monkeys is at around 10-11 am.

The only method reported for hunting spider monkeys is with shotguns, which has been the method of choice for at least 2-3 generations. Cartridges are bought in the city of Borbón on the black market and are highly valued, hence the main reason for preferring to hunt spider monkeys over howlers or capuchins is a higher probability of killing them with fewer less cartridges. A hunting party of 4 can kill between 1-3 spider monkeys, since they flee after the first shot.

Hunting spider monkeys is always opportunistic; hunters do not actively seek them but go hunting for whatever prey they can find. If they find spider monkeys (normally by listening to them vocalising) they actively pursue them though the forest. Spider monkeys are not considered important enough to specifically go hunting for them, however they do appreciate the flavour of the meat and family members (women and children) do suggest hunters bring back spider monkey meat.

The months when it is most likely finding spider monkeys (and hence hunt them) is August and September, it is also when they find larger groups. The largest group reported by the hunters was 20 individuals, but all of the hunters mentioned they occasionally find only one individual or smaller groups of 3-5 individuals.

The frequency of hunting trips ranged from once a week (2 hunters in Estero Vicente) to once or twice per year. The most common answer was once or twice per month (Figure 5.4)

I asked the hunters to tell us the number of monkeys they normally hunt per month, however as there are months where they do not find them, it was easier for them to answer with the number of monkeys hunted per year (see Figure 5.5). As I also interviewed other hunters in the same communities I could provide better

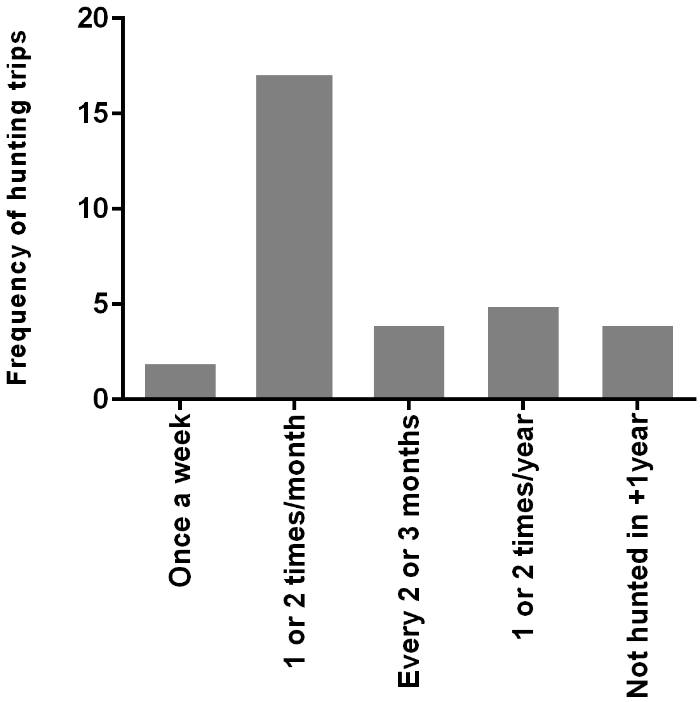

Figure 5.4: Frequency of hunting trips in Chachi communities

verification of this number. The numbers used are from the previous year's hunt (2012). The communities with the higher numbers are the ones situated closer to the CCER.

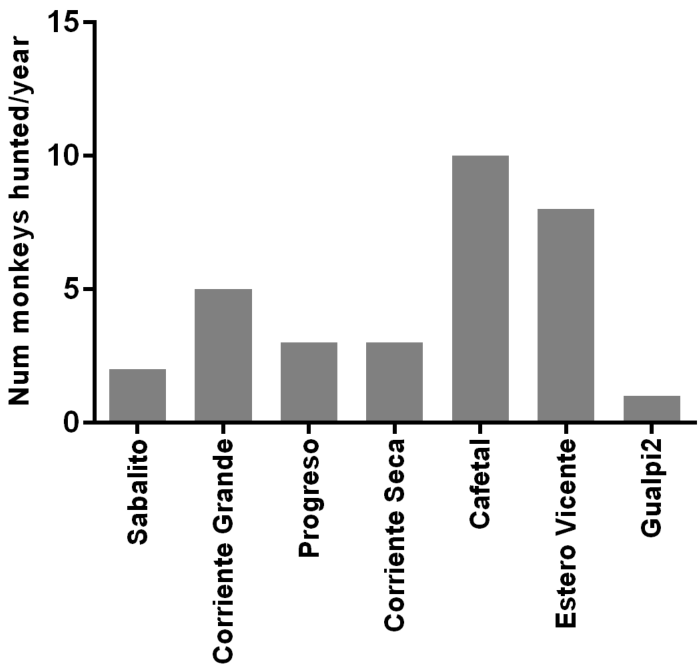

Figure 5.5: Number of monkeys per year hunted in each village

The only problems reported while hunting spider monkeys was the possibility that spider monkeys would not die from the shots or that they would die on top of the tree. If this was the case they cut down the tree, since wasting meat is not considered an option.

The behaviour of the spider monkeys reported by all the hunters is consistent with observations in the CCER, where, contrary to areas without hunting pressure such as Tesoro Escondido (see Chapter 3), spider monkeys immediately flee, sometimes even without making the usual alarm calls (pers. observation). Most of the hunters did not have a preference for male or female monkeys when they are hunting, as they have to shoot at them quickly before they flee, however if there are female monkeys in the group carrying an infant hunters do target them as they tend to keep infants as pets.

All of the hunters acknowledged the fact that spider monkeys are 'endangered'. This word and concept does not exist in Cha'palaa or in the Chachi culture, however they do mention that they find less monkeys now compared to 5 years ago, and each time they need to travel further into the forest.

5.4.6 Medicinal use of *A. f. fusciceps*

All the hunters that were interviewed mentioned the fat extracted from brown-headed spider monkeys as having medicinal properties. Two uses were mentioned, the main one was its use for women giving birth and the other for rheumatism.

An elder Colono in Hoja Blanca mentioned the use of the heated skin of a female spider monkey put overnight over the back as cure for lung disease. An elder hunter in Chontaduro mentioned the fat and meat from *Alouatta palliata* as being important in the development of children, for strength.

5.4.7 Attitudes towards management and law enforcement approach in the CCER

The Ecuadorian law recognises the right of indigenous peoples and Afroecuadorian to hunt within their own territories however hunting in Protected Areas (such as the CCER) is forbidden (see Environmental Law Article 26 Ecuador (1993)). Furthermore given the critical status of populations of brown-headed spider monkeys, since 2000 it has been forbidden to hunt or trade brown headed spider monkeys in the whole country for an indefinite time (Resolución No. 105 Ministerio del Ambiente, Registro Oficial No. 5 del 28 de enero del 2000).

The Ministry of Environment enforces these laws in the CCER through park guards who patrol the reserve and surroundings, however their presence has little impact on hunters who simply walk in and out of the Reserve. All of the hunters who were interviewed were aware of the fact that it is forbidden to hunt inside the CCER; they know that if caught, their shotgun gets confiscated and they might end up in jail or paying a large fine. When I asked them what would happen with the meat if they are caught by a park guard they all answered that the park guard would probably keep it for himself. Out of the 32 hunters interviewed, 11 complained about the park guard in that area (Charco Vicente, San Miguel) who is also a Chachi. Some hunters did not understand why the park guard stopped them if he is Chachi himself and knows that animals are there to be eaten and furthermore he himself hunts.

This raises an important issue, acknowledged by the Ministry of Environment itself in its evaluation and Management Plan (see Minsiterio del Ambiente (2007)) about the lack of control over hunting in the Reserve and the ineffective role of park guards. The mitigation strategies proposed by the MAE are along the lines of better law enforcement and further environmental education workshops (Minsiterio del Ambiente, 2007). However if they do not take into account the cultural context and beliefs of the Chachis, environmental workshops will not have the desired effect.

5.4.8 Brown-headed spider monkeys as pets in Chachi communities

During the first trip to Chachi communities in 2011 I found two spider monkeys kept as pets in the villages of Guaudal and Progreso, an adult female and a subadult male respectively. There was also a young male kept as a pet in Chontaduro. I heard about three other pet spider monkeys that year in other villages along the river although I never saw them.

During the second trip when conducting the interviews the hunters and people in the villages reported that the Ministry of Environment had confiscated all the pet monkeys in all the villages along the river Cayapas. They confiscated in total 5 monkeys. All the hunters expressed their discontent against this measure, especially because it was carried out without any compensation for what they had invested in the monkey (i.e. food, etc). All of them denied having been given a full explanation other than the fact that it was illegal.

90% of the hunters interviewed said they had kept at least one infant spider monkey as a pet during the last 5 years. Baby monkeys often die in this process, especially if they are very young, according to 10 hunters reporting having experiencing this. If they survive, when they become adults they normally get sold to a neighbour or to another community; the reason according to all of the hunters is that they become to difficult to handle. If they sell them, the price ranges from USD20 to USD35.

5.5 Conclusions

I could gather enough reliable data to use as parameter calibration (see Chapter 6) in the development of an agent-based model looking at the survival of *A. f. fusciceps* under different scenarios of anthropogenic threats. This was possible through the qualitative method of semi-structured interviews.

I gathered relevant information on the attitudes of hunters towards law enforcement, and towards environmental projects. Two hunters had already worked with an international NGO carrying out population censuses in the CCER as parabiologists and were interested in getting involved in similar projects. This approach may be key in developing more effective measures to stop hunting of spider monkeys.

In the case of Colonos in the Hoja Blanca area, law enforcement may be the best strategy to stop the bushmeat trade, as well as environmental education workshops and participatory research as parto of conservation projects.

The recorded interviews may be uploaded to the Endangered Language Archive (SOAS, n.d.) with an explanation of the project to contribute to the preservation and dissemination of the Chap'alaa language upon discussion with the Chachi council in Chontaduro.

A novel approach using Agent-Based modelling to identify priority conservation areas for critically endangered species: a case study of *Ateles fusciceps fusciceps* in the Ecuadorian Chocó

6.1 Summary

Determining the effects of fragmentation, hunting and habitat degradation on populations viability of this primate is crucial before investing heavily in local sustainable livelihoods and conservation initiatives. A bewildering range of fragmentation metrics are available to study habitat fragmentation, yet their relationship to survival of populations of conservation concern remains to be quantified. I applied an agent-based model (ABM), calibrated on field-collected datasets on forest fruit dynamics, behaviour and feeding ecology of *A. f. fusciceps*, to first identify an optimised fragmentation statistic to be used to screen satellite imagery and identify remaining priority conservation areas in unprotected, fragmented forests in NW Ecuador. I then used the ABM to further explore the combined impacts of fragmentation, hunting and logging as many key tree species favoured by loggers are also preferred feeding trees for *A. f. fusciceps*. Mean Patch Area was the best predictor of population numbers, I identified a MPA of 174.9 hectares as the cut-off point for the survival of brown-headed spider monkeys given the lowest combinations of logging activity and hunting pressure and I used it to identify priority conservartion areas in NW Ecuador.

6.2 Introduction

The brown-headed spider monkey *Ateles fusciceps fusciceps* is one of the 25 most endangered primates in the world (Schwitzer *et al.*, 2014); only 250 individuals have been estimated to remain in the forests of the Ecuadorian Chocó Biogeographical Region (Tirira, 2004). A major cause of population decrease is the high rate of deforestation in North West Ecuador, both by commercial timber extraction and by agricultural expansion, which have reduced the original forest cover by 80% (Tirira, 2004). Forest clearance leads to habitat fragmentation, where continuous habitat is broken apart into smaller pieces (fragments) scattered within a matrix of non-habitat (Arroyo-Rodríguez *et al.*, 2013); this can be extremely detrimental for primates inhabiting the canopy and preferring primary and continuous forest (Defler, 2004) such as the genus *Ateles* (Peres, 2001). Studies have shown for instance that forest fragmentation can affect habitat quality by reducing the number of large tree species in smaller patches causing a decline in the quality and quantity of food sources for howler monkeys *Allouatta palliata* (Arroyo-Rodríguez & Mandujano, 2006).

Habitat can be eliminated from a landscape in several different ways, resulting in an array of different spatial patterns (Fahrig, 2003). These patterns represent dissimilar degrees of fragmentation and may have different implications for the survival of species living in them. The four main effects in the habitat fragmentation process are: reduction in habitat amount, increase in number of habitat patches, decrease in sizes of habitat patches, and increase in isolation of patches (Fahrig, 2003), with various other effects within each main category. In fact there are more than 100 metrics able to describe the fragmentation process (McGarigal *et al.*, 2012), and due to its numerous effects, there is not a single metric which entirely represents it. These metrics can be narrowed down by focusing on the specific needs of the species in focus.

Mean Patch Size (MPS) in particular is the widest used metric in the study of effects of fragmentation on primates (Benchimol & Peres, 2014).; for instance Michalski & Peres (2005) report it to be the strongest predictor of the occurrence of primates and carnivores in the fragmented Southern Amazonia. Nevertheless it is worth screening for other fragmentation metrics relevant to the species such as distance between patches or number of patches left in the environment, as suggested by Arroyo-Rodríguez *et al.* (2013).

In the conservation of endangered species it is crucial to understand extinction thresholds, which are used to analyze the minimum proportion, size or habitat amount required for a population to persist in the landscape (Fahrig, 2003).

A threshold can be defined as the point or zone where there is a dramatic change in the state of a variable or a system (Lindenmayer & Luck, 2005). Particularly in ecology, at the landscape level, thresholds occur when the response of a species or group of species to habitat loss is not linear, but an abrupt change to a certain, critical level of loss (Toms & Lesperance, 2003). The concept of ecological thresholds has been useful in proposing conservation management alternatives (Huggett, 2005), however, more information is needed on thresholds for particular species in specific habitats (Mandujano *et al.*, 2005).

Understanding how primate populations respond to habitat changes is challenging by the fact that in nature, factors are not isolated; some are interrelated or aggravated by each other (Lacy, 2000). For example, the removal of a few trees via logging may not have a serious impact on primate populations at first, however the roads to access timber may provide access to hunters ((Peres, 2001), and/or to people immigrating and extending into the forest (Rimbach *et al.*, 2013). This may be the case for *A. f. fusciceps* in NW Ecuador, where anthropogenic activities are quickly reducing and fragmenting the habitat and where subsistence hunting by indigenous groups may no longer be sustainable. The critical status of brown-headed spider monkeys is pushing research towards the development of methods that allow cost-effective, precise and faster identification of priority conservation areas, where available funding can be targetted in effective conservation strategies.

One way of evaluating the survival of brown-headed spider monkeys in different scenarios of habitat fragmentation logging and hunting activity is the use of an agent-based model (ABM) where monkeys interact as realistically as possible in a real environment with different fragmentation levels and where logging and hunting activity scenarios can be easily modelled based on field data and available literature on the genus. ABMs are a powerful tool in ecology and in the understanding of the interaction of populations with their environment. They have the potential to provide information over extended time spans in long-living species such as spider monkeys, that would otherwise be more difficult to obtain. They could also reduce fieldwork time and costs by aiding in the identification of remaning forests most likely to sustain populations (Imron *et al.*, 2011).

The objectives of this study are:

- To develop an Agent-Based Model for *A. f. fusciceps* calibrated with fieldwork data
- To evaluate the effect of habitat fragmentation on the survival and carrying capacity of *A. f. fusciceps* in NW Ecuador.
- To evaluate the combined effects of habitat fragmentation, logging and hunting on the survival and carrying capacity of *A. f. fusciceps*.
- To identify priority areas of viable habitat for *A. f. fusciceps* in NW Ecuador to focus conservation efforts.

6.3 Methods

6.3.1 Development of an agent-based-model for *A. f. fusciceps*

The description of the agent-based model (ABM) used for this study follows the ODD protocol (overview, design concepts and details) for describing agent based models proposed by Grimm *et al.* (2006). The model was developed in NETLOGO v.5.0 (Wilensky, 1999).

Overview

Purpose

The main objective of the development of the Spider Monkey Model is to look at the effect of human threats and landscape configuration on the survival of the critically endangered brown-headed spider monkey *Ateles fusciceps fusciceps* in NW Ecuador.

State variables and scales

Individuals

The model is composed of a single agent: monkeys. They are modelled as male or female, adults or subadults (includes juveniles and infants). See Table 6.1.

Spatial Units

The environment "forest" consists of LANDSAT images taken from NW Ecuador (LANDSAT 6.0) of 2500 ha with pixel resolution of 30m x 30m. These pixels form the environmental "patches". I modelled the forest to consist of three types of food patches. The first type, "Staple fruits", consists of patches that have a continuous fruiting pattern and therefore are available throughout the year. Trees of this type include for instance the commercially logged *Brosimum utile.*

The second type "Preferred fruits" are patches that represent the fruit trees that are most preferred by spider monkeys based on the in the Chesson Index analysis (see Chapter 2). The third type are "Other fruits", which represent all other trees found at the study site, Tesoro Escondido, NW Ecuador. The percentage of each fruit tree type in the model was based on their relative abundance in my field site (Tesoro). See Chapter 2 for further details on the habitat and diet of *A. f. fusciceps.*

Each patch type is represented in the model by a different colour: purple for "Preferred", light green for "Staple" and dark green for "Other". Patches that are logged or that represent fragmented areas are shown in brown. Preferred fruits for spider monkeys are thought to have a higher calorific content and are thus preferred by spider monkeys over more abundant fruits. All patches in the model have a fruit value, this is used to direct the movement of monkeys, preferred patches have a value of 1.15 whereas staple and other fruits have a value of 1. I obtained this ratio by dividing the calorific values of preferred feeding trees by not preferred trees (1.15:1 preferred:not preferred ratio). In the model, patches that are logged or represent fragmentation have a fruit value of 0.

Patches visited by spider monkeys have their fruit value set to 0 every tick (time step) of the model. This represents the depletion of fruits in patches spider monkeys feed on, as reported by Chapman (1988) and observed during my fieldwork as well.

Table 6.1: State variables and units of spider monkeys

Individuals	**State variables**	**Description**	**Values and units**	**Reference**
Spider monkeys	Age classes	classes of age	• Subadults and infants 0-8 years • Adult 8 – 24 years	*Shimooka et al. (2008)*
	Gender	sex classes	male – female	
	Energy	Energy level of an individual Hunger	0-2000kcal <1040kcal	*Felton (2008)*
	Reproduction related status	Female state variables related to reproduction condition		

Time Units

Every tick in the model represents one day. The modelled time horizon is 100 years after which the model stops. This time frame has been previously used in an ABM looking at ateline population dynamics (Wiederholt, 2010). The model also stops if there are no monkeys left in the environment.

Process Overview and Scheduling

Ageing

The age of monkeys increases one day per tick, with monkeys becoming adults at 8 years of age.

Movement

Monkeys move towards the patch with the maximum fruit value within a radius of 5 patches, which represents approximately 150m (this distance can be modified in the model). I added a second movement option, which is used when there are no patches available around a monkey. In this case, it keeps moving and searching for feeding patches.

Feeding

Spider monkeys in the wild have been observed to feed on average on 1kg and up to 2.4 kg of fruit per day (Felton *et al.*, 2008). The nutritional value of fruit in Tesoro suggests that 1kg is equivalent to 1040kcal with 2.4kg representing an estimated of 2000 kcal. In the model monkeys get "hungry" when their energy levels fall below 1040kcal, and begin to move around looking for food, they do not eat more than 2000kcal per day. The Total Energy Expenditure (TEE) per day for spider monkeys is calculated by the formula (Leonard & Robertson, 1997):

$$\mathrm{TEE} = 86 \times \mathrm{Weight}^{0.792}. \tag{6.1}$$

Considering the average weight of spider monkeys at 8.81 kg, the mean TEE used is 464kcal per day. This energy expenditure value also takes into account energy loss associated with resting, although this is not explicitly represented in the model.

Reproduction

Female spider monkeys are fertile when they become adults (8 years old), with an interbirth interval of approximately 4 years between each birth. In the model, females are fertile at adulthood and if their energy baseline is higher than 1040kcal. If there is an adult male in a radius of 400ha (average home range of the genus) they reproduce, this is represented in the model by 'breed-area' and can be modified. Each female has an individual internal timer set for the next reproduction event. Spider monkey groups are usually female biased (Shimooka *et al.*, 2008) which is also represented in the model as a 2:1 female to male ratio of newborns.

Mortality

Spider monkeys in the model can die either by old age (more than 24 years old) or by starvation, when their energy levels drop below 0. Monkeys can also die due to hunting activity, which is set to a certain number of monkeys extracted from the environment per year.

Design concept

Emergence

The dynamics of the spider monkey population emerge from the interaction between the spider monkeys and their environment, in the presence of logging events and hunting (offtake per year).

Interaction

The main interaction in the model is between spider monkeys and their environment by sensing patches with more fruit in a given radius and gaining or losing energy as they move, which can be affected by logging activity and habitat fragmentation.

Details

Initialization and input

The model starts with a population of 100 monkeys, with a monkey female:male ratio and adult:subadult ratio based on values from my observations at my field site

(See Chapter 1 for more details).

Observation

The observed output is the final number of spider monkeys after 100 years. This number effectively represents the carrying capacity of *A. f. fusciceps* within in a 2500ha area in NW Ecuador for fragmentation/logging scenarios and an indication of stable population levels under scenarios that include hunting.

Model Analysis

I tested parameters that I hypothesised would have an impact on the final carrying capacity of the system. For each parameter tested I ran 100 iterations and compared results to the null model run. For each parameter I evaluated extreme minimum and maximum values. See Table 6.2.

Table 6.2: Baseline and tested values

	Baseline value	Values tested
Initial monkey population	100	10, 300
Breed-area (patches)	75	<3, 164
Foraging distance (patches)	3	>10
Initial adult monkeys	60%	40%
Initial subadult monkeys	40%	60%

6.3.2 Effect of habitat fragmentation on survival and carrying capacity of *A. f. fusciceps* in NW Ecuador

To study the effect of habitat fragmentation on the survival and carrying capacity of brown-headed spider monkeys, I ran the ABM for spider monkeys in 60 randomly chosen forest samples extracted from a real landscape from LANDSAT imagery used by Peck *et al.* (2010). Each forest sample patch in the model represents approximately the size of my study area (2500 hectares). The 60 forest samples were chosen using a random number generator to represent real levels of forest fragmentation patterning in NW Ecuador (Figure 6.1) (**?**).

Using ESRI Arc GIS 10.0 individual pixels were classified into forested and not-forested areas (represented by 0=not forested; 1=forested). Each of the 60 forest

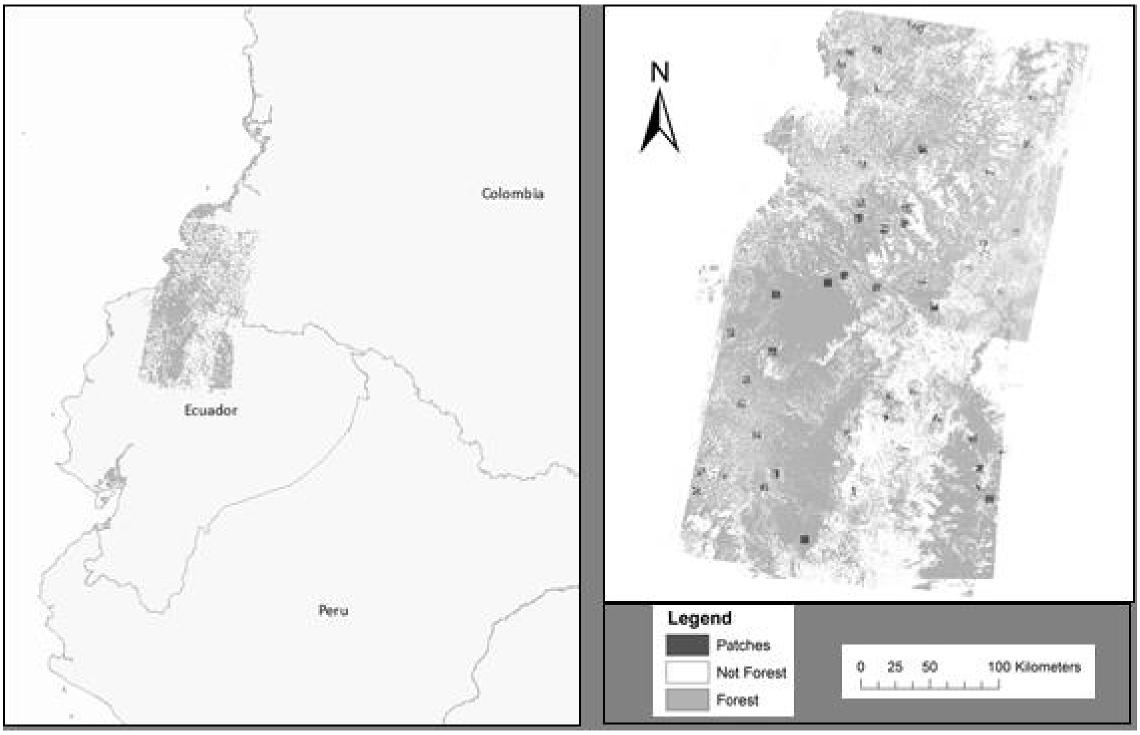

Figure 6.1: Location of Landsat image and distribution of the random sample habitat patches across the Landsat image

samples were then analysed using FRAGSTATS (v. 2.0) to obtain fragmentation metrics for Mean Patch Area (MPA), Number of Patches (NP), Largest Patch Index (LPI), Distance between Patches (ENNM) and Total Edge (TE). I then ran the ABM for each sampled forest patch and plotted number of pimates after 100 years against each fragmentation metric.

When plotting the LogMPA metric against number of remaining monkeys in a simpler ABM after 100 years, Marshall (2013) found that the shape of the graph produced is very similar to that of the dose response curves found in ecotoxicology. Therefore, the same principles of the dose response curve can be applied to the graph to identify a cut off point. LC50 is a threshold value used in ecotoxicology where a concentration of a chemical will kill 50% of test subjects.

The dose-response model, with LC50 value identified, can be applied to a plit of number of primates surviving against a fragmentation metric (such as Log MPA). Patch metrics below the 50% value would have a much higher risk of extinction. This method of quantifying the priority conservation regions may provide a technique for identifying priority conservation regions with less uncertainties than using MVP or the 50/500 rule (Marshall, 2013).

I explored this method with other metrics able to describe fragmentation and with potential interest for spider monkey conservation. Therefore I tested the fit of each of the metrics described above (NP, MCA, ENNM and TE) to a three parameter dose-response curve and chose the metric with the best fit (given by the highest r^2 value) (GraphPad Prism software v.6.0). The agent based model for brown-headed spider monkeys was used to assess the impacts of habitat fragmentation (measured as MPA) on the survival of *A. f. fusciceps*. I ran the ABM through the 60 forest samples (20 iterations each) recording i) the probability of survival and ii) the number of monkeys remaining after 100 years.

I defined the probability of survival (PS) as the ratio of the number of iterations resulting in survival over the total number of iterations (1 being survival in all the iterations). I fitted the relationship of probability of survival against LogMPA using a three parameter dose-response curve with GraphPad Prism software (v.6.0). I then obtained the FS_{95}, which I define as the fragmentation level with a probability of survival greater than 95% (PS >=0.95).

Although survival of monkeys in the environment provides valuable information, the number of actual remaining monkeys is important for longer-term population survival. For this reason I also focused the analysis on the number of monkeys remaining after 100 years, which can be defined as the final carrying capacity of the system given a certain condition, in this case different levels of habitat fragmentation.

I took the median population number of spider monkeys remaining after 100 years from each set of iterations and graphed them against LogMPA. Since this relationship fits a dose-response curve, I was interested in obtaining the FP_{50} value. The FP_{50} identifies the level of habitat fragmentation that results in a 50% reduction in potential carrying capacity (analogous to the use of EC_{50} value in ecotoxicology).

I screened the GIS MPA layer (see section below for details) using the FS_{95} and the FP_{50} value to generate a map highlighting forest area with a >=95% chance of survival for *A. f. fusciceps* and areas with a survival of at least half of the original carrying capacity of an unfragmented forest system for a period of at least 100 years respectively.

6.3.3 Effect of hunting and selective logging in fragmented forest scenarios

I ran the ABM through the 60 forest samples (with different levels of fragmentation described by Mean Patch Area) and added three levels of hunting activity: (*Low, Medium* and *High*) representing 5, 10 and 15 monkeys hunted per year respectively.

I also modelled levels of logging activity (*Low, Medium* and *High*). Each patch in forest samples in the model environment represents an area of approximately 30m x 30m, which in reality harbours around 10 trees with a Diameter at Breast Height (DBH)>40cm (the minimum harvesting DBH according to current Ecuadorian Forestry Law) (Ecuador, 2004).

I tested three intensity levels for logging, the lowest being 5% removal of existing patches. This represents sustainable harvesting quotas reported by the Ecuadorian Ministry of Environment (MAE) and by the locally operating timber company BOTROSA (5 trees per hectare in 20 year cycles). I also tested two further logging levels: *Medium* and *High*, removing 10% and 15% of all patches in the environment respectively. I ran the ABM using the Behaviour Space tool in Netlogo (v.5.1) (Wilensky, 1999) to analyse all possible combinations of logging and hunting under various levels of habitat fragmentation represented in the 60 forest samples.

The resulting data provided information on i) Probability of Survival for each scenario and ii) Number of spider monkeys remaining after 100 years for each scenario.

6.3.4 Mapping priority conservation areas for spider monkeys in NW Ecuador in real scenarios of habitat fragmentation, logging and hunting activity

I downloaded 30m LANDSAT forest cover datasets from a recent global analysis of forest cover (Hansen *et al.*, 2013) merging and clipping tiles 0°N 80°W and 10°N 80°W to my area of interest (top 1.14°N, left 79.51°W, Right 78.12°W, Bottom 0.15°S) using GIS (ArcGIS v 10.0, Esri, Redlands, CA, USA). From the forest cover dataset from 2000 I deleted forest loss and added forest gains until 2012. I then reclassified pixels with >90% forest coverage to a forest category of value 1 and other pixels as zero.

The forest dataset,covering some 130 km by 130 km of NW Ecuador (row size 4640 pixels, column size 4982 pixels, cell size 27.78m), was exported as an ASCII file (with header information deleted) to the spatial pattern analysis program for categorical maps (FRAGSTATS 4.2, McGarigal *et al.* (2012).

A square moving window analysis (4640 m by 4640 km window) was used to generate fragmentation statistics raster datasets for the Mean Patch Area metric. Header information was added back to these ASCII raster datasets and they were reimported to GIS, a coordinate system (WGS_84) applied, and the layers converted to GEOTIFF files to generate a GIS layer with MPA metrics.

6.4 Results

6.4.1 Development of an ABM for *A. f. fusciceps*

Sensitivity analysis

The model proved to be robust to variations in parameter values relevant for the persistence of the population of spider monkeys as shown in Figure 6.2.

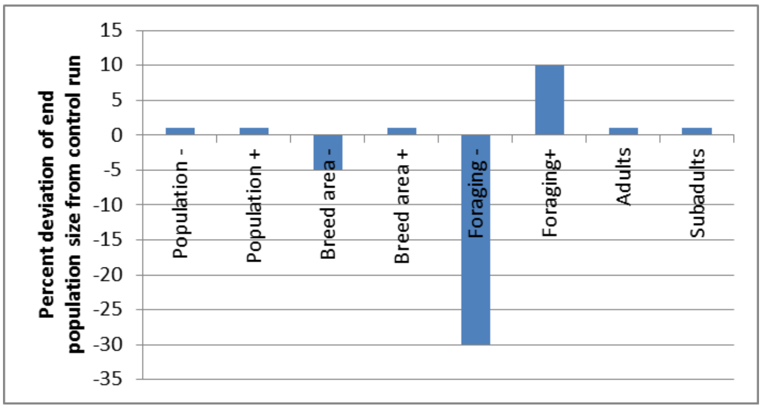

Figure 6.2: Results of sensitivity analysis for median population size after 100 years represented as percent deviation in population size from the control run (representing unfragmented 2500 hectare forest area). Positive + or Negative - signs indicate positive or negative differences from control model values.

Most of the parameters had an effect of < 1% on the population compared to the control run. "Breed area" and foraging distance had the largest effects. "Breed area" was tested at its minimum value of <1, which in reality would represent a male being present within a radius of approximately 30m. Above this distance this area does not appear to have an effect on the population size.

The model seems to be sensitive to changes in the ”foraging distances” values, which refer to the radius a monkey searches for fruiting trees with maximum fruit. I calibrated the model with a radius of 5 (representing a radius of 150m) as this is the value I observed at the study site.

The sensitivity test shows that allowing a larger movement radius would have an impact on the end population, however I decided to leave the baseline value of 5 since I also tested the model in fragmented scenarios, where having a higher foraging value of i.e. 10 would result in monkeys jumping across fragmented areas (a behaviour not seen in this arboreal species). It is, however, worth keeping in mind the impact that this parameter has on the population.

6.4.2 Effect of habitat fragmentation on survival and carrying capacity of *A. f. fusciceps* in NW Ecuador

I chose to use MPA as the metric describing fragmentation in this study, since it showed the best fit to a three parameter dose-response curve (see a comparison of the curves and fit of other metrics in Appendix 2).

I identified the FS_{95} cut-off point at an MPA 11.35ha and the FP_{50} cut-off point at 32.02ha and over as shown in Figure 6.3 and in Figure 6.4).

Using these two measures I show in Figure 6.5 two areas of viable habitat for *A. f. fusciceps* in NW Ecuador; in green the area with a >=95% chance of survival (given by the FS_{95}) covering 9657km^2 and in orange the viable habitat given by the FP_{50} cut-off point. The map based on the FP_{50} value shows the areas where the primate survives at populations of at least half of the original carrying capacity of an unfragmented landscape for at least 100 years, this covers an area of 6667km^2 (Figure 6.6).

6.4.3 Effect of hunting and logging in fragmented scenarios

I summarize the results from combinations of hunting and logging effects in Table 6.3. Of the 60 levels of fragmentation that were analysed there were scenarios where only 3 of 60 patches showed survival of the primate. All these patches had MPA values above 175ha.

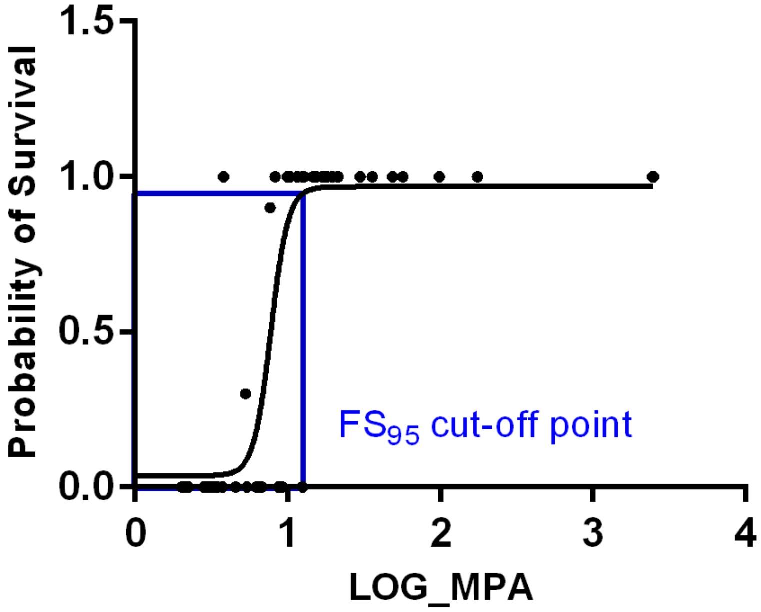

Figure 6.3: Probability of Survival of *A. f. fusciceps* against LogMPA fitted with a three parameter dose-response curve in patches representing 2500 hectares

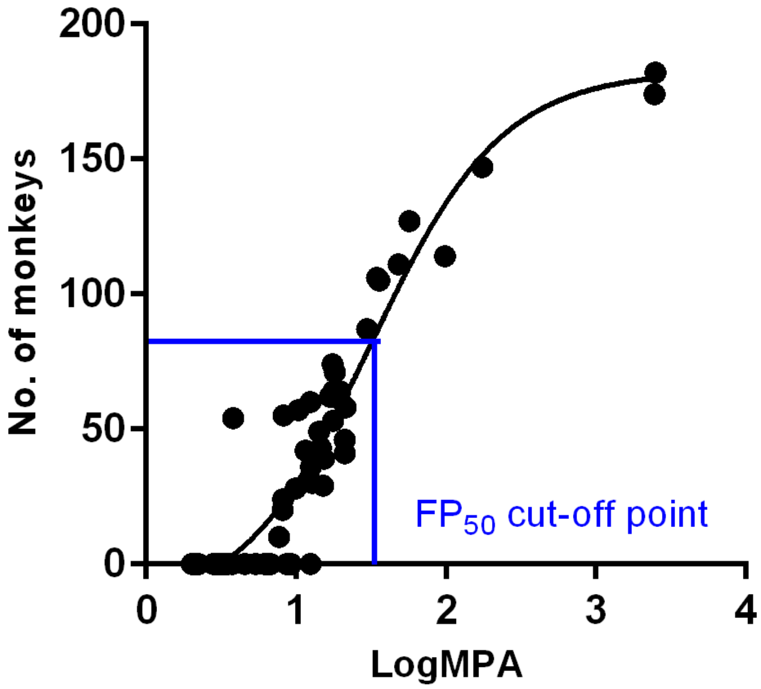

Figure 6.4: Population number of *A. f. fusciceps* against LogMPA fitted with a three parameter dose-response curve in patches representing 2500 hectares

I mapped this area, which represents the minimum viable habitat where there is any survival of brown-headed spider monkeys given conditions of *medium* logging

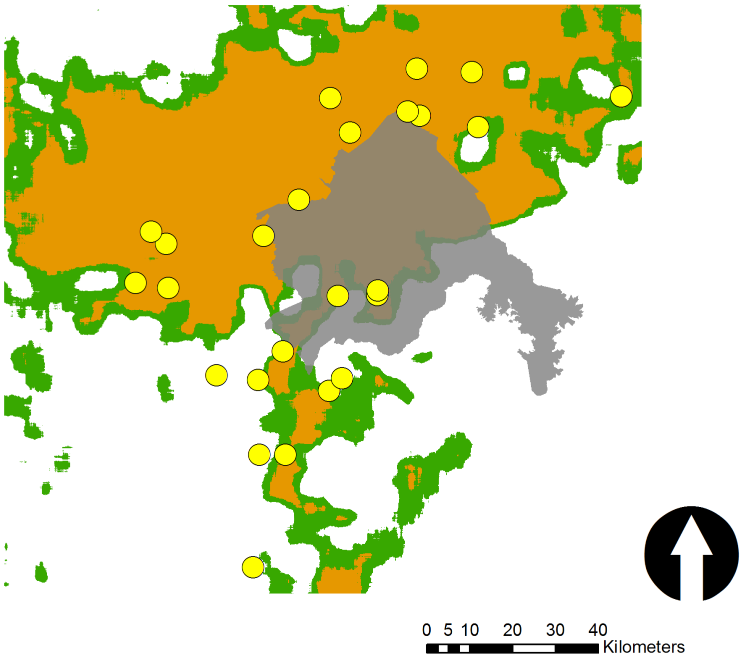

Figure 6.5: Map of NW Ecuador highlighting areas of viable habitat for the survival of *A. f. fusciceps* compared to unfragmented landscape; in green, area with a >=95% chance of survival; in orange area, for the survival of at least half of the carrying capacity. The protected area Cotacachi Cayapas Ecological Reserve is represented in grey, while field observations of *A. f. fusciceps* are represented by yellow circles.

combined with *low* hunting and *high* hunting with *zero* logging.

I overlapped this map with the previously obtained highlighting areas with >=95% survival. This map, (Figure 6.6), shows how logging and hunting drastically reduces the viable habitat for brown-headed spider monkeys, from 9657 km^2 to $3543km^2$.

Table 6.3: Mean patch areas (MPA) values for >=90% for *A. f. fusciceps* in 2500 hectare windows under different logging and hunting intensity levels

	Zero Logging	**Low Logging**	**Medium Logging**	**High Logging**
Zero Hunting	11ha	12ha	15.45ha	31.55ha
Low Hunting	42ha	175ha	175ha	No survival
Medium Hunting	175ha	No survival	No survival	No survival
High Hunting	175ha	No survival	No survival	No survival

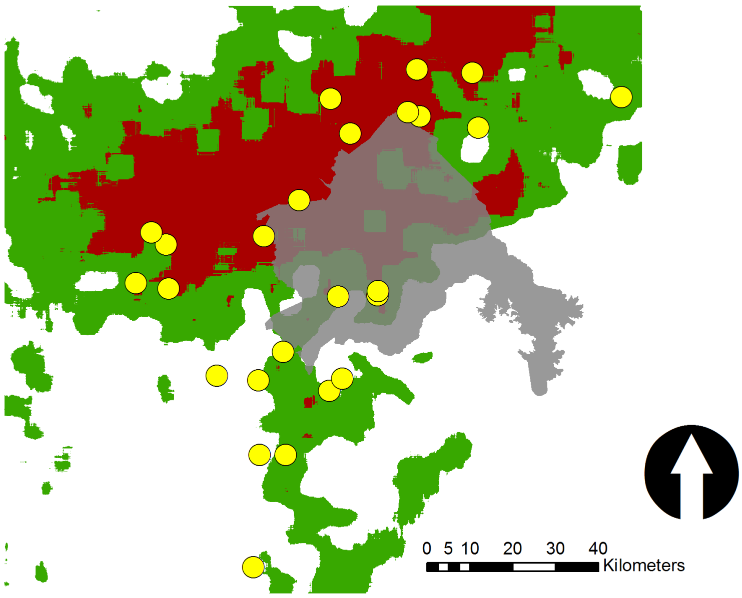

Figure 6.6: Map of NW Ecuador highlighting areas of viable habitat for the survival of *A. f. fusciceps*; in green, area with a >=95% chance of survival without logging or hunting activity; in red area for a >=95% chance of survival with minimum levels of logging and hunting activity.The protected area Cotacachi Cayapas Ecological Reserve is represented in grey, while field observations of *A. f. fusciceps* are represented by yellow circles.

Figure 6.7 shows a comparison of the size of the areas with 95% chance of primate survival (FS_{95}) in a scenario of fragmented forest, but with no logging or hunting; the FP_{50}, where at least half of the original carrying capacity of brown-headed spider monkeys survives in a zero hunting and zero logging scenario and the FS_{95} in a scenario of habitat fragmentation and minimum logging and hunting.

Figure 6.8 shows the scenarios in which there is >=90% survival of spider monkeys under Low, Medium and High Logging with Zero Hunting, and Zero Logging and the change in the final carrying capacity. Figure 6.9 shows the final population abundances and the confidence intervals (95%) around this value. There is a statistically significant effect ($p<0.05$) of each of the scenarios compared to the original carrying capacity for a scenario with zero logging and zero hunting.

There was no survival of spider monkeys in any combined effects of logging and hunting activity except for *low* logging and *low* hunting and *medium* logging and *low* hunting. However, survival was only observed in three out of the 60 patches

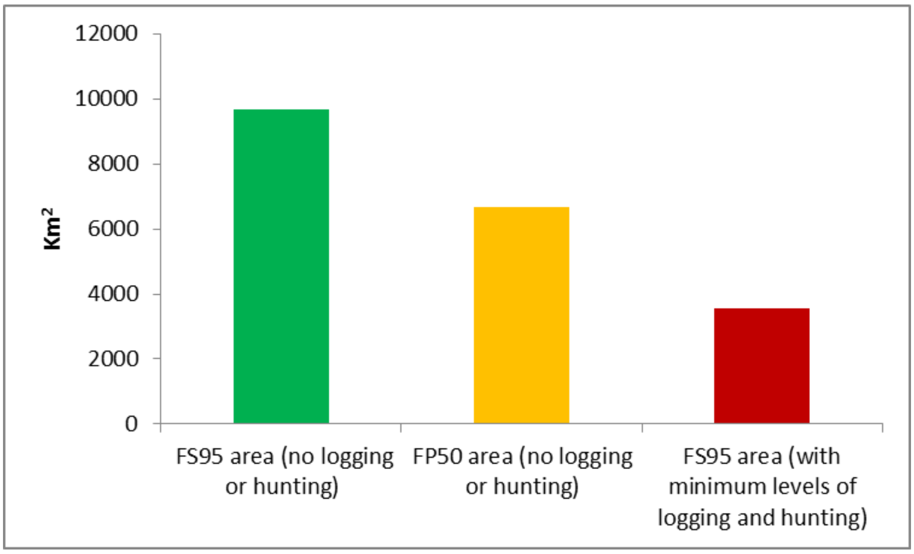

Figure 6.7: Comparison of areas with different scenarios for the survival of *A. f. fusciceps* and for at least half of carrying capacity in NW Ecuador.

analysed and were therefore not included in the analysis. This was also observed for *low* hunting with no logging scenarios, with no survival in less than 10 patches.

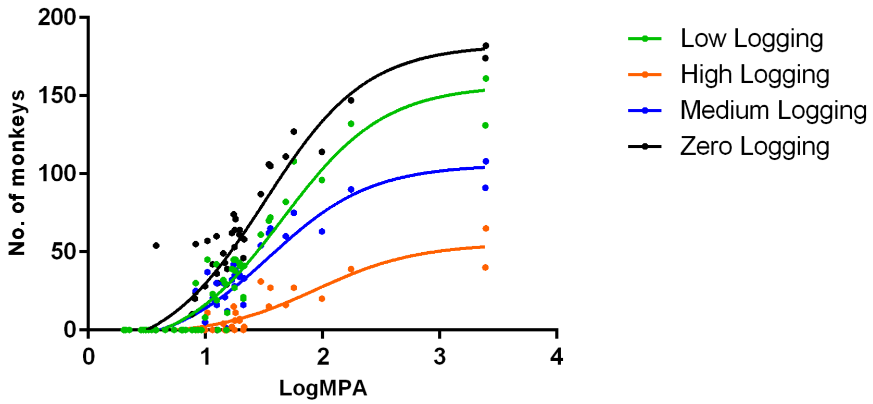

Figure 6.8: Number of spider monkeys after 100 years in four different logging scenarios against LogMPA

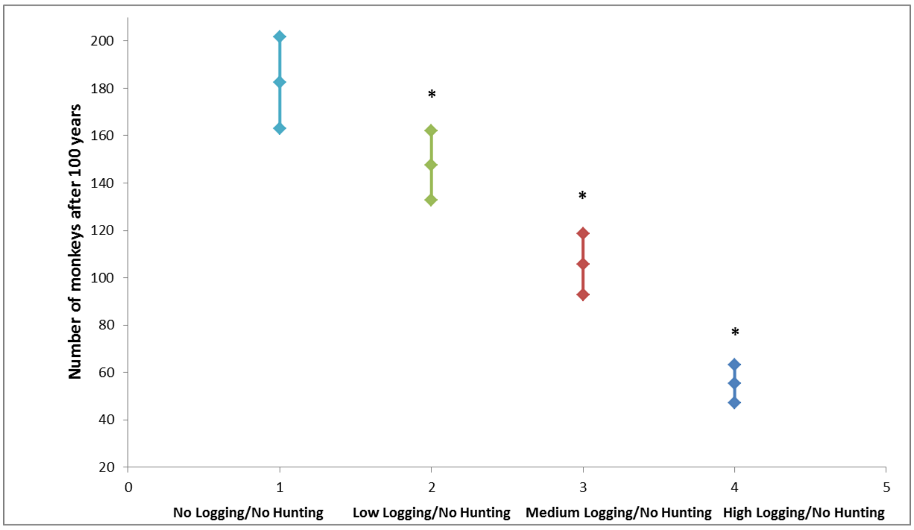

Figure 6.9: 95% Confidence Intervals of the final population levels (number of monkeys after 100 years). Scenarios with significant effect ($p<0.05$) tested with a Wilcoxon signed rank test compared to the original zero logging/zero hunting scenario are highlighted with a star

6.5 Discussion

Estimates of minimum population size that will guarantee the survival of a population in a specified time period, given certain circumstances is crucial in the conservation of endangered species. One way of obtaining these is by using population viability analysis (PVA: Shaffer 1981). There is little research to date focusing on population viability analysis on spider monkeys, however a PVA on the closely related *Brachiteles arachnoides* (Strier 1993) has elucidated that the main variable influencing population extinction is area of available habitat along with probability of environmental catastrophes.

Dowd (2009) developed a PVA for *A. f. fusciceps* with the available information at the time, which relied mostly on estimates from interviews by Tirira (2004). Nevertheless this study highlighted the extinction risk in habitat loss and hunting scenarios, it also became clear that there was the need to develop a model that could incorporate more specific data on the brown-headed spider monkey and its particular relationship with its habitat.

One of the aims of agent based models applied to ecology is to understand the interrelationships between individual traits and system dynamics, so instead of thinking about populations in terms of birth and death rates depending only on population size, an ABM approach allows us to incorporate the study of wider processes e.g. how survival of individuals is impacted by habitat, other individuals and adaptation (Grimm, V. & Railsback, 2005).

In the case of the brown-headed spider monkey, little was known about its relationship to its habitat in the Ecuadorian Chocó. I discuss here the relevance and necessary detail of field work data in the development of a species specific ABM with a focus on conservation, considering time, costs and usefulness according to my experience from the current study. For the development of my model I parameterized population variables (birth rates, age to maturity, etc) from the literature on the genus, with the exception of age ratio (adults vs subadults, infants and juveniles) which in the case of the population in Tesoro was adult biased. In the sensitivity analysis I see that this parameter (compared to ranges of values seen in the literature) does not significantly impact the final population abundances.

The model was also shown to be robust to changes in the radius distance at which females could find suitable males (breed-area, estimated from literature), except for a difference of <5% for radius less than 3 (representing less than 90m radius), this parameter may have implications in fragmented habitats and different distances should be tested in fragmented forest scenarios in the future.

The environment was modelled based on data collection from the habitat of *A. f. fusciceps*. This included specific abundances of types of trees based on diet preference as well as site specific fruiting patterns during the year. Even though energy gain and loss is parameterized from the literature, it is evident that data on availability of trees during the year and the interaction of monkeys with them was critical to determine realistic carrying capacity for the system. I validated the modelled population density (8 individuals/km^2) against results from rapid census (9 individuals/km^2 (Moscoso, 2010)) and my census data from line transects in Tesoro (15.79 individuals/km^2).

I aimed to develop the simplest model to provide relevant information on the survival of brown-headed spider monkeys under a range of different scenarios, therefore I excluded behavioural aspects such as emigration of females, male patrolling, social relationships, natal care and activity budgets. These variables would have given us a more detailed yet more complex model, and it is possible that the outcome would have been different. However I am also demonstrating that a simple model is capable of providing meaningful results to inform conservation strategies for an endangered species.

Various studies have shown the vulnerability of the genus *Ateles* to habitat disturbance as well as the reduced densities in selectively logged and disturbed areas (Lovejoy *et al.*, 1986; Michalski & Peres, 2005). In particular, research by Michalski & Peres (2005) showed that the probability of occurrence of spider monkeys was 50% or higher in forest fragments larger than 100ha, and that patch connectivity was a significant predictor of spider monkeys' presence. This study evaluated presence/absence whereas my research went further in evaluating probability of survival and effects of fragmentation on carrying capacity. However, I only focused on one predictor (based on mean patch area). It would therefore be important to evaluate the secondary role of connectivity in my study as well.

The precarious situation of brown-headed spider monkeys in NW Ecuador requires the identification of priority conservation areas for this species, especially in areas lying outside government protection. Conservation strategies are costly and funding is usually quite limited, and should be used effectively. Therefore it is vital to be able to target initial efforts in areas where there is a higher probability of survival of viable populations of the species. In the case of *A. f. fusciceps*, it may be counterproductive to attempt to focus conservation effort on areas that are too fragmented to support a viable population in the short to medium term, for instance areas with a MPA value below175ha.

Previous research by Peck *et al.* (2010) identified viable habitat for this primate in NW Ecuador. Here I take a further step in identifying remaining habitat capable of maintaining populations of at least half of the carrying capacity of the species for real scenarios of hunting and logging activity.

The method developed here, combining species-specific field data, agent-based modelling and habitat fragmentation analysis is a novel approach that may be used to determine a cut-off point for areas capable of supporting a viable population given real scenarios with lower uncertainty than using the minimum viable population (MVP) or the 50/500 rule (Franklin, 1980; Shaffer, 1981). This would avoid investment in conservation strategies in areas with reduced levels of success.

Mean Patch Area as a metric describing fragmentation was useful in my data analysis, however there are limitations in its use, mainly because it reports an average of the patch size and therefore does not give any information about the number of patches in the environment, which could be ecologically relevant. I recommend further analysis of the effects of other metrics on the survival and carrying capacity of brown-headed spider monkeys, especially of the distance between patches and number of patches, which would inform projects investigating connectivity and establishing biological corridors in the area.

The fragmentation data used fo this study (the 60 patches from the LANDSAT image) was obtained randomly with the aim of best representing the pattern of fragmentation in the region. Even though this was the right approach, my results show that I am lacking data, especially in the MPA values where the spider monkey population begins to decay. From my results I can certainly say that MPA levels below 174ha do not support a population of spider monkeys in any scenarios of hunting or logging. This result is relevant for mapping priority areas, however I am lacking a more complete spectrum of the effects in MPA values above 174ha. I recommend undertaking further screening of a LANDSAT image to identify further patches with the MPA values that can fill the gap in the analysis presented here.

The decision to screen for 2500ha patches resides in the fact that my study area (Tesoro Escondido) is about the same size and provides a unique calibration point from field abundance estimates. Logging and the subsequent forest fragmentation is a reality I have encountered since I started my work in Tesoro. Since it was identified as a priority area, strategies have been implemented to stop agricultural expansion and forest exploitation, therefore Tesoro Escondido can work as a proxy and conservation model for similar situations in NW Ecuador. Nevertheless screening window size may influence the final mapping result such that screening for areas of larger size might provide different and possibly more complete results, and it is something I recommend in future work, although it should be noted that the computing demands and modelling time will also increase.

Using the same methods as Peck *et al.* (2010) I would obtain an area similar in size. However, results based only on probability of survival can be misleading, especially when working with a species as vulnerable as *A. f. fusciceps*. This is why, focusing on carrying capacity under different habitat fragmentation levels provides a further screening step, one that can be vital for conservation purposes and that is possible using ABMs. Comparing the areas obtained by the FS_{95} with only fragmentation and the FS_{95} incorporating both logging and hunting (see Figure 6.6) it is evident that the viable area is drastically reduced and a high degree of connectivity is lost.

Habitat fragmentation in NW Ecuador is mainly driven by logging activity and agricultural expansion, however, timber extraction in the province of Esmeraldas has never been put into the context of the conservation of a critically endangered species, such as *A. f. fusciceps*. Logging, even under sustainable management, can have serious negative impacts on highly arboreal species, particularly on specialists, such as spider monkeys. Even though Ecuadorian government policy has slowly moved towards more sustainable forest management, endangered fauna is rarely taken into account when designing or approving management plans. Even selective logging (lowest impact) can have serious detrimental effects on the forest and on the biodiversity it contains. Damage associated with logging such as road building, construction of log-loading areas and destruction during felling and log dragging, has in fact the greatest impact on the forest environment (Johns, 1988). my modelling of logging activity is in fact quite csince it does not take into account collateral damage to the forest and is only based on removal of a set percentage of trees. Even so, my results indicate that even the lowest level of logging (5 trees per hectare every 20 years) has detrimental effects for the carrying capacity of spider monkeys in a fragmented landscape after 100 years, similarly, the combined effects of hunting activity and fragmentation are negative: spider monkeys survive in only less than 10 of the forest patches (of 60 patches total) and in no case at the full carrying capacity seen in unaffected forest.

Peres (2001) previously demonstrated a synergistic effect between hunting and fragmentation, considering it a possible cause of extinction for large-bodied vertebrates in the Neotropics. Hunting of *A. f. fusciceps* is mostly restricted to subsistence hunting by indigenous Chachi groups, with no evidence of bushmeat trade outside their communities. Sustainability of hunting of brown-headed spider monkeys has not been assessed to date, mostly due to the small numbers of this primate and the lack of information on hunting activity in this area of Ecuador. My modelling approach indicates that hunting activity, even at low numbers is not sustainable in fragmented landscapes. It appears that below a value of MPA 30ha there is no survival of spider monkeys at the lowest hunting level (5 monkeys per year). This result is actually quite worrying, since the off-take value is very low, it could even come from natural mortality such as predation or infant mortality (currently not modelled in the ABM). I therefore recommend developing an educational programme specifically aimed at reducing (or even eliminating) hunting of brown-headed spider monkeys within the indigenous Chachi communities (see suggestions for this in Chapter 3).

Based on my results I also recommend carrying out rapid surveys to determine the presence of this species in the NW section of the Cotacachi Cayapas Ecological Reserve, especially north and north-east of the Pambilar Wildlife Refuge as this appears to be a critical area for the future conservation of the brown-headed spider monkey.

This area is owned and managed by the indigenous Chachi people, yet a large part is co-managed by the timber company Botrosa S.A.. Given the fact that even low logging activity (and their collateral damage to the forest) can be very detrimental for brown-headed spider monkeys I strongly suggest designing strategies to work together with the Chachi groups. This may influence a change towards conserving their forests and rejecting the incursions of the extractive logging industry and companies such as Botrosa S.A.

Providing the Ecuadorian Ministry of Environment (MAE) the results of this study may contribute to the design of more effective conservation strategies in the area, such as the ones we have pioneered in Tesoro Escondido (see Chapter 7).

A conservation strategies roadmap for critically endangered species: A study case on the brown-headed spider monkey *Ateles fusciceps fusciceps* in NW Ecuador

7.1 Introduction

The main threats to critically endangered species, primates amongst them, are primarily habitat loss, habitat fragmentation and hunting pressure (Schwitzer *et al.*, 2014). This is especially so when they are found in areas under no governmental protection, as is the case of the critically endangered brown-headed spider monkey *Ateles fusciceps fusciceps* (Peck *et al.*, 2010).

Implementing conservation strategies in these areas is a challenging task. Here, close-knit interactions between people and nature (i.e. tropical forests) are often found. Complex interactions occur between resource exploitation, poverty, lack of basic health and education services, abandonment by local and federal government and pressure from extractive industries. This difficult and often shifting environment, complicates the implementation of conservation strategies and makes their long term success challenging. Often the answer is a community conservation approach (Waylen *et al.*, 2010).

Projects have been integrating development within conservation goals, or 'community based conservation', for the last 35 years with the aim of shifting control from top-down, centralized powers to smaller, local groups often left out of mainstream projects (Waylen *et al.*, 2010). Notwithstanding, community based conservation also faces challenges especially because communities, far from being a cohesive social group, are changing units, accurately defined by Carlsson (2000) as 'multi-dimensional cross-scale social political units or networks changing through time'. Thus working with communities towards a joint conservation goal requires addressing complex and changing mind-sets.

Furthermore it is possible that community based institutions by themselves are unable to deal with the full range of conservation issues in a particular area. An alternative framework, proposed by Barret *et al.* (2001) is to distribute management across multiple institutions, rather than focusing on just one.

In this chapter I address a stepwise approach towards developing and implementing conservation strategies for critically endangered species (see Figure 7.1), using a case study of the brown-headed spider monkey *Ateles fusciceps fusciceps* in NW Ecuador.

With this study I aim to contribute towards the new wave of conservation science, one that addresses issues simultaneously at various scales (Berkes, 2004, 2007)) and where researchers and stakeholders interact in the definition and solution of specific problems.

I provide an outline of the steps followed during my project in collaboration with the University of Sussex, local Ecuadorian NGO's and a local farmer community. I provide a short background to the subject if it has been applied elsewhere and a description of my experience at the field study site. I conclude with an analysis of the work undertaken so far and recommendations for the future.

7.2 Identification of priority conservation areas: Developing effective mapping techniques

Conservation plans for endangered species requires information such as population size, population decline and probabilities of extinction . Obtaining such data is often challenging as some species only occur at in very low densities in dense forests, isolated locations or tough and challenging terrain. Estimates of total numbers and specific distribution is also often impeded by lack of funding for long-term fieldwork, especially in developing countries. More recent development of rapid census methods and modelling techniques have aided in identifying priority conservation areas of

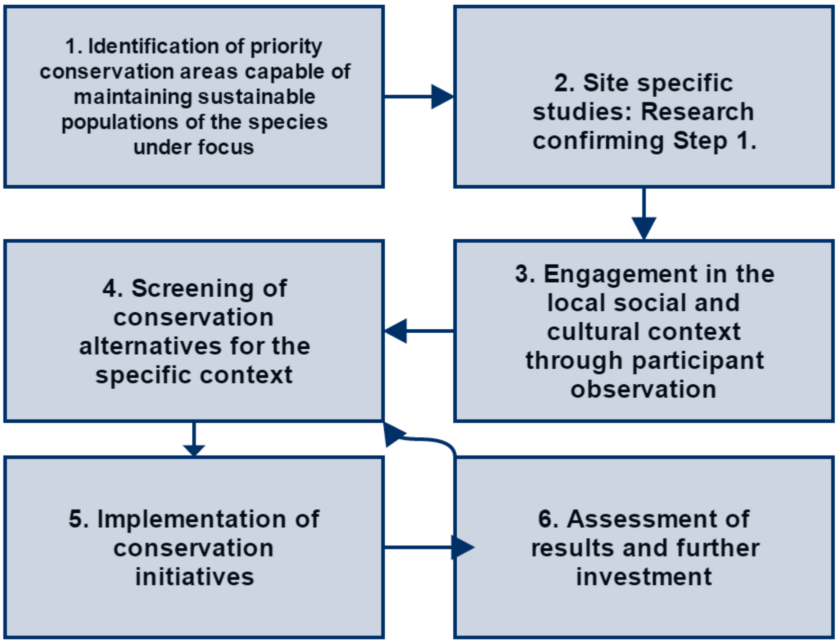

Figure 7.1: Conservation roadmap for the implementation of conservation strategies for endangered species

suitable habitat, extinction risks, landscape change, etc. and thus contributing to a better knowledge and management of endangered species (Peck *et al.*, 2010; Huang, 2013).

Modelling techniques allow for the development of species-specific landscape maps (using tools such as GIS) and more recently individual based modelling approaches have been able to highlight the effects of current threats to endangered species populations such as habitat fragmentation, logging activity and hunting pressure and have been used in the conservation planning for endangered species covering many taxa (DeAngelis & Mooij, 2005).

My case study focuses on the conservation of the most endangered primate in Ecuador and one of the 25 most endangered globally, the Ecuadorian brown-headed spider monkey *Ateles fusciceps fusciceps* (IUCN Red List 2014; Schwitzer *et al.* (2015)).

The critical status of the populations of the brown-headed spider monkey *Ateles fusciceps fusciceps* was reported by Tirira (2004) who estimated a total population abunance of only 250 individuals remaining in the forests of the Ecuadorian Chocó.

7.3 Site specific studies

Once a site has been identified as priority area for the persistence of the species under study either through modelling techniques, rapid census field work and/ or local interviews, it is necessary to carry out site specific studies to corroborate initial assessment and to gather further information on the species, i.e. habitat requirements and and specific threats.

In the case of *A. f. fusciceps* I undertook a year long research phase in the year 2012 within the forest cooperative Tesoro Escondido.

Tesoro Escondido is a 3000 ha forest cooperative owned by 42 farmer families, located in the buffer zone of the Cotacachi Cayapas Ecological Reserve (RECC), 8km south from the Pambilar Wildlife Refuge (RVSP). It lies in an area denominated "Canandé watershed", which, as one of the last remnants of the Chocó biodiversity hotspot, harbours extremely high levels of biodiversity, both flora and fauna, yet it is heavily threatened by the presence of timber companies, monocrop plantations (mainly African palm) and agricultural expansion (Moscoso *et al.*, 2012; Jestrzemski, 2010).

Farmers in Tesoro and Hoja Blanca are 'Colonos', a term used in Ecuador to principally describe people who have arrived from other provinces within the country. Most of the landowners in Tesoro live in the town of Cristobal Colón, located 15km to the South of Tesoro, with only a few farmer families (11) living inside the forest cooperative. Around 80% of the total area still remains primary forest, the rest has been turned into crop fields (mainly cacao plantations but recently also African palm). Land is also converted to grasslands to raise cattle. Local extraction of wood is also a common practice among families living in Tesoro, even though the price they obtain for it does not provide a significant economic benefit since it has to pass through at least two intermediaries on the way out.

Land conversion is an ongoing process accelerated by poverty, lack of alternative income opportunities and by the low prices farmers get for their products, mostly because of the isolation of the area. Owning primary forest does not provide any financial profit and therefore it is not regarded as valuable. Most farmers are just waiting for the timber company to buy their land. . Furthermore the terrain in

Tesoro makes clearing forest in some parts difficult, this is one of the main reasons why it is still intact in some areas. Isolation is also the reason people in Tesoro are demanding roads to access the closest towns. At present, demands for road building are a threat to primary forest in the South section of Tesoro. Roads can equally be used to extract timber and facilitate agricultural expansion.

The reality in Tesoro and its surrounding is complex and challenging from the conservation point of view. Any attempt to design strategies aiming at protecting this forest need to take into account all angles and perspectives, as well as the role of local stakeholders if they are to be successful in the long term.

Little was known about the ecology of the brown-headed spider monkeys, therefore I started by focusing research on its population density, diet and behaviour. I also collected data on habitat and threats faced by this primate such as hunting by the indigenous Chachi (See Chapter 3, 4 and 5).

Research in Tesoro was carried out by volunteers and by students, both national and international. The year 2012-2013 was the first solid step in building a long-lasting relationship with the community of Tesoro, which has been crucial in the development of further projects.

It is also important to point out that there are farmers in Tesoro who have been involved in conservation of their forests without any incentives or external influence. These families have protected their forest against invasions, illegal logging and illegal hunting, and even fought against the local timber company, enforcing a form of communal law for the protection of the environment. This agrees with a report by Shanee *et al.* (2014), from a case study in Peru, arguing that rural communities can actively promote and participate in conservation initiatives defying the rooted reputation of farmers to be destructive and anti-conservation. In Tesoro, it is also the case that destructive behaviours towards the environment are predominantly associated with economic and legal pressures rather than an actual intention against nature.

7.4 Engaging with the local social and cultural context

Immersion in the local context of the field site under study can be a decisive step in the success of any conservation initiatives to be implemented. In fact engagement with the local cultural context is one of the main factors in predicting success of conservation interventions (Waylen *et al.*, 2010).

One way of engaging with the local social and cultural context is 'participant observation', which is one of the fundamental tools used by ethnographers to understand behaviour in a new cultural context and enable effective use of any other methodology (environmental education, etc.). It consists of participating as unobtrusively as possible in the daily lives of the community and it has been suggested as a strategy in community based conservation especially during the initial phases (Russell, 2003).

At my study site, valuable initial information was collected through interviews and participatory meetings by Moscoso & Peck (2012), pinpointing socioeconomic drivers in the community and potential community development projects such as eco-tourism and organic cacao. However, participant observation, and becoming an actual member of the community during the long term research on the brown-headed spider monkey in Tesoro allowed the identification of specific drivers and potential mitigation strategies for ongoing deforestation and agricultural expansion in the area.

7.5 Screening process for conservation strategies

Developing and implementing effective conservation strategies for endangered species while addressing the needs of local communities that have a direct impact on the species and its habitat is a challenging task as previously mentioned by Savage *et al.* (2010). Community education programmes address only part of the problem; issues related to poverty can be more damaging to the long-time conservation of species and their habitats.

In this case study I envisioned a comprehensive cross-scale programme to tackle conservation issues in Tesoro, designed mostly from the bottom-up but at the same time linked to and strengthened by connection to local institutions and interdisciplinary projects in the area.

In the process of developing such a conservation programme, a screening process is needed to assess the feasibility of potential strategies and hence proceed to allocating available funds and effort to initiatives with a higher probability of success.

I developed a screening process in collaboration with ClientEarth (http://www.clientearth.or
from July-August 2013. Myself and Pamela Ferro (environmental lawyer with ClientEarth) undertook the study to analyse the feasibility of several alternatives proposed to reduce agricultural expansion in Tesoro and protect the remaining forests.

I assessed the following alternatives:

- Establishing a protected area in Tesoro
- Linking the conservation of the brown-headed spider monkey's habitat to the Government initiative 'SocioBosque'.
- Linking cacao production to the conservation of brown-headed spider monkeys.
- Scientific tourism in Tesoro
- Parabiologist Programme

7.5.1 Establishment of a protected area in Tesoro Escondido: The importance of taking risks

The possibility of creating a legally established 'Community Protected Area' in Tesoro Escondido to ensure the long term conservation of the remaining forests was evaluated. To this end a number of meetings with the Ministry of Environment (MAE) were held and we also explored the possibility with the community through meetings and interviews.

Community Protected Areas are foreseen as a sub-system of the SNAP (National System of Protected Areas) however they have not yet been implemented in practice. In fact, there are no specific requirements and/or guidelines to formally create them at present except the legally recognised land titles as the minimum requirement.

The importance of land registration in this area resides in the fact that landholders can then access credits or loans for agricultural purposes, government programmes such as the Socio Bosque scheme and legally sell the land, however few of them are interested in registering their properties. Land titling is a complex issue to address in Tesoro and in the Esmeraldas province in general. This is mainly due to the history of land tenure there but also due to periods of lack of organization and changes in state offices. In fact, a large portion of land in Tesoro lies within the Forest Heritage Category (Bloque 10 Patrimonio Forestal) originally designed to manage timber extraction. On land occupied within this zone the legal titling requires the design of a management plan under which no more than 30% of the forest can be extracted. The remaining land within Tesoro is dealt with through the Lands Secretariat.

The titling process (both through the MAE and the Lands Secretariat) is a long, expensive and complicated procedure, therefore very few landholders are interested in undergoing this process, even if they would be interested in establishing a Community Protected Area. A more direct alternative proposed by some members of the community is for us as a project to directly buy forested land from owners who would otherwise want to transform it into pastures, croplands or sell it to timber companies. This option requires purchase of land even if it is untitled, risking legal procedures down the line. However, on the other hand, this approach brings it immediately under protection though our research and community programmes as land boundaries are generally well respected in the region.

The feasibility of this last option rests on agreement and understanding by possible funders as to the potential risks as well as being able to directly communicate effectively with landowners in Tesoro to arrange land purchase.

7.5.2 Payment for Ecosystem Services: Linking landowners to Ecuador's 'SocioBosque' scheme and the conservation of the brown-headed spider monkey

Payment for Ecosystem Services (PES) is considered a targeted and direct way to achieve conservation goals as well as being an effective strategy to channel resource to rural populations otherwise overseen (Koning *et al.*, 2011). Its popularity has increased over the last 40 years with large scale projects across Latin America especially in Costa Rica and Mexico (Morse *et al.*, 2009; Muñoz-Piña *et al.*, 2008).

In 2008 Ecuador implemented the national programme 'Socio Bosque' with the goal of reducing deforestation as Ecuador has the highest reported rate of deforestation in South America. Furthermore the 'Socio Bosque' programme also aimed to reduce the country's ecological footprint and alleviate poverty in rural areas (SENPLADES, 2009).

The SocioBosque scheme consists of transfer of economic incentives to land owners and communities who voluntarily commit to protect their primary forests for a period of 20 years. Beneficiaries receive up to USD 30.00 per ha per year (USD 30.00 for the first 50ha; USD 20.00 between 51 and 100 ha; USD 10.00 between 101 and 500 ha, USD 5.00 between 501 and 5000 ha, USD 2.00 between 5001 and 10000 ha and USD 0.50 for areas over 10001ha).

The buffer zone around the CCER was targeted as priority region for Sociobosque by the Environmental Ministry of Ecuador, and the programme started with the inclusion of lands belonging to indigenous Chachi communities (Koning *et al.*, 2011).

Lands in the buffer zone of the CCER do not qualify as ancestry lands (belonging to indigenous or afro-Ecuadorian communities) as they belong to Colonos. Some families have occupied the area for more than forty years, and have made a living out of agriculture and timber extraction, however there are still families owning lands with intact primary forest that has not been exploited yet, such as in Tesoro Escondido and neighbouring cooperatives (such as Simon Platatorres, 10 de Abril).

The Southern section of Tesoro in particular is still forested, and used by spider monkeys. This section is threatened mostly by a rapid conversion to agriculture. Nevertheless some farmers are interested in joining SocioBosque but are unable to do so as the first requirement for accessing funds is too have legal titles of the land. In the case of Tesoro, families do not hold property titles to the specific portions of land they occupy and the process required to obtain them is long and expensive.

In collaboration with interested members of the community I developed an initiative whose aim is to protect forested areas in Tesoro and neighbouring cooperatives by lending the necessary funds (at zero interest) to farmers to allow titling of their land (estimated at $3000 for a 50 ha plot). In return the farmer would agree to join the SocioBosque Government programme and to repay the debt over the next 10 years from funds earned through the scheme.

7.5.3 Linking cacao production to the conservation of the brown-headed spider monkey

Chocolate (cacao) has a substantial internal market and is a major export commodity from Ecuador, especially the province Esmeraldas (Nelson & Galvez, 2000)). In cacao growing countries land clearance to allow extensions of cacao croplands is a major cause of deforestation and even linked to the extirpation of primates (Bitty *et al.*, 2015).

Nevertheless there are successful examples of how crops such as cacao or coffee can be directly linked to the conservation of endangered primates such as gorillas in Virunga, Congo DR or coffee protecting gibbons in central Java Indonesia (Original Beans, 2015; Setiawan *et al.*, 2014).

In Tesoro, most of the families living in the northern section are cacao growers, having cleared the original forest cover in their lands for agriculture. Depending on the level of interest from the family and the location of their land, the amount of forest being cleared varies, however most of them still have forested areas. These forest areas are quickly disappearing to extend cacao croplands and through local timber extraction. The northern section of Tesoro is accessible by road to the towns of Chontaduro and Hoja Blanca, allowing easier access for farmers to sell their crop products and timber to intermediaries. It is worth noting that lands with forest are not considered valuable by most farmers, and hence the owners either clear the forest to work the land or wait for an offer from the local timber company, who generally buys the trees from the land (not the land itself) leaving the farmer cleared land ready for agriculture and with money from the sale of the trees (pers.observation).

Moscoso & Peck (2012) identified cacao in Tesoro as a potential alternative for improving local livelihoods. However, as this activity is one of the main drivers of deforestation in Tesoro, any initiatives regarding cacao needed to be directly linked to the conservation of the forest through community participation.

Due to initial interest I started a project in collaboration with the University of Sussex, interested donors and local NGO's as well as with the community that would link existing cacao production in Tesoro with both protection of the forests and reforestation of degraded areas. I assessed the possibility of selling cacao from Tesoro to specialized gourmet markets to obtain increased economic benefits while conserving the remaining forests in Tesoro. I did so by:

- Evaluating the type and quality of the cacao beans grown in Tesoro
- Assessing attitudes and possible agreement scenarios with cacao farmers in Tesoro

- Evaluating possible markets for an improved cacao linked to the conservation of the brown-headed spider monkey.

7.5.4 Scientific tourism

Scientific tourism organizations such as Operation Wallacea (www.opwall.com) work towards the design and implementation of biodiversity and conservation management supported by research students. This enables large extensive and spatial data collection in highly biodiverse yet threated sites and also provides income to the area as local sites provide accommodation, food, and support for fieldwork.

A collaboration with Operation Wallacea was considered an opportunity to initiate a scientific tourism project in Tesoro, to provide an alternative income for interested families. In effect scientific tourism had already been set into motion successfully on a small scale with two families receiving researchers from the University of Sussex and national and international volunteers throughout 2012 and 2013.

In 2014 I intended to carry this out at a bigger scale, working together with Operation Wallacea and groups of 17-18 year old students to undertake small research projects on the local flora and fauna. This would involve the local community in various aspects such as buying local products from them (fruits, vegetables, milk, cheese, arts crafts, etc.) as well as hiring services (accommodation, cooking, guiding and transportation).

Organisers of Operation Wallacea and members visited Tesoro in 2014 to assess the feasibility of conducting a field season with students.

Unfortunately several factors contributed to the decision not to pursue this project at that time. In particular Operation Wallacea protocols and methods of working and interacting with communities was not properly assessed beforehand, and was incompatible with our community-based approach. Families in Tesoro themselves opposed this project.

Nevertheless it is possible that this idea can be revisited in a near future if such a project is designed and managed by the same community.

7.5.5 Parabiologist programme

The term 'parabiologist' is used to describe local people with no formal education who receive training to become research assistants contributing with their knowledge of the area and becoming ambassadors for the conservation message in their communities. Training of local people as research assistants has been used as a way of involving communities in the conservation of endangered species. In Bolivia a large parabiologist programme is successfully protecting the 'Gran Chaco' environment in Bolivia and Paraguay. In Ecuador research supported by parabiologists has been reported by Treves & Schloegel (2010) addressing human-wildlife conflict in Sangay National Park.

The parabiologist approach has always been central to our project to conserve brown-headed spider monkeys. This started with the training of at least 20 parabiologists in Los Cedros Protected forest (Peck *et al.*, 2008). In Tesoro a training workshop for parabiologists was also run in 2010 with at least 15 people attending.

I carried out an assessment of the feasibility of a long-term parabiologist programme based in Tesoro by reviewing previous experiences, potential for funding, interviews with previous parabiologists and local attitudes in Tesoro towards becoming a parabiologist.

During the three year UK government funded Darwin Initiative PRIMENET project that ended in 2008 (Peck *et al.*, 2008) the main challenge identified was medium to long term funding, vital in ensuring continuing education and salaries for fieldworkers. During that project it also became evident that it was difficult to change ingrained views of forest communities as 'lower class' citizens in society. From interviews with parabiologists trained during that project I gathered first that indeed securing funding for salaries is essential. Even if there is an interest in pursuing a parabiologist career, people will chose jobs that secure the support for their families. Of those parabiologists trained by Peck *et al.* (2008), few continued to work in conservation and none of them permanently. From these interviews it was also evident that formal recognition of the parabiologist's work is needed, such as a national certification. This is also related to how rarely the parabiologist's fieldwork is recognized in publications by academics in Ecuador.

I interviewed parabiologists trained in the workshop carried out in Tesoro in

2010. Of the 15 people that attended the workshop none of them were subsequently hired in conservation or research projects, due to raised expectations and subsequent disappointment and lack of understanding of the objectives of the workshop. This was unfortunate as a number of the people who attended were genuinely interested in working with conservation of spider monkeys. The problem again was lack of funding to continue research, a consequence of short term funding cycles that would support parabiologists.

From this assessment I concluded that it was feasible to establish a permanent parabiologist programme in Tesoro if the following criteria were taken into account:

- Start at a small scale: Training only a small number of local people (maximum 5) prioritizing local residents of Tesoro.
- Securing funding for at least a year for at least three of the people trained.
- Keeping the workshop short in theoretical concepts and focused on the practical aspects of the work
- Offering salaries that match salaries offered by the local timber company that included costs of food and lodging
- Prioritizing a full inclusion of parabiologists in research frameworks in Tesoro.
- Ongoing training in a range of practical ecological survey and transferrable skills (basic informatics, ecological survey techiques for a range of other taxa, wilderness, first aid, etc.)

7.6 Action: Implementing conservation strategies

7.6.1 Establishing a protected area: The Brown-headed spider monkey reserve

Rapid agricultural expansion in the southern section of Tesoro lead to a risky yet more direct alternative: to buy untitled forested land to establish a core area with the minimum size of the home range of spider monkeys (400ha). Purchasing lands provides the opportunity to become a decision-maker within the community, and even though working towards conservation, respecting the way of life of the area. In fact, studies investigating variables affecting success of conservation initiatives have shown that these are more successful if they are conscious of local institutions and culture (Waylen *et al.*, 2010).

In light of this the vision for the 'Brown-headed spider monkey Reserve' is to welcome and promote local participation. To link to other stakeholders I aim to undertake ongoing research projects on biodiversity and sustainability in the area in conjunction with national universities thus also contributing to the training and knowledge of young Ecuadorian professionals.

7.6.2 Linking cacao production to the conservation of the brown-headed spider monkey

An agreement was designed with the cacao farmers wherein they commit to no logging of any of their forest for a period of two years. In that time our project commits to finance workshops to improve the quality of the product and to find a suitable buyer for the cacao produced in Tesoro. The buyer would need to pay a premium for the product as it would be directly linked to protection of the forest and conservation of the brown-headed spider monkey as this would also form a key aspect of their ethical standards and/or marketing strategy. The agreement required farmers with less that 50% of forested areas to also commit to a reforestation/restoration project.

7.6.3 Parabiologist programme

In January 2013 we initiated the 'Parabiologist Project' in Tesoro Escondido. The aim of the project was to train local people in collecting data on primates (census, habitat, behavioural data) This would enable them to work as scientific fied assistants (parabiologists) in research programmes to investigate ecology and behaviour of the critically endangered brown-headed spider monkey and assess forest habitat. Three parabiologists have been working on primate surveys and other research projects. This strategy, though long-term, may be the key to empower local young people, as well as providing an alternative source of income and actively involving and recognizing local knowledge.

7.7 Evaluation and investment

As a final step I propose regular evaluation of the strategies being implemented, through constant presence in the field and by open and transparent communication process with the community.

To this end I propose establishment of monthly community meetings during which people can openly express their views, problems with the implementation of certain strategies, suggestions, etc. This will further reinforce bonds between the project and the community in addition to serving as a 'clearing house' to identify possible weaknesses and suggest improvements in a participatory manner. Furthermore, any new strategies suggested by the community during these meetings should follow another round of assessment and implementation at the small scale in the form of 'action research'.

Our study case is the first of its kind in the area that is working towards the conservation of an endangered species through the understanding of the dynamic interaction between the farmers, forest, markets and government institutions. The aim is to prove the effectiveness of a balanced working model that may represent a long-term solution for the conservation of species on the edge of extinction such as the brown-headed spider monkey *Ateles fusciceps fusciceps* and their habitat, which has the potential for replication throughout the region.

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Appendix 1

Questions for interview to Chachi hunters

1. Community name: _______________
2. Chachi : ☐ Colono: ☐
3. Age: 18-20 ☐ 20-30 ☐ 30-40 ☐ 40-50 ☐ +50 ☐
4. Did you grow up here? Yes ☐ No ☐
5. Have you lived outside the community? ☐ For how long? ______________
6. Education level: ______________ What is your main activity? _______________
7. Marital status: _____________________
8. How many people are supported by your income? _____________
9. Number the following reasons for you to hunt spider monkeys in order of importance (1-most important, 10-least important)

   Food for your family _____
   Selling the meat _____
   Celebrations in the village _____
   Fun with friends (social activity) _____
   Keeping them as pets _______
   Selling them as pets _________
   No other animal available _____
   Better meat (better flavour) _____
   Part of your culture _______

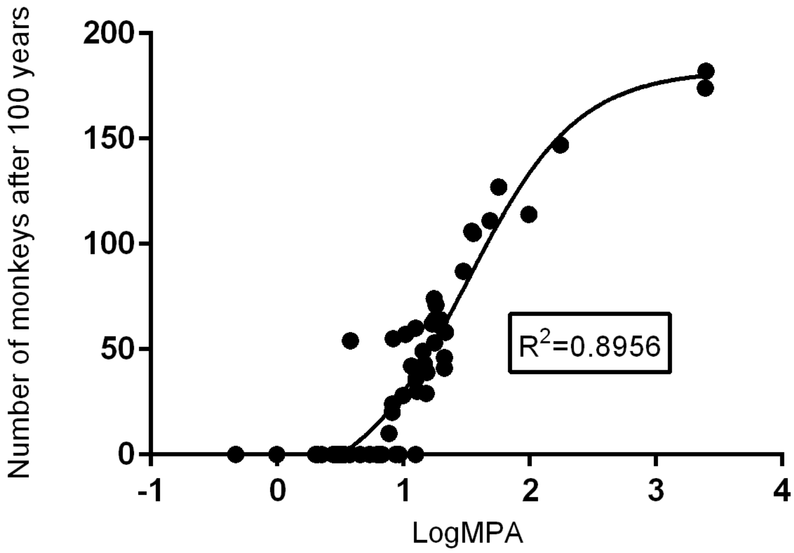
10. How many hunters are there in your family? ________
11. How many of your friends are hunters? _______
12. How many hunters are there in this community? ________
13. In order of preference which one is your favourite prey:
    1. _________________________
    2. _________________________
    3. _________________________
    4. _________________________
    5. _________________________

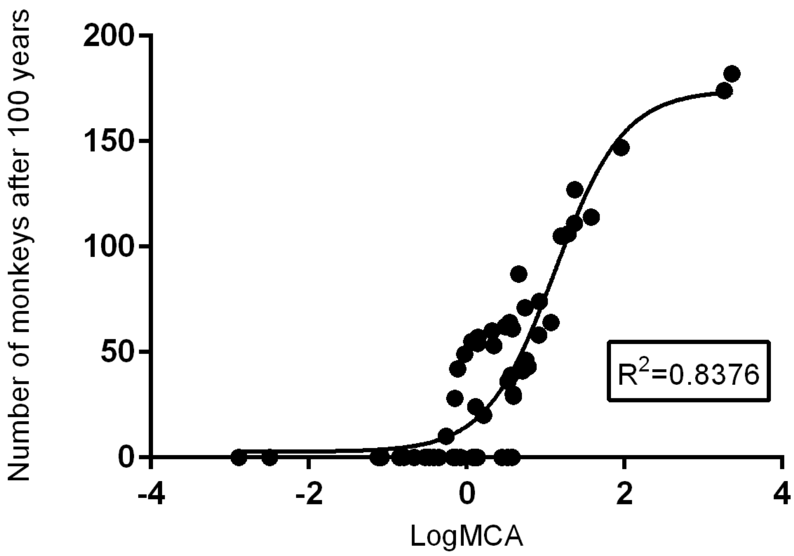
Answer the following questions ranking them with numbers from 1-5.
1-very important, 5-not important at all

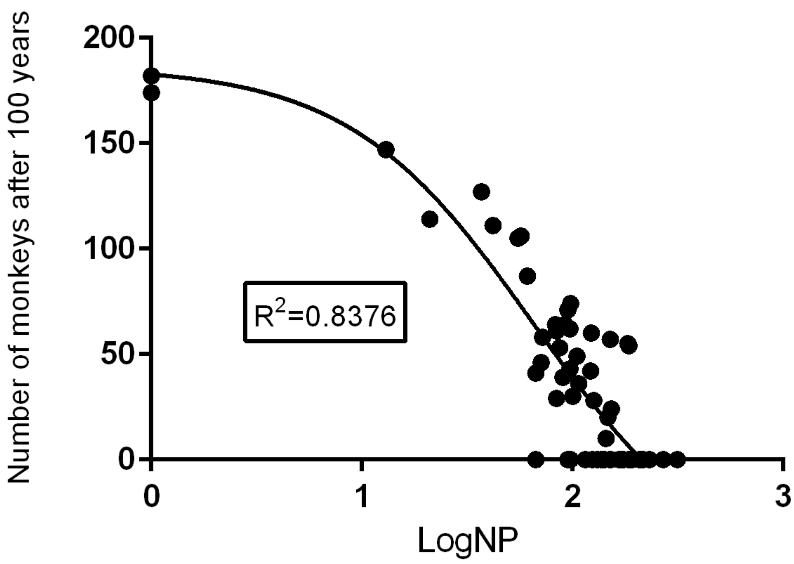
		1	2	3	4	5
14.	How important is hunting spider monkeys for your culture?					
15.	How important is hunting spider monkeys in your life?					
16.	Does your family think hunting is important?					
17.	Do your friends think hunting is important?					
18.	Is it important to learn how to hunt spider monkeys?					

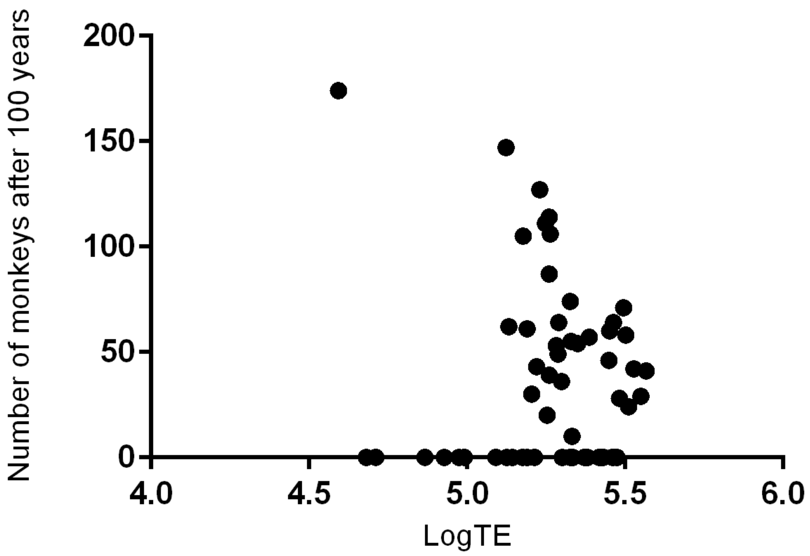
21. What primates do you prefer hunting? Why? ______________________________
    Spider monkeys ☐ Howler monkeys ☐ Capuchin monkeys ☐
22. How often do you hunt spider monkeys?
    Never ☐ Every month ☐ Every week ☐ Every day ☐
23. In what months is it better to hunt spider monkeys? Why? ____________________
    Jan Feb March April May June July August Sept Oct Nov Dec
24. What time during the day do you go hunting? Why? __________________________
    Morning ☐ Noon ☐ Afternoon ☐ Evening ☐
25. Are spider monkeys difficult to find? _________________
26. Are spider monkeys difficult to kill? __________________
27. What size are the groups of spider monkeys you find in the forest?
    1 5 10 20 +20
28. Do you prefer to hunt females or males? Why? ______________________________
29. Do you normally kill females or males? Why? _______________________________
30. Do you go alone or with friends? How many? ______________________________
31. How many hours do you have to walk to go hunting? _________________________
32. What is the best technique to hunt spider monkeys?
    ____
33. How many people does it take to hunt spider monkeys?
    1 5 10
34. When you go out hunting, how long do you go out for? Do you stay in the forest?
    Half day ☐ All day ☐ Days_______
35. How many monkeys/prey pieces can you bring back?
    1 2 3 4 5 +5
36. If you hunted another animal and you find spider monkeys, what do you do?
    ____
37. Are you allowed to hunt spider monkeys? Are you allowed to hunt other animals? Why?
    ____
38. Have you had any problems with the law when hunting primates? Why? ________
39. If you had more money or a fixed job would you still go hunting? Yes/No
40. What other jobs are available in the community? Is it always like this or does it change during the year? ____
41. Would you take a job where you help to protect primates and the forest? Yes/ No Why?
    ____
42. Which of the following activities would you like to do the most? Why?
    Hunting Hunting primates Agriculture Job in the city A job in the forest (parabiologist)

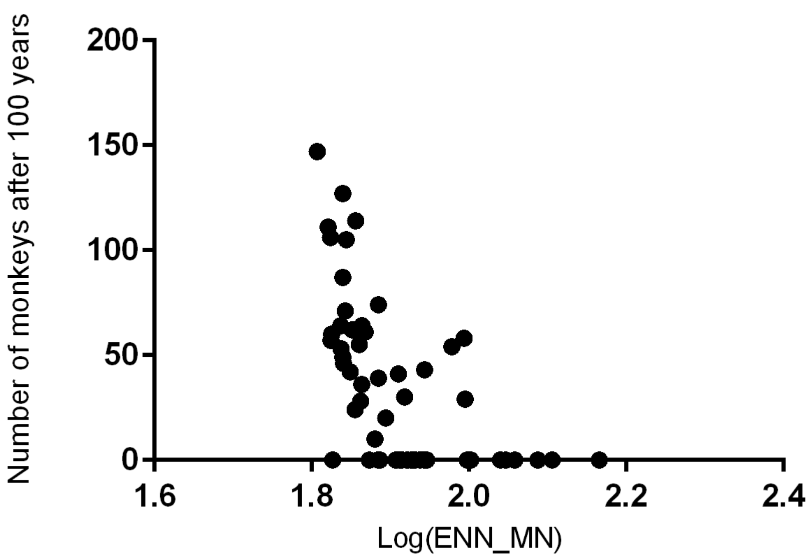
Appendix 2: Comparison of curve fitting of five fragmentation metrics to a dose-response curve








Number of monkeys after 100 years
200
150
100
50
0
4.0
4.5
5.0
5.5
6.0
LogTE


Number of monkeys after 100 years
200
150
100
50
0
1.6
1.8
2.0
2.2
2.4
Log(ENN_MN)