USING PRIMATES TO ESTABLISH PRIORITY CONSERVATION SITES IN MEXICO

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Abstract

Suitable habitat for some of the most threatened species is dwindling fast and with limited conservation resources available, it is essential that we invest those resources in areas with great biodiversity value. The Uxpanapa Valley in Mexico is one of Mesoamerica's largest forest remnants, is considered as a main biodiversity hotspot and has recently been established as a Protected Area. However, only minimal research has been conducted on the distribution of species in the area and deforestation activities remain high. The initial management proposal lacked zonation as well as species sampling data and did not include a portion of the Uxpanapa Valley in which there are several threatened species, including two primates present in the region (*Ateles geoffroyi* and *Alouatta palliata*). The main aim of this project was to identify areas most suited to biodiversity protection and conservation based on primate distribution. This was achieved through the following steps: first, primate distribution and group sizes were established and primate presence/absence was associated with landscape attributes. Spider monkeys were found to be positively associated with tall forest. Second, threats present in the study area were quantified (fire incidents, hunting activities and natural predation) but no clear impacts of these factors were found on primate distributions. Third, the potential for primates to act as umbrella species for bat species was investigated, and a positive association was found between the distributions of endangered bats and spider monkeys. In the final analysis, all the above results were combined in a Systematic Conservation Planning approach, and Priority Conservation Sites were selected. The final output should contribute toward structuring an effective management plan for the Protected Area that will ensure maximum protection for biodiversity. Overall, this work provides information on the effectiveness of using primates for developing conservation strategies and their potential to be used as a proxy for ensuring tropical forest maintenance.

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Aknowledgments

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Declaration

I confirm that the work presented in this thesis is my own work, with the following exceptions:

Field data on feline diets used in Chapter 3 was collected by MSc. Brenda Solórzano. Field data on bat distribution used in Chapter 4 was collected by Dr. Cristina McSwiney.

CHAPTER 1. General introduction and context

With current extinction rates it is likely that at least 10% and maybe as much as 50% of the world's biodiversity will disappear over the next few hundred years (Mace et al. 2007). In this scenario, protected areas (PAs) are considered to be the cornerstone of most conservation strategies (Hockings 2003), since their main role is to protect elements of biodiversity from the processes that threaten their existence in the wild (Margules and Pressey 2000). Nevertheless, PAs around the world have been consistently established in areas that do not necessarily make an effective contribution towards biodiversity conservation, due to political and economic interests (e.g. housing and commercial development are prioritized above species/habitat conservation) (Margules and Pressey 2000). To regulate this situation, Systematic Conservation Planning (SCP) has been developed to support the systematic identification of conservation priorities (Margules and Pressey 2000). While SCP approaches have been widely used in a variety of contexts, relatively few applications have been undertaken in tropical regions, such as Mexico (Cayuela et al. 2009). The establishment of Mexican PAs started more than 100 years ago and they currently cover over 12.92% of the country (CONANP 2012). Unfortunately, as in most countries, PAs have generally been established for reasons unrelated to the protection of biodiversity and without clear conservation objectives or systematic, scientific prioritization of the areas (Cantu et al. 2004; Urbina-Cardona and Flores-Villela 2010). Furthermore, only 60 of the 175 PAs have management plans (CONANP 2012), which provide basic information on the existing resources within them. Therefore, the degree to which these reserves serve to protect important elements of biodiversity in the country is unknown (Cantu et al. 2004). Systematic Conservation Planning has not been widely used in Mexico and most PAs have failed to effectively preserve biodiversity and to avoid the impacts of human activities (Figueroa and Sanchez-Cordero). Therefore, there is a pressing need for an example of well-designed PA using systematic planning approaches in the tropics and specifically in Mexico. This research could provide the basis for systematic PA planning in Mexico, thereby helping to strengthen biodiversity conservation efforts.

This research will concentrate on the application of SCP using Multi Criteria Analysis to an area in Southern Mexico, focusing on howler (*Alouatta palliata*) and spider monkeys (*Ateles geoffroyi*). These species have been selected because they are "charismatic" species of high conservation importance and are both listed as critically endangered (Cuaron et al. 2008). Within Mexico, very few research projects have combined specific landscape characteristics with data on environmental and human factors to determine primate distributions, which I intend to provide with this study. Moreover, primates have not been used as biodiversity surrogates or to establish priority conservation sites in this country. Primates as indicators serve as a conservation "shortcut", using subset taxonomic group is more financially and time efficient (Lambert 2011). If this approach is found to be effective, my research could contribute towards generating practical and cost effective methods that enable both primate and biodiversity conservation in the neotropics.

1.1 Protected Areas - General overview

Protected Areas (PA) are an important and commonly adopted tool in conservation as they are a cornerstone of most current biodiversity strategies (Gaston et al. 2008; Hockings 2003). It is recognized that biodiversity protection at various scales (local, regional and global) can be achieved through the establishment and maintenance of carefully planned PAs (WDPA 2006). Furthermore, PAs have been effective at protecting both ecosystems and species, as well as preventing land clearing, which is considered to be the most serious threat to biodiversity (Bruner et al. 2001). Their effectiveness is also evidenced by the growing tendency for many of them to become isolated amid heavily exploited or disturbed habitat (DeFries et al. 2005).The idea of setting aside areas of natural or semi-natural land dates back thousands of years, but it was not until 1872 that the modern PA movement started (CBD 2004). Though numerous definitions of PAs can be found, the ones proposed by IUCN and CBD are the most accepted. The Convention on Biological Diversity (2004, p. 8) defines a protected area as:

"a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives".

The definition of a protected area by the IUCN (2010), developed at the IVth World Congress on National Parks and Protected Areas in 1992, is:

"An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means"

At the global scale, PA distribution and sizes are highly variable, with a majority of them being of recent creation (West et al. 2006). Over the past decades, >160,000 terrestrial and marine protected areas have been established (Mascia et al. 2014), encompassing 13% of the planet's terrestrial surface (Venter et al. 2014), although more recent estimates indicate that up to 15.5% of the world's land surface is contained within a protected area category (Soutullo 2010).

Despite the apparent growth in the number of protected areas worldwide, human activities are still strongly impacting species survival and are causing loss of habitat at an alarming rate (Mora and Sale 2011). Clearly, there are many issues disguised by the simple statistics of number and extent of PAs. More fundamentally, PA systems need to be carefully designed to be effective at conserving biodiversity (IUCN 2010), especially in a dynamic and changing environment (Gillingham et al. 2014). As human pressures have contributed to rapid species decline in recent years, the basic role of reserves is to separate elements of biodiversity from processes that threaten their existence in the wild (Lawler et al. 2003; Margules and Pressey 2000). Although reserves are considered highly valuable for biodiversity conservation, the costs of establishing and managing them can be very high, which is why rigorous, systematic approaches should be used to establish them, in order to maximize benefits while minimizing costs (Brooks et al. 2004). Species distribution data are essential for planning effective PAs (Brooks et al. 2004), particularly because reserves have often been located in places that do not contribute to the representation of biodiversity (Margules and Pressey 2000).

1.2 Multi Criteria Analysis – General Overview

Ideally, the creation of any PA should be based on the Systematic Conservation Planning approach. The achievement of an SCP approach has been the focus of intensive research in recent years, leading to the development and application of a range of different tools (Pressey et al. 2007). Within the broader context of SCP, there is a fundamental analysis called spatial conservation prioritisation, which is used for identifying key biodiversity areas and how conservation goals for these areas might be achieved efficiently (Kukkala and Moilanen 2013). So-called reserve selection (also known as site selection, area selection, reserve design, or reserve network design) is a specific kind of problem frequently encountered within spatial prioritisation (Kukkala and Moilanen 2013). Within the spatial conservation prioritization context, it is species occurrences which determine the importance of each location-action-combination (Arponen 2012). In general, research in biogeography, ecology and biodiversity depends on data on species distributions and environmental conditions to uncover the mechanisms shaping the spatial distribution of life on Earth (Beck et al. 2014). Furthermore, knowledge on the current, and potential distribution of species is of great importance for developing strategies for conservation, public health and sustainable development (de Souza et al. 2011).

Multi Criteria Analysis (MCA) is one of the tools that is commonly used for guiding the decision maker(s) through the process of defining both the evaluation criteria (attributes and/or objectives), and the values that are relevant to each situation (Malczewski 2010). The use of Geographic Information Systems (GIS) has increased as a result of the need to handle the spatial aspects of criteria-based evaluation for prioritization and selection of potential conservation areas (Phua and Minowa 2005). In this regard, GIS provides a set of procedures for processing geographic data that will allow decision making: GIS-MCA is a process that combines and transforms geographical data (the input) into a decision (the output) (Rahman et al. 2014). On a global scale, MCA techniques have been used to optimize policy selection in the remediation of contaminated sites, the reduction of contaminants entering aquatic ecosystems, the optimization of water and coastal resources, and the management of other resources (Huang et al. 2011).A comprehensive review on MCA-GIS publications shows the major application areas include: Environmental planning and management, urban and regional planning as well as agriculture and forestry, amongst others (Malczewski 2010).

1.3 Threats to primates and primates as biodiversity indicators

Certain species may be of particular value for establishing priority conservation sites, owing to their biological characteristics and habitat requirements (Fleishman et al. 2000, Andelman and Fagan 2000, Mann and Williams 2003, Coppolillo et al. 2004). Species should be selected in order to ensure that the conservation efforts directed towards their survival will enable the conservation of as many other species as possible. For example, by comparison to many other taxa, the order primates consist of mostly large, easily observable, diurnal species (Harcourt 2000; Meijaard and Nijman 2003). Primates play an important role in the maintenance of ecosystems (Chapman 2005; Link and di Fiore 2006; Nunez-Iturri and Howe 2007; Lambert 2011; Norconk et al. 2011), mainly through their foraging activities which directly impact the structuring of tropical forests (Redford 1992). Moreover, primates can be considered ideal umbrella taxa for biodiversity planning due to their endangered status, because their ecology is well known and they are forest dependent (Smith et al. 1997). For instance, primates have played an important part in conservation education, the creation of conservation programs and the establishment of several PAs in Brazil (Mittermeier et al. 2005). Gorillas and chimpanzees have been successfully used for creating, as well as maintaining, protected reserves in Africa (Litchfield 2001), the golden snub-nosed monkey has been used to promote conservation strategies and management in China (Xiang et al. 2011) and woolly monkeys have been recently selected as a flagship species in Colombia, to sensitize and teach local inhabitants about sustainable practices and conservation (Maldonado 2012).Overall, the fruit-eating diet and arboreality that characterize most primates, means they impact highly on a variety of forests across the world. Thus, for their seed dispersal capabilities alone, nonhuman primates are essential components in tropical ecosystems worldwide, while their kinship with humans has also made them an umbrella species for biodiversity protection (Norconk et al. 2011).

Certain authors have suggested that focusing protection activities on areas of high primate richness is also likely to benefit a disproportionately large number of threatened taxa, through habitat conservation (Hacker et al. 1998). Nevertheless, for specific areas such as Borneo, it has also been stated that primates may be unsuitable for general conservation site selection due to lack of congruence between primate and diversity hotspots for birds and insects (Meijaard and Nijman 2003), but the authors also mention that this dissimilarity may be due to different sampling efforts or speciation processes and consider primates could be useful predictors of biodiversity patterns (Meijaard and Nijman 2003). It is crucial to obtain more information to determine if primates can be used to develop conservation strategies at a regional scale and to select priority conservation sites. Furthermore, through the use of SCP, selecting key sites for primate conservation potentially benefits numerous species, as well as supports forest maintenance.

Almost half (48 percent) of the world's 634 primate species are classified as threatened with extinction on the IUCN Red List of Threatened Species (IUCN 2012). The three primate species found in in Mexico (*Alouatta palliata*, *Alouatta pigra* and *Ateles geoffroyi*) are found on the IUCN Red List. Specifically, both howler (*Alouatta palliata*) and spider (*Ateles geoffroyi*) monkeys are listed as critically endangered (Cuaron et al. 2008). Spider monkeys are a highly frugivorous species (up to 87% of the diet consisting on fruits (Chaves et al., 2011; González-Zamora et al., 2009; Russo et al., 2005)), which limits them to range in areas where large trees that produce fleshy fruits occur (Chaves et al., 2012). Because of their specific suspensory locomotion, spider monkeys may also be restricted to areas characterized by canopy connectivity and homogeneity of tree structure, which allows them to move unconstrainedly (Youlatos, 2002), and their home ranges usually vary between 150-350 ha (Wallace 2008). Spider monkey sub-group size has been reported to range between 5-28.5 and densities 2.1-89.5 individuals/km^2 throughout their distribution range; since it is rare to see entire *A. geoffroyi* communities together, as they live in a fission-fusion society, "group" size usually refers to sub-group (Di Fiore and Campbell 2007). In Mexico, sub-groups are between 1-44 individuals, while their densities vary from 2.9-78.7 inds/km^2 (Chaves et al. 2011; Ortiz-Martinez 2008; Estrada et al. 2004). In contrast, howler monkeys have small home ranges (Di Fiore et al., 2011) and can shift from a fruit-based to a leaf-based diet (Dunn et al., 2009; Righini et al., 2014) providing them with the advantage of being able to inhabit a diverse array of habitat types ranging from undisturbed tall evergreen forests to highly disturbed small fragments (Pozo-Montuy et al., 2008). Throughout their distribution, *A. palliata* group sizes vary from 2-45, though on average group size tends to be 15 individuals and their densities have been reported to be between 4.9-30 ind/km^2 (di Fiore and Campbell 2007). Specifically for Mexico, reports on howler monkey data in fragmented areas show group size can be between 2-7 and the densities range from 3-133 ind/km2 (Solórzano-García and Rodríguez-Luna 2010; Ameca et al. 2010; Cristóbal-Azkarate et al. 2005; Estrada and Coates-Estrada 1996; Estrada 1982). As with most primates, habitat loss and transformation negatively affect the distribution and the number of howler and spider monkeys (Arroyo and Dias 2010; Cristobal-Azkarate et al. 2005; Ramos-Fernandez and Ayala-Orozco 2003). As areas become more fragmented and reduced, they also become more accessible or exposed to anthropogenic activities (Link et al. 2010), making wild populations increasingly susceptible to parasite and disease transmission (Kowalewski and Gillespie 2009) and physiological stress (Martinez-Mota et al. 2007). Human modification of habitats can also raise the rate and risk of primate predation (Miller and Treves 2007), particularly in areas with large cat presence, such as jaguars (*Panthera onca*) and pumas (*Felis concolor*). These predators include howler and spider monkeys in their diet (Chinchilla 1997; di Fiore 2002; Matsuda and Izawa 2008) and, although considered a rare event, it has been reported that a single jaguar can eradicate a small howler monkey group (Peetz et al. 1992). Wildfires can also play an important role in regulating primate distribution, as they detrimentally affect canopy dwellers, mainly due to a decline in live-tree density (or high mortality rates of large trees) (Barlow and Peres 2004). Thus, generating data sets that combine information on primate population distribution, land-use patterns, human settlements, geological and climatological features, as well as vegetation types can provide the diagnostics required to identify critical areas for conservation or risk for individual primate populations, or species in particular countries, or geographic localities in the region (Garber et al. 2005).

Two main methods are employed for assessing wild animal populations: 1) long-term monitoring of home range size and overlap in conjunction with group size data and 2) line transect surveying (Hassel-Finnegan et al. 2008). The most widely used technique for estimating primate population densities is the line transect method (Buckland et al.2010), but this standard method sometimes proves nearly impossible to apply due to terrain conditions, both statistically (e.g. site conditions do not allow for randomized transects, producing biased density data) and physically (e.g. severe slopes limit accessibility) (Peck et al. 2011). As parts of my study site lie on a karst platform, certain areas become highly rugged and inaccessible (PRONATURA 2009; JMW Day unpublished data). Furthermore, ongoing social issues regarding land use (e.g. illegal cannabis plantations and ownership disputes over "unclaimed" land) also restricted my access. Consequently, I do not report primate densities (impossibility of applying transect method), solely the detected and counted individuals/groups as a first assessment of the primate distribution in the Uxpanapa Valley. These data is then combined with the environmental factors and human induced threats gathered in the area, which in turn allow the selection of priority conservation sites that will support conservation for both primates and biodiversity in the region.

1.4 Mexican Reserves

Mexican PAs are defined as terrestrial or aquatic areas that represent diverse ecosystems and whose original environment status have not been altered substantially; there are currently 176 Federal Reserves, which cover approximately 25,387,972 ha (CONANP 2010). Conservation strategies in this country rely heavily on PAs, which have been considered to effectively prevent land cover change in many areas (Figueroa and Sanchez-Cordero

2008). Despite Mexico being a country of global importance for biodiversity, there are many species that are not protected by its existing reserve network: 48.5% of the globally threatened species occurring in Mexico and 55.5% of all globally threatened plant and animal species endemic to Mexico (117 species) are not covered in any part of their ranges (Brandon et al. 2005). Furthermore, there is at present little information available about the natural resources in these reserves. Thus the degree that those reserves serve to protect important elements of biodiversity in the country is unknown (Cantu 2004).

In Mexico, one of the states most affected by deforestation is Veracruz, where the rate of vegetation loss has been between 1-2% annually over the past 20 years (Aguilar et al. 2000). It is in this State that the Uxpanapa Valley is located. The Uxpanapa Valley is part of Northern Mesoamerica and is distinguished for being one of the most biodiverse areas in Mexico (PRONATURA 2008). It has been included within the Mesoamerican Hotspot by CEPF and is considered by the IUCN as a Centre of Plant Diversity, as well as being one of the 200 global ecoregions for priority conservation actions (WWF 2007). Although the biological importance of Uxpanapa Valley has been widely recognized, few institutions have pursued activities for its protection and management at a regional scale (PRONATURA 2008). Furthermore, it is only recently that Mexican authorities have considered declaring the area as a Natural Reserve (Milenio 2010). The threats to Uxpanapa's biodiversity began in the 1970's, when large extensions of tropical forest (more than 600,000 ha) were removed to establish intensive agricultural activities, stemming from an indigenous relocation program that intended to provide land to Chinanteco peasants that were evacuated from their homes owing to the construction of the Cerro de Oro dam (Gómez-Pompa 1979; Williams-Linera 1983). This colonization and subsequent destruction of the tropical forest caused unprecedented disputes between Mexican scientists and the federal government, during which early conservationists formulated a set of recommendations to improve natural resource management and quality of life, for both relocated and local indigenous populations (Gómez-Pompa 1979), which have not been fulfilled to the present day. Currently, an estimated 75% of the population in the

Uxpanapa Valley subsist from agricultural activities and is considered to be one of the most marginalized areas in the State of Veracruz (Hernández-Gómez et al. 2011). The main studies conducted in this area have so far been of a general nature, including plant and animal inventory (PRONATURA 2008; CONABIO 2003; Márquez et al. 1981; Gómez-Pompa 1979), description of particular social issues (CEPF-CI 2004, PRONATURA 2008; CIESAS different years), as well as land use reports (PRONATURA 2008; INEGI 2000). Even though these studies have proved to be of great value, this study represents the first research into the current threats and status of species inhabiting this area. Primate studies in this region are especially urgent since there is no information on their densities and distributions. The latest Mexican Primate Conservation Assessment and Management Plan (CAMP) marks Uxpanapa Valley as a critical site to study primates, since no information is currently available (Rodríguez-Luna et al. 2009). Previous to this study, no data were available on primate distributions in the Uxpanapa Valley. Furthermore, there was also no data on the factors that are potentially regulating the primates' distribution/population size, the threats they are facing or on the conservation needs for the area, information which this work aims to provide, as it is vital to develop conservation strategies.

Fig. 1.1 The study site, Uxpanapa Valley, shown as the darker area in the State of Veracruz, Mexico.

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1.6 List of Acronyms

Acronym (alphabetical order)	**Meaning**
AIC	Akaike’s Information Criterion
ALT	Altitude
BIO15	Precipitation Seasonality
BIO4	Temperature Seasonality
BIOCLIM	Bioclimatic variables
CAMP	Conservation Assessment and Management Plan
CBD	Convention on Biological Diversity
CEPF	Critical Ecosystem Partnership Fund
GIS	Geographic Information Systems
GLM	Generalized linear model
GPS	Global Positioning System
HM	Howler monkey
HS	Human settlements
ILWIS	Integrated Land and Water Information System
IUCN	International Union for Conservation of Nature
MCA	Multi criteria analysis
MCE	Multi-criteria evaluation
MODIS	Moderate Resolution Imaging Spectroradiometer
MSF	Mature secondary forest
NASA	National Aeronautics and Space Administration
PA	Protected area
PCL	Priority Conservation Level
PRONATURA	Mexican non-governmental organization for the environment
RP	Rubber Plantations
SCP	Systematic conservation planning
SF	Secondary forest
SM	Spider monkey
SPOT	Satellite Pour l'Observation de la Terre
TEF	Tall evergreen forest
TH	Transformed habitat
UTM	Universal Transverse Mercator
VIF	Variance influential factor

CHAPTER 2. The effect of vegetation type on spider and howler monkey distribution

Abstract

As primate habitats are reduced at unprecedented rates on a worldwide scale, the number of endangered species has risen over the past decade. Knowing the distribution and demography of endangered primates within the remaining forested areas has become essential to ensure primate survival. In this study, I investigated how vegetation and amount of transformed habitat together with human settlement size differentially affect the presence of mantled howler and spider monkeys in the Uxpanapa Valley, one of the most biologically important areas in Southeastern Mexico. The vegetation was assessed and surveys were conducted on howler and spider monkeys in 54 forest plots of 25 km^2. Howler monkeys were detected in 30 plots, with an average of 5.2 ± 2.37 individuals per group (N=22). Spider monkeys were found in 32 plots, with on average 5.9 ± 3.0 individuals per sub-group (N=75). Howler monkey presence was not related to any particular vegetation type and contrary to expectation they were less likely to be present at a site than spider monkeys. In contrast, the percentage of tall forest was higher for locations where spider monkeys were present, whilst the percentage of secondary forest was higher for sites where they were absent. Human settlements or the extension of transformed habitat did not significantly influence the presence of either species. These results confirm that spider monkeys are most dependent on tall forest; while the presence of howler monkeys cannot be solely explained by vegetation. The variables that may be impacting these primates' distribution patterns are further reviewed, highlighting tall forests as being critical habitat for their conservation.

2.1 Introduction

Global and regional efforts to conserve species are usually hindered by limited data on population distribution (Karanth et al., 2010) and demography (Weghorst, 2007) as well as a lack of knowledge of the underlying mechanisms that determine species' relationships with their environment. Understanding the ecological factors that affect species abundance and distribution has become increasingly urgent as human pressures contribute to the decline of animal populations worldwide (Hanya and Chapman, 2013). This is particularly true of primates since almost half of the world's primate species are classified as threatened with extinction (IUCN, 2012). On a worldwide scale, threats to primates have been directly linked to human settlement expansion causing land cover change and reduction of viable primate habitat (Estrada 2013; Lee, 2010; Marsh, 2013). Moreover, the construction of roads and other infrastructure provides access to forest interiors (Laurance et al., 2009; Sherrow, 2010), facilitating hunting and logging activities that reduce primate populations even before deforestation eradicates them completely (Chapman and Peres, 2001).

Species distribution is greatly influenced by the type of available habitat (Chapman et al. 2014). Particularly, forest distribution and structure have been considered to be primary drivers of primate species richness (Gouveia et al. 2014). Regarding demography, the many factors that influence group size can be summed up in two main categories: predation risk and resource requirements (Majolo et al. 2008; Pollard and Blumstein 2008) and group sizes have been shown to be habitat-specific and to reflect an individual species' ecological adaptations (Dunbar 1996). While primatological studies have increased in number within the neotropics, continued work incorporating environmental, landscape and human factors, together with primate population surveys of understudied or unexplored regions within Mesoamerica is urgently required to identify "hot spots" of high conservation value or risk for individual primate populations (Garber et al. 2006). In order to develop successful conservation plans it is crucial to further understand the links between the environment and demographic parameters. Particularly, the relationship between group size and the type of habitat occupied must be examined to evaluate a population's viability and the degree of threat it faces (Di Bitetti and Janson 2001; Alberts and Altmann 2003).

Howler (*Alouatta spp.*) and spider (*Ateles spp.*) monkeys belong to the subfamily Atelinae, and although they form part of the same monophyletic group (Di Fiore et al., 2011), their habitat requirements differ substantially. Habitat occupancy by howler and spider monkeys has been related to landscape characteristics, such as the size and shape of forest patches and degree of fragment connectivity (Anzures-Dadda and Manson, 2007; Arroyo-Rodríguez et al., 2013; Boyle and Smith, 2010) as well as specific floristic composition (e.g., tree species diversity associated with certain vegetation types) and food quality and abundance (Cristóbal-Azkarate et al., 2005; Sorensen and Fedigan, 2000). For example, as spider monkeys have a fruit-based diet (55.6 - 87% of the diet consisting on fruits (Chaves et al., 2011; González-Zamora et al., 2009; Russo et al., 2005)) they are forced to range in areas where large trees that produce fleshy fruits occur (Chaves et al., 2012). Spider monkeys may also be limited to areas characterized by canopy connectivity and homogeneity of tree structure, which allows them to move unrestrictedly (Youlatos, 2002). In Mexico, spider monkey sub-groups are typically between 1-44 individuals, while their densities vary from 2.9-78.7 inds/km^2 (Chaves et al. 2011; Ortiz-Martinez 2008; Estrada et al. 2004). In contrast, the fact that howler monkeys have small home ranges (Di Fiore et al., 2011) and are able to shift from a fruit-based to a leaf-based diet (Dunn et al., 2009; Righini et al., 2014) provides them with the advantage of being able to inhabit a diverse array of habitat types ranging from undisturbed tall evergreen forests to highly disturbed small fragments (Pozo-Montuy et al., 2008). Most studies on howler monkeys in Mexico have been developed in fragmented areas, and in this context group size can be between 2-7 and the densities range from 3-133 ind/km2 (Solórzano-García and Rodríguez-Luna 2010; Ameca et al. 2010; Cristóbal-Azkarate et al. 2005; Estrada and Coates-Estrada 1996; Estrada 1982).

Mexican mantled howler (*Alouatta palliata* ssp. *mexicana*) and spider (*Ateles geoffroyi* ssp. *vellerosus*) monkeys are classified as critically endangered due to habitat loss and fragmentation (Cuaron et al., 2008). In

Mexico, demographic information of Atelines derives from studies in anthropogenically fragmented landscapes (e.g., Los Tuxtlas (Cristóbal-Azkarate et al., 2005; Estrada and Coates-Estrada, 1996; Solorzano and Rodriguez-Luna, 2010)), but less is known about demographic parameters and habitat use of populations inhabiting areas that still have large tracts of primary vegetation. Therefore, the goal of this study was to determine the presence of mantled howler and spider monkeys in the Uxpanapa Valley, Veracruz and most importantly, if their distribution is associated with specific vegetation types within the area. The results will enhance knowledge of the drivers for both species' distributions and their conservation status and will contribute towards their future conservation.

2.2 Aims and objectives

Aim

Establish the presence of spider monkeys and howler monkeys within the Uxpanapa Valley and explore if their distribution is related to specific forest types.

Objectives

To test the hypothesis that the occurrence of spider monkeys will be associated with habitats where vegetation structure is characterized by large trees (i.e., tall evergreen forest), and they will be absent in anthropogenically transformed habitats.

To test the hypothesis that howler monkeys will be prevalent in all vegetation types, including areas adjacent to human settlements, thanks to their ability to exploit habitats with different degrees of disturbance.

2.3 Methods

Study area

The Uxpanapa Valley is located in the southern part of Veracruz, Mexico (Fig. 2.1), between 17°17'–17°21′ N and 94°05' W, with a total extension of 6,200 Km^2 (PRONATURA, 2008; Ruiz-Guerra et al., 2014). The original predominant vegetation here is tropical rain forest (Ruiz-Guerra et al., 2014), though at least 43% of the territory has suffered severe transformation (Hernandez-Gomez et al., 2011) and agricultural practices currently dominate the landscape (Rodríguez-Luna et al., 2011). Uxpanapa Valley has undergone severe transformation since the 1970's and the annual deforestation rates have been 2.1% over the past 40 years (Gómez-Pompa, 1979; Hernandez-Gomez et al., 2012; Williams-Linera, 1983), placing this area within two of the deforestation hotspots of the Petén-Veracruz Moist Forest ecoregion (Vaca et al., 2012). However, there remain large extensions of relatively well-preserved rainforest, resulting in the classification of the Uxpanapa Valley as one of the most biodiverse areas in Mexico and the world (Castillo et al., 1998; Lira-Torres et al. 2012; PRONATURA, 2008). The mean annual temperature is between 24^{o}-26^{o} C, with 1,500-3,500mm precipitation per year (INEGI, 2008).

The Uxpanapa Valley forms part of the Selva Zoque, one of the largest remaining tracts of tropical rainforest in Mexico, also highlighted as an important area for biodiversity in Mesoamerica, and it is assumed that this area harbours important populations of Mexican primates (Dunn et al. 2013; Oropeza-Hernández and Rendón-Hernández 2012). *A. p. mexicana* and *A.g. vellerosus* are both present in the Uxpanapa Valley, but information on their demography and distribution or the vegetation variables to which they are associated had never been collected before.

Fig. 2.1 The study site, Uxpanapa Valley, shown as the darker area within the five municipalities (Jesus Carranza, Hidalgotitlan, Minatitlan, Las Choapas and Uxpanapa) in the State of Veracruz, Mexico.

Data collection

Before beginning the exploration of the study site, the ArcMap Sampling Design Tool was used to randomly select 54 plots of 25 km^2 each, within the Uxpanapa Valley (Figure 2). All plots contained forest cover to ensure primates had available habitat, where forest cover could be any or a mixture of the following: secondary (rapid growth pioneer species, such as *Myriocarpa longipes*, *Croton pyramidale*, *Cecropia obtusifolia*, *Heliocarpus appendiculatus*), mature secondary (secondary forest <20 years of growth and presenting species typical of conserved areas such as *Pouteria sapota*, *Ficus* spp, *Rinorea guatemalensis*) or tall evergreen forest. The tall forest in this area was found to maintain high plant species diversity, including slow growth and high biomass species such as *Dialium guianense*, together with *Astrocaryum mexicanum* palms which are typically found in well preserved areas (JC Lopez-Acosta et al., unpublished data).

We located primates using a two-stage process which incorporated local knowledge of residents active in the area (Urbani 2005; Heyman et al. 2002). The first involved informal interviews with local hunters and villagers of the communities found in or near the selected plots. We asked them to describe the presence and distribution of howler and spider monkeys both in and the area surrounding the specific plot. The second stage involved surveying each plot by the field team to locate primates by listening to vocalizations and then walking through the forest with the aid of local guides. This was performed regardless of the information provided by locals in the first stage. Plots were designated as ‘primate absent’ if both the information provided by locals (stage 1) and our surveys (stage 2) indicated there were no primates. Plots were designated as ‘primates present’ if the locals said there were primates in the area and we located primates on our surveys. We did not encounter a contradiction between information gathered in stage 1 and stage 2; we always found primates in the plots where locals indicated there were primates present and vice versa.

I encountered constraints to perform typical distance/transect sampling due to the region’s inaccessible and rugged terrain, as well as ongoing social issues regarding land use, resorting to traversing the forested areas we could safely access with the aid of local guides with ample knowledge of the area. Under these conditions, I sampled within the established plots, during the dry season (March to June), examining the western part in 2010 and the eastern part in 2011, walking a total of 267.2 km and 269.5 km respectively. Each area was sampled for a full day (minimum 8 hours), starting between 4:30 and 5 am. For both species, the plots were intensively inspected by using randomly laid out paths and actively searched for visual or vocal detection of primates. Vocalizations were recorded by GPS point and following the vocalization direction with a compass, particularly for howler monkeys as they are much more difficult to detect visually. When a primate group was found, we recorded geographic coordinates using a Global Positioning System (GPS) as well as number, sex and age of individuals and vegetation type. Group sizes reported take into account all observed individuals, including infants and in the adult class we did not differentiate between sub-adults and adults. Primate counts and identification were performed by a minimum of two experienced observers and a local guide. We were not able to determine sex or age for 92 spider monkey individuals, as on some occasions the site conditions limited our ability to view or follow them. In addition, many of the areas where we detected howler monkey vocalizations were located on karst walls, so were impossible to access, and a total of 47 groups were not observed directly (Annex 1).

Mapping

Five SPOT 5 scenes captured in the dry season of March and April 2011 (ERMEX/SEMAR, 2010) were used to classify vegetation cover and land use in the study area. The images were projected to the UTM projection based on the World Geodetic System 1984 (WGS_84) and a mosaicked image was created from the five SPOT scenes (CA Munoz-Robles, unpublished data). Six vegetation cover/land use types for the Uxpanapa Valley were established: Tall Evergreen Forest, Mature Secondary Forest, and Secondary Vegetation, Transformed Habitat (rubber plantation, grassland /traditional agriculture or bare soil) (Fig. 2.2), Water body and Human settlement areas. To verify classification from images, 500 locations were visited and their coordinates, vegetation and land cover categories were recorded. Each visited location was in homogenous areas within the vegetation or land cover types to minimise geo-positional errors. The achieved overall classification accuracy was 88% (CA Munoz-Robles, unpublished data). All image processing was conducted in PCI Geomatica 12 (PCI Geomatics, Enterprises, Inc., 2011). The observed primate distribution within the study site was mapped and the percentages of vegetation composition, extent of human settlements and transformed landscape were established for each plot, as well as the distance between primate populations and human settlements with ArcMap v. 10.1.

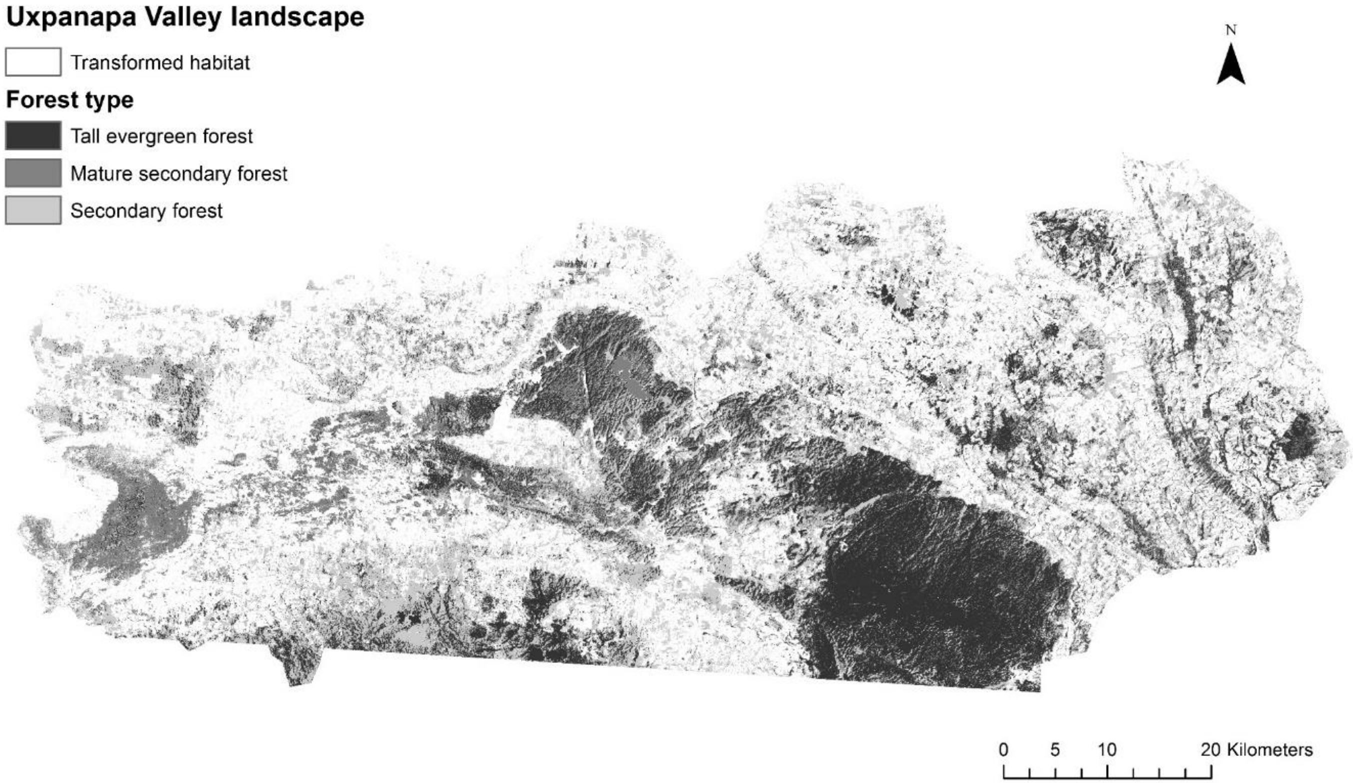

Fig. 2.2 Uxpanapa Valley landscape, white areas represent transformed habitat, black areas represent tall evergreen forest, dark grey areas mature secondary forest and light grey secondary forest.

Data analysis

We analyzed the occurrence of spider and howler monkeys as a dependent variable with the percentage of vegetation type cover within the plot, using generalized linear models (GLMs) with a logit link function and binomial error structure (Crawley, 2007). We conducted three analyses to predict 1) the presence of spider monkeys, 2) the presence of howler monkeys, and 3) the presence of both species within the same sampled plot. Presence of all detected (visually or heard) groups were included in the analyses. Predictor variables were the percentage of secondary forest, secondary mature forest, and tall forest estimated for each sampled plot. We also considered as predictors the estimated percentage of transformed habitat, the percentage of area occupied by human settlements, and the number of primate groups of a given species per plot. We tested for multicollinearity between predictor variables using the "faraway" R-package and found transformed habitat had a large variance influential factor (VIF) value. We removed this variable and the remaining predictors maintained low VIF values (i.e., < 8). For each data set, we created a 0 - 1 response variable in which 0 represents the absence and 1 the presence of each primate species (in the case of the third analysis, 1 represents locations with both primate species). First, a full model with all predictors included was run, using the library MASS and then used the function 'dredge' in the package MuMIn to select the best model based on Akaike's Information Criterion (AIC). In order to determine the ability of the model to explain the variation in the data, the fit of the best model selected was compared against a null model that included only the intercept, using a likelihood ratio test. All statistical analyses were carried out in R 2.15.1(R Core Team, 2012).

This study complied with the legal requirements of Mexico (SEMARNAT- DGVS/03660/11) and was approved by the Universidad Veracruzana.

2.4 Results

The landscape composition of the 1350 km^2 encompassed within the 54 sampled plots was as follows: 23.52% tall evergreen forest (TEF), 14.19% mature secondary forest (MSF), 28.33% secondary forest (SF) and 33.13% transformed habitat (TH), while the human settlements (HS) occupied 0 .36% of the total area. Primates were found in 42 (78%) of the 54 sampled plots, were deemed absent in 12 (22%), while both species coincided in 19 (35%) of them.

Spider monkeys

Eighty six spider monkey sub-groups were found in 32 plots (67 through direct observation, 8 through direct observation, but unable to count individuals in sub-group and 11 heard) (Fig. 2.3) and 391 individuals were observed. The average (SD) sub-group size was 5.9±3.0 individuals, composed by 1.8±1.4 adult males, 2.4±1.8 adult females, 0.4±0.7 juveniles, and 0.8±0.9 infants (N=67). The composition and sub-group size of spider monkeys was similar across vegetation types (Table 2.1).

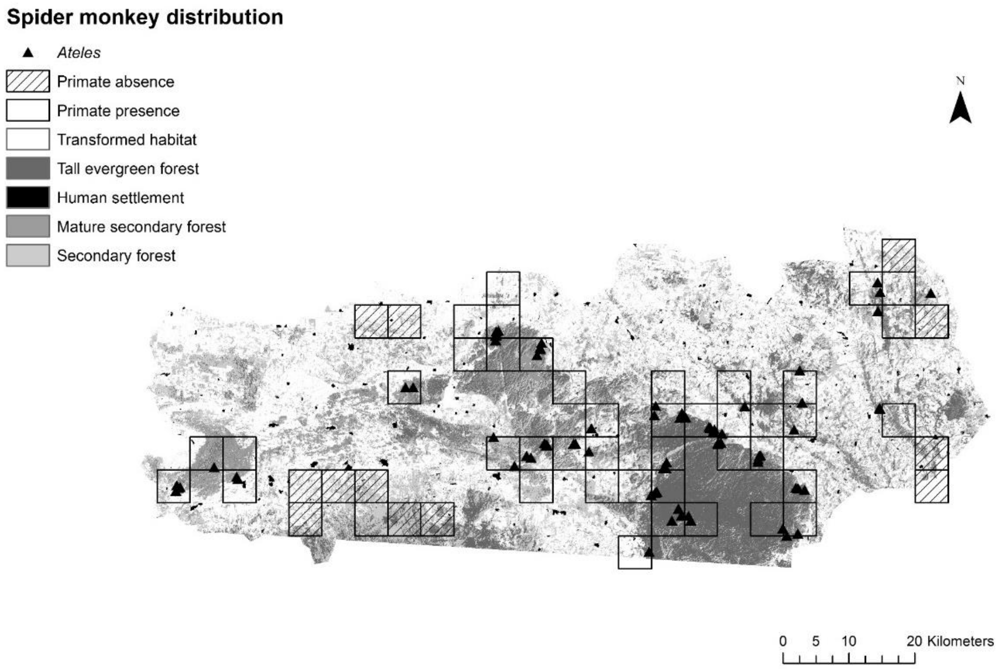

Fig. 2.3 Spider monkey (*Ateles g. vellerosus*) distribution in the Uxpanapa Valley. The triangles represent each spider monkey sub-group that was recorded. The clear squares indicate plots in which primates were found and hatched squares the plots in which no primates were detected. Vegetation types are marked in darker shades and the white areas represent transformed habitat, while the black areas represent human settlements.

Most (81.3%) sub-groups were evenly distributed in MSF and TEF, while 18.7% were found in SF (Fig. 2.4). Human settlement proximity varied from 415 m to 4.9 km, the overall average being 2.35 km. The GLM indicated that percentage of tall forest (β=0.105, z-value= 2.566, CI= 0.025 - 0.185, N= 54, $p < 0.05$) and percentage of secondary forest (β=-0.072, z-value= -2.203, CI= -0.136 - -0.008, N=54, $p < 0.05$) were the strongest predictors of probability of occurrence of spider monkeys (Table 2.2). An increase in the percentage of forested area characterized by tall forest increases the probability of *A. geoffroyi* being present (Figure 2.5), whilst an increase in the percentage of area covered by secondary forest decreased the probability of their occurrence (Figure 2.5). The percentage of secondary mature forest, the area occupied by human settlements, and the percentage of transformed habitat did not have significant effects on the probability of presence of spider monkeys. Similarly, the presence of howler monkey groups did not have significant effects on the probability of spider monkey occurrence.

Table 2.1. Sub-group size, composition, and sex and age ratios of spider monkeys inhabiting three vegetation types in the Uxpanapa Valley.

	Sub-group size (N=67)	Adult males	Adult females	Juveniles	Infants	U	M:F	F:IMM
Tall forest	5.1±2.5	1.9±1.8	1.6±1.1	0.2±0.6	0.5±0.6	43	1 : 1.3	1 : 0.6
Mature secondary forest	5.8±2.6	1.8±1.3	2.8±1.9	0.4±0.6	0.7±0.7	26	1 : 1.9	1 : 0.5
Secondary forest	7.8±4.6	3.5±2.1	2.0±1.1	0.6±1.1	1.8±1.7	23	1 : 1.9	1 : 1

M:F= male to female ratio; F:IMM= female to immature ratio; U= individuals whose sex could not be determined.

Table 2.2 Results of the GLM analysis of *Ateles geoffroyi*

	β	z-value	p-value	Lower CI	Upper CI
Intercept	0.712	0.703	0.482	-1.273	2.696
Secondary forest	-0.072	-2.203	0.028	-0.136	-0.008
Tall forest	0.105	2.566	0.010	0.025	0.185

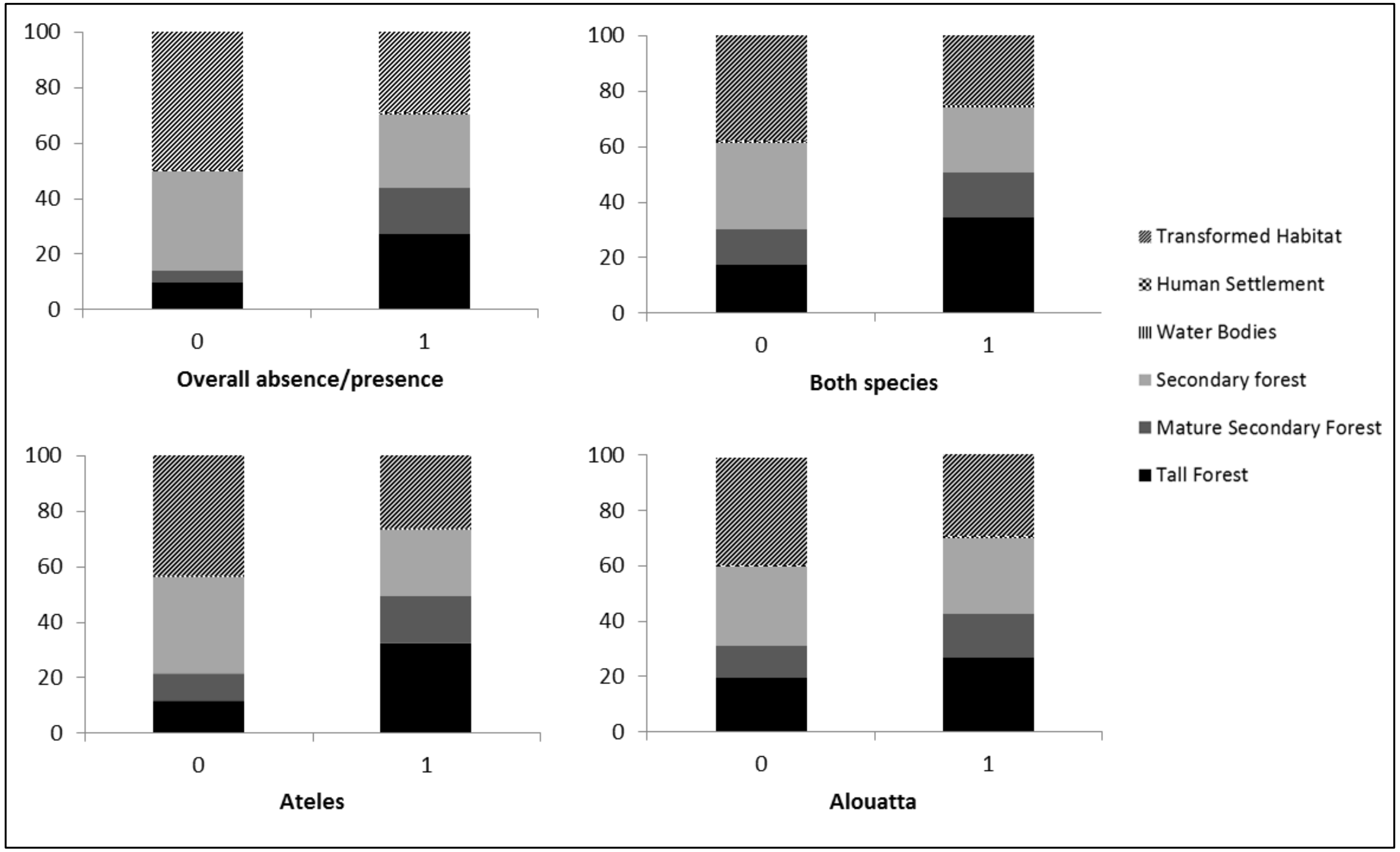

Fig. 2.4 Variation in the percentages of Water Bodies , Transformed Habitat, Human Settlement, Tall Forest, Secondary Mature Forest and Secondary Forest in the plots which held either species, both species and where both were absent. In each case, 0 represents absence and 1 represents presence.

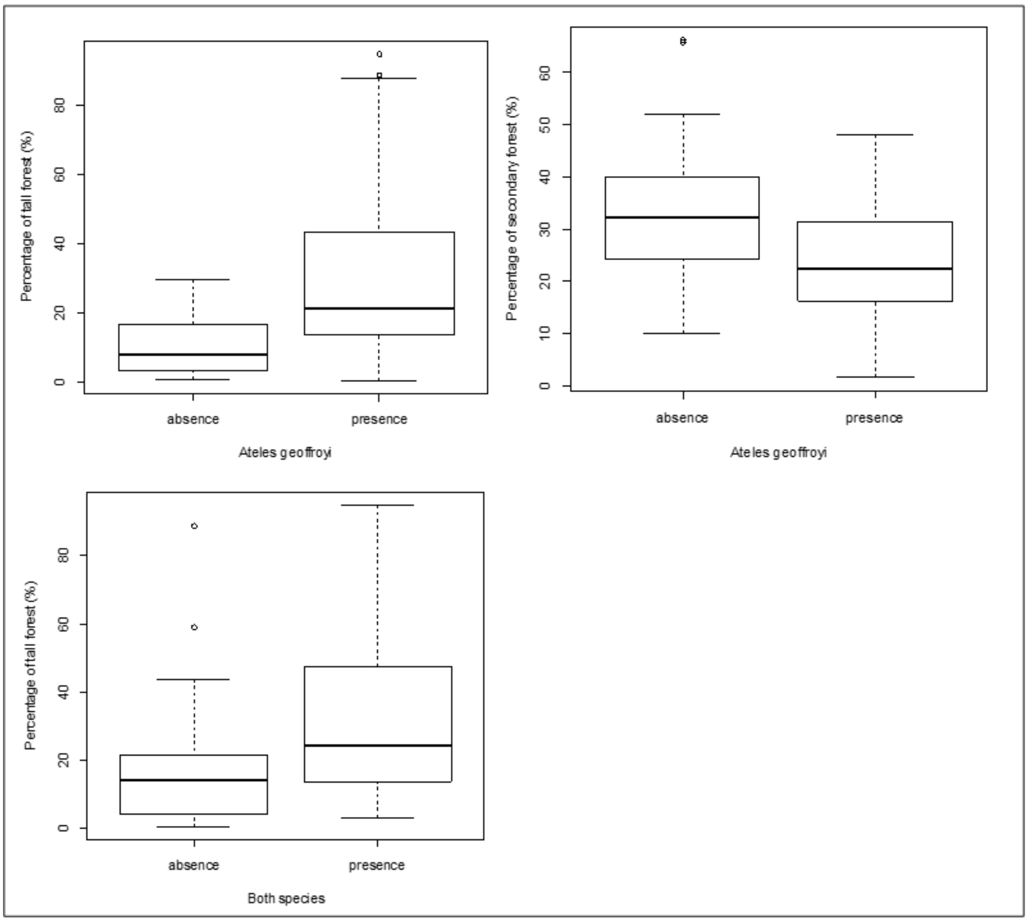

Fig. 2.5 Tall Forest and Secondary Forest related to primate presence and absence in the Uxpanapa Valley.

Howler monkeys

Sixty nine howler monkey groups were detected in 30 plots (Fig. 2.6), while 117 individuals were recorded through direct observation, distributed in 22 groups. Another 47 mantled howler groups were recorded through vocalizations. The average group size was 5.3±2.4 individuals, composed by 1.6±0.7 adult males, 2.3±1.1 adult females, 0.2±0.5 juveniles, and 1.1±1.2 infants (N=22). Howler monkey group size and composition was similar across vegetation types (Table 2.3):44% of the groups were found in MSF, 42% in TEF and 14% in SF (Fig. 2.4). The distances between human settlements and *A. palliata* groups varied from 529 m to 3.5 km, and the overall average was 2 km. The GLM analysis showed that the presence of howler monkeys was not significantly related to any vegetation types or measure of disturbance, nor affected by the presence of spider monkey sub-groups (GLM analysis: Table 2.4).

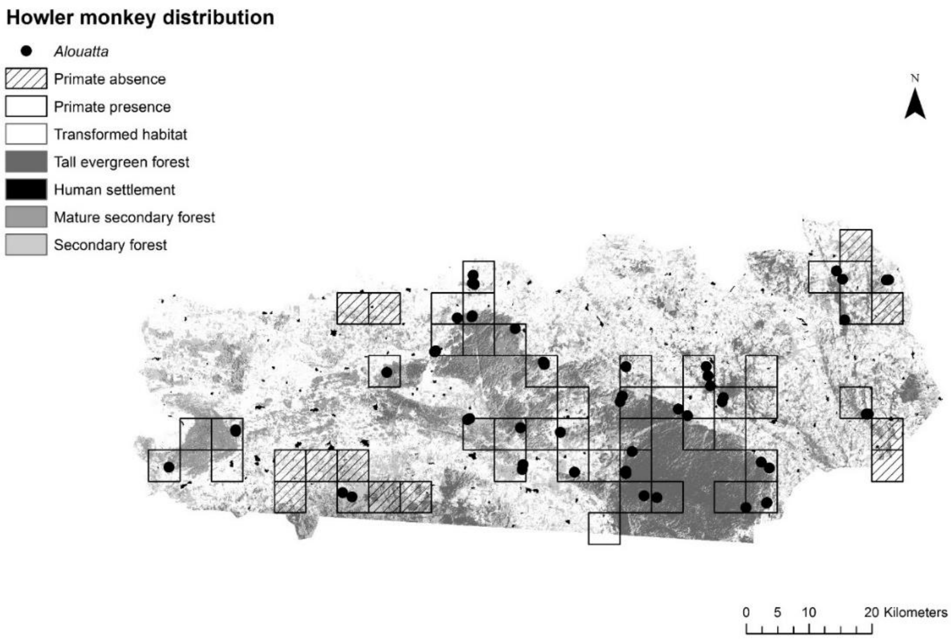

Fig. 2.6 Howler monkey (*Alouatta p. Mexicana*) distribution within Uxpanapa Valley. The black circles represent each howler monkey group that was recorded. The clear squares indicate plots in which primates were found and hatched squares the plots in which no primates were detected. Vegetation types are marked in darker shades and the white areas represent transformed habitat while black areas represent human settlements.

Table 2.3. Group size, composition, and sex and age ratios of mantled howler monkeys inhabiting three vegetation types in the Uxpanapa Valley

	Group size (N=22)	Adult males	Adult females	Juveniles	Infants	M:F	F:IMM
Tall forest	6.5±2.7	1.9±0.8	2.8±1.1	0.3±0.5	1.3±1.5	1 : 1.8	1 : 0.6
Mature secondary forest	4.5±1.8	1.3±0.5	2.0±1.1	0.3±0.8	1.0±0.8	1 : 1.8	1 : 0.7
Secondary forest	3.3±0.6	1.3±0.6	1.3±0.6	0.0	0.7±0.6	1 : 1	1 : 0.7

M:F= male to female ratio; F:IMM= female to immature ratio.

Table 2.4. Results of the GLM analysis of *Alouatta palliata*

	β	z-value	p-value	Lower CI	Upper CI
Intercept	-13.0656	-0.97	0.332	-39.464	13.333
Secondary forest	0.1319	0.962	0.336	-0.137	0.401
Secondary mature forest	0.1633	1.148	0.251	-0.115	0.442
Tall forest	0.1376	1.03	0.303	-0.124	0.400
Human settlements	-0.3167	-0.539	0.59	-1.469	0.835

Effects of vegetation types on the presence of both species

When considering the presence of both species occurring at the same sampled plot, the GLM showed that an increase in the percentage of tall forest increased the probability of the primates being present in the same site (β= 0.034, z-value= 2.33, CI= 0.0055 - 0.063, P-value < 0.05; Figure 2.4). Other predictor variables did not have significant effects on the probability of occurrence of both primate species at the same site.

2.5 Discussion

There is a clear need for assessment of unsurveyed areas to drive conservation and management plans. My work provides the first report on presence, demography and distribution of spider monkey and howler monkey in the northern part of the Selva Zoque, the most biologically important and unprotected forest in Veracruz, Mexico. I also examined the relationship between vegetation type and the presence/absence of howler and spider monkeys. Overall, my results indicate that Uxpananpa Valley is a potentially important site for primate conservation in Mesoamerica.

My results show that in the study site, the presence of spider monkeys and the combined occurrence of both howler and spider monkeys were related to the increased area of tall evergreen forest. The association between spider monkey presence and tall forest was expected, as spider monkeys heavily rely on habitats characterized by diversity of feeding resources rich in energy content (e.g., fruits), high density and abundance of large tree species, and increased amount of continuous forest cover (Sorensen and Fedigan 2000; Wallace 2008; Gonzalez-Zamora et al. 2009), all of which are more likely to be found in tall evergreen forests. The observed sub-group size was larger than those found in severely fragmented sites of Los Tuxtlas, Mexico (average 4.6 individuals, ranging from 2-7 inds per sub-group) where the same sub-species of howler and spider monkeys coexist (Solórzano-García and Rodríguez-Luna 2010). Sub-group size was also higher than those of different howler and spider monkey species in recently transformed sites in Colombia 3.9 (± 2.9) (*Alouatta seniculus* and *Ateles hybridus* (Link et al. 2010). On the other hand, observed sub-group sizes were similar to those at different sites where howler monkey and spider monkeys coincide, such as in Yaxilan (5.6±3.0) and Calakmul Biosphere reserve, Mexico (7.7±3.8) (*Alouatta pigra* and *Ateles. g. yucatanensis* (Estrada et al. 2004)). In northeastern Oaxaca *A. geoffroyi* has a wider distribution and higher presence than *A. palliata* (Ortiz-Martinez et al. 2008). This finding supports the conclusion that the remaining tall forest expanses in Uxpanapa Valley are currently large enough to support typical spider monkey groups. However, further fragmentation towards the level observed at Los Tuxtlas would probably result in a decrease in group size and consequently the overall spider monkey population.

Howler monkey group size and composition was similar across vegetation types and their presence was not significantly related to any vegetation types or measure of disturbance. These findings confirm the hypothesis that howler monkey distribution is not strongly associated to a particular vegetation type, possibly due to their adaptive behavioural and physiological traits. However, since howler monkeys are known to be resilient to habitat alteration and to survive in areas where other primate species cannot (Estrada and Coates-Estrada, 1996) and because primary forest extensions remain available, we expected howler monkey group presence to be higher than spider monkey's, and for their group size to be in the upper limits of what is reported throughout their distribution. Nevertheless, we detected less howler monkey than spider monkey groups and found their group size to be even smaller than what has been reported for fragments with varying degrees of degradation (7.09±4.22) (Cristobal-Azkarate et al. 2005). Our results coincide with average group size reported for these species when coexisting with spider monkeys in less conserved areas (5.8, 2-7 individuals (Solórzano-García and Rodriguez-Luna 2010)). Howler monkey group sizes vary due to site-specific events, and in our study site it could be due to factors such as forest fires or predation, particularly as howlers live in areas where they are more exposed and are potentially easy targets for large cats (Cuaron 1997; Peetz et al. 1992). Since vegetation type does not, on its own, explain howler monkey presence and distribution in our study site, we suggest howler monkeys could be sensitive to other, poorly understood factors such as hunting and natural predation, which will be discussed in further chapters.

Studies on arboreal primate such as colobus monkeys (*Colobus vellerosus*, (Kankam and Sicotte 2013)), bearded saki monkeys (*Chiropotes satanas chiropotes*), red howler monkeys (*Alouatta macconnelli*), and spider monkeys (*Ateles paniscus*) (Boyle and Smith, 2010) showed that the presence of primates is negatively influenced by decreased fragment size and their presence in an area was highly related to the proportion of fruit in their diet.

Particularly, forest characteristics such as tree density, variety of feeding resources, larger height and canopy size, amongst others (Arroyo- Rodriguez, 2007; Paciulli, 2010; Stevenson et al., 2000) have a direct link to primate presence. In our study, this appears to be true for spider monkeys but not necessarily for howlers. The next step is to further examine which of the intrinsic habitat components (such as tree traits including fruit tree species and basal area), are the key drivers of primate presence, together with factors such as inter specific competition or "external" activities (e.g. hunting, natural predators and fires) and through this, determine which conservation actions will ensure primate survival within tropical forests.

Finally, conserving the remaining large extensions of forest is not enough, and further studies on human activities and environmental factors are recommended, in order to define what conservation strategies are the most appropriate for these highly threatened species and the complex area in which they are found.

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2.7 Annex 1

Plot Number	SM groups visual	SM total groups detected	HM groups visual	HM total groups detected	Primates reported by villagers	Primates detected by team
1	4	5	1	1	Yes	Yes
2	1	1	0	0	Yes	Yes
3	0	0	1	2	Yes	Yes
4	2	2	0	0	Yes	Yes
5	0	0	1	3	Yes	Yes
6	1	2	0	1	Yes	Yes
7	0	0	0	2	Yes	Yes
8	0	0	2	5	Yes	Yes
9	0	0	1	3	Yes	Yes
10	6	6	0	3	Yes	Yes
11	2	2	0	0	Yes	Yes
12	2	2	1	2	Yes	Yes
13	2	4	0	1	Yes	Yes
14	5	6	0	1	Yes	Yes
15	0	0	1	2	Yes	Yes
16	0	0	2	4	Yes	Yes
17	1	2	0	0	Yes	Yes
18	1	1	0	0	Yes	Yes
19	0	1	0	2	Yes	Yes
20	0	0	0	3	Yes	Yes
21	1	1	0	0	Yes	Yes
22	1	1	0	0	Yes	Yes
23	0	0	0	1	Yes	Yes
24	4	5	1	3	Yes	Yes
25	4	4	0	0	Yes	Yes
26	3	3	1	5	Yes	Yes
27	3	5	0	1	Yes	Yes
28	5	5	0	1	Yes	Yes
29	1	2	0	1	Yes	Yes
30	1	1	1	3	Yes	Yes
31	4	4	0	1	Yes	Yes
32	0	0	1	3	Yes	Yes
33	3	4	0	0	Yes	Yes
34	1	1	0	0	Yes	Yes
35	2	2	0	0	Yes	Yes
36	0	1	0	0	Yes	Yes
37	3	3	0	2	Yes	Yes
38	1	3	1	3	Yes	Yes
39	3	3	1	1	Yes	Yes
40	1	1	2	3	Yes	Yes
41	0	0	1	1	Yes	Yes
42	1	2	0	2	Yes	Yes
43	0	0	0	0	No	No
44	0	0	0	0	No	No
45	0	0	0	0	No	No
46	0	0	0	0	No	No
47	0	0	0	0	No	No
48	0	0	0	0	No	No
49	0	0	0	0	No	No
50	0	0	0	0	No	No
51	0	0	0	0	No	No
52	0	0	0	0	No	No
53	0	0	0	0	No	No
54	0	0	0	0	No	No

CHAPTER 3. Human disturbance, natural predation and hunting: effects on Uxpanapa Valley primates

Abstract

Various studies have established that loss of forest cover is the main driver for loss of biodiversity. However, few studies have focused on examining the effects of hunting, predation and wildfires on wildlife, and particularly, on Mexican primates. The main aim of this study was to establish a) whether hunting, wildfires and natural predation are occurring within Uxpanapa Valley, Veracruz, Mexico, and b) the effects these variables are having on the distribution and number of groups of howler and spider monkeys. We examined 54 different field sites, and obtained primate and predator data through direct observation and scat collection, I interviewed 340 villagers from the different field locations to obtain data on hunting and used NASA information for wildfire data. Results show that hunting and wildfires are ongoing in the area, but do not have a significant effect on the primates. A significant negative relationship was found only between predation and number of spider monkey groups, indicating that predators and spider monkeys have similar habitat requirements. Possible explanations for my findings could be: primate hunting seems to be decreasing due to changes in Mexican wildlife laws, which have harsher penalties for primate trafficking and wildfires have been closely monitored and controlled by local inhabitants over the past years to avoid crop losses. Nevertheless, ≥50% of the primate groups were found in areas in which the examined variables were less extensive. It is highly recommended that further studies be conducted on a long term basis and over a larger area to fully comprehend the effects hunting, natural predation and wildfires have on primates and to analyse other factors that may be actively impacting howler and spider monkey distribution in the area.

3.1 Introduction

It has been well documented that the main cause of species decline world-wide is deforestation (Estrada 2013). Nevertheless, other activities which occur simultaneously in the remaining forested areas, such as small-scale forest disturbance (e.g. plant extraction and pole cutting), human-created fire, cattle grazing and bushmeat hunting, also have direct impacts on wildlife

(Mugume et al. 2015), but have been much less studied. Overall, a better understanding is needed of the factors that limit animal species persistence in the face of non-deforestation related disturbance and the effects these different types of disturbances have on tropical animal populations (Poulsen et al. 2011).

Hunting

Wildlife in tropical forests has been hunted for thousands of years, but consumption rates have greatly increased over the last few decades (Peres 2009). The impact hunters have on animal populations depends on the way hunters harvest species (Bodmer et al. 1997) and in many modern societies, the subsistence or commercial purposes of this activity have been gradually replaced by recreational values (Peres 2009). In this sense, hunting is contributing to a tropical forest extinction crisis in ways not readily detectable using forest change cover assessments alone (Wilkie et al. 2011). In many sites the abundance of wildlife is more correlated with hunting patterns than with forest type, fragment size or level of protection, especially as the establishment of protected areas has not done much to prevent poachers entering to harvest species (Harrison 2011). Furthermore, the varying cultural aspects of each human population can affect wildlife on different scales, so it is necessary to know which species are chosen or avoided (and why), what hunting techniques are used, the number of animals harvested, as well as the purpose for hunting by particular human populations in order to determine the impact this activity has on wildlife (Melo et al. 2015).

Bushmeat hunting has been widely studied in African countries (Fa and Brown 2009) and is considered to be among the principal threats to larger-bodied vertebrate species, such as primates (Cronin et al. 2016). In the Neotropics, most studies on hunting have been developed in Brazil's continuous forests (Cullen et al. 2000), while less attention has been focused on the causes and consequences of hunting for primate populations and species in Mesoamerica when compared to other tropical areas (Jones and Jost 2007). Furthermore, to this date only a few studies have addressed primate use/ hunting in Mexico (Duarte-Quiroga and Estrada 2003; Cuaron

2005; Ortiz-Martinez et al. 2008). In this sense, it is not clearly understood to what extent primate populations are affected by locals in remaining forests fragments in this region. In the absence of hunting, fragmentation seems to have few direct short-term effects on the persistence of large vertebrates, but the interactions between hunting and different scales of forest disturbance remain poorly understood (Peres 2001). A combination of environmental factors, rather than any one factor, drive regional patterns of primate community structure and in one study in Peru, primate biomass was higher in non-hunted sites than in either lightly or heavily hunted sites (Palminteri et al. 2011). Primates are hunted as a food source in many countries (Fa et al. 2005; Peres 1990) and in Brazil hunting is one of the main factors affecting howler monkey density and biomass (Peres 1997). But the main reason that has been reported for hunting in Mexico is the pet trade (Duarte-Quiroga and Estrada 2003) and it is usually spider monkeys which are the preferred species (Cuaron 2005; Ortiz-Martinez et al. 2008). An understanding of hunting practices, hunter preferences, and their sociocultural underpinnings can be crucial to primate conservation (da Silva et al. 2005). Having detailed records on wildlife hunting can complement the environmental and biological information obtained for a specific site, allowing researchers to make informed decisions regarding habitat and species management and to better distribute limited time and resources.

Although primates are under legal protection in Mexico, very few local inhabitants of areas where primates are present are aware of these laws (Ortiz-Martinez et al. 2008). So, despite communal and private initiatives for conservation, hunting for the pet trade threatens primate conservation alongside habitat loss and disturbance (Ortiz-Martinez et al. 2008). Primate hunting has rarely been studied and associated to primate distribution in Mexico, but hunting could potentially be regulating howler and spider monkey distribution, whether it is directed specifically towards primates or targets other species which co-habit the area, since hunting has been shown to have profound implications on the structure and dynamics of the forest (Stoner et al. 2007). As mentioned above, it is widely acknowledged that illegal hunting is a major threat to species and having data on this activity for my study site could provide additional input that will enable the development of suitable conservation strategies for primates and other species in the area. Furthermore, since many studies do not actively incorporate hunting data as part of their evaluation, my results could potentially indicate the importance of collecting this information as part of future projects directed towards species protection. The aim is therefore to provide general information on wildlife hunting in the Uxpanapa Valley and specifically address whether hunting impacts primate presence in the area.

Predation

The jaguar (*Panthera onca*) and puma (*Puma concolor*) are the top predators of tropical environments in the Americas, and are sympatric throughout their range in Mexico (Hernández-SaintMartín et al. 2015). Both felids are opportunistic hunters, often using prey according to its availability and it has been reported that in areas with lower degree of fragmentation their diets tend to be less diverse and be dominated by one or two species, while in highly fragmented landscapes the diet diversity is greater (Foster et al. 2010; Hernández-SaintMartín et al. 2015). Across their distribution range, the principal prey species of both cats are similar: mainly peccaries, large rodents, deer and armadillos (Oliveira 2002). On the other hand, raptors have the highest mean percentage of primates in their diets (36.6%) of any predator group in the Neotropics; all other predators consume negligible numbers by comparison (Hart 2007). Furthermore, primates are considered to be a less preferred prey (Bidner 2014) but if primary prey abundance is reduced by human hunting practices, predators could be forced to rely on primates as an alternative feeding source.

Predation influences primate behaviour, population dynamics, spatial distribution, and group size (Farris et al. 2014). As predators and primates are increasingly forced into isolated fragments of forest, natural or exacerbated predation rates by predators may negatively impact primate populations that are simultaneously being limited by declining habitat quality and human encroachment (Farris et al. 2014). Thus, primate distribution within my study site may be affected by large cats, such as jaguar (*Panthera onca*) and puma (*Felis concolor*), as they include howler and spider monkeys in their diet

(Chinchilla 1997; Matsuda and Izawa 2008). Under certain conditions, jaguar and puma can be the most threatening predators to adult monkeys (Matsuda and Izawa 2008). It has been documented that a single jaguar can eradicate a small howler monkey group (Peetz et al. 1992). Predation is thought to be more likely to negatively impact howler monkeys than spider monkeys, as they live in more fragmented areas and reports suggest they are easy targets for large cats (Peetz et al. 1992; Cuaron 1997). Forest fragmentation may increase predation on canopy dwelling primates as a result of the reduction in tree size, since smaller trees facilitate access to prey (Ludwig et al. 2007). Other studies have pointed out that when acting synergistically, forest fragmentation and large cat predation can cause major damage to small primate populations, specifically to those which have slow reproductive rates and/or low colonization abilities (Irwin et al. 2009). Furthermore, even if forest fragmentation remains the ultimate cause of primate extinction, researchers should be wary of the stochastic nature of predation and its potential for rapidly decimating groups, even when short-term surveys show stable or increasing populations (Irwin et al. 2009).

Humans could alter the likelihood of predation in a number of ways, namely: (1) predators may avoid human altered habitats, reducing predation risk; (2) anthropogenic habitats may facilitate certain predators, increasing predation risk; or (3) the predator assemblage of a habitat could change, with potentially drastic effects on endemic wildlife that lack the experience and selection-driven behavioral patterns necessary to avoid these predators. As primate’s habitats become increasingly anthropogenic, their predation risks—and potential predators—are bound to change (McKinney 2009). Documentation and quantification of the extent of primate predation by felines is scanty (Bianchi and Mendes 2007). In this sense, this work aims to contribute towards establishing whether predation is actively occurring in the Uxpanapa Valley and the extent to which it is impacting primate presence.

Fire

Wildfires can have devastating effects on biodiversity via the removal of vegetation, refuge habitat, and food sources and by increasing the subsequent vulnerability of surviving animals to predation (Pastro et al. 2011). Wildfires detrimentally affect canopy dwellers in particular, mainly due to a decline in live-tree density (or high mortality rates of large trees) (Barlow and Peres 2004), although certain primate species may switch diets to adapt, species with specialized diets become increasingly vulnerable (Barlow and Peres 2004). Some reports mention that the severity of surface wildfires can affect the distribution of howler monkeys and favour their abundance, because in the medium term recurrent fires can increase the production of high-quality foliage (Michalski and Peres 2005, Michalski and Peres 2007). Nevertheless, intense fires, such as those reported for the Los Chimalapas-Uxpanapa region in 1998 (Asbjornsen et al. 2005), may also have reduced the howler population in the area. Fire events affect species in different ways. Single fire occurrences can have a huge impact on the tree resources available to primates, but this effect increases significantly in areas that succumb to two fires within a 10 year period (Barlow and Peres 2006). In particular, changes in composition and abundance of fruit trees as well as in habitat structure within burnt forests can alter the abundance of many large-bodied vertebrate species (Barlow and Peres 2006).

This work aims to enhance knowledge of the effects current fire events have on primate distribution within a specific area and determine whether recurrent fire episodes have an effect on primate distributions. Wildfires will be included in the same analyses as hunting activities and predation pressure to determine whether any of these factors impact on howler and spider monkey presence/absence, as well as on their group numbers in the Uxpanapa Valley.

3.2 Aims and objectives

Aim

To assess the impact hunting, predation by large cats and wild fires currently have on primate distribution in the Uxpanapa Valley. This will be addressed by analyzing hunting occurence, fire incidents and feline diet data within areas of howler and spider monkey presence and absence, together with the specific primate demographic data obtained from the Uxpanapa Valley.

Objectives

To test the hypothesis that hunting influences howler and spider monkey distribution in Uxpanapa Valley.

To test the hypothesis that predation affects howler and spider monkey presence and distribution.

To test the hypothesis that wild fires are limiting primate distribution in the Uxpanapa Valley.

Specific activities

1. Determine the role of hunting on the presence/absence of primates.

    a) Document human use of wildlife , particularly primates, in the study site
    b) Establish whether hunting patterns (hunting intensity) coincide with primate population numbers
    c) Establish which are the top harvested species
    d) Establish how landscape attributes vary in hunting areas
    e) Establish the main drivers behind hunting

2. Determine effects of large cat predation on primate presence/absence

3. Establish fire occurrence frequency per sampled plot and determine impact on primate presence/absence.

4. Determine whether the differences in landscape attributes within each plot are related to the level/degree of hunting/predation/fire incidents.

3.3 Methods

Data collection

Hunting

Local inhabitants within the sites where primate presence and absence were previously recorded (see Chapter 2) and who acknowledged being hunters were interviewed during May-July 2014. Interviews were semi-structured and included information such as gender, age and economic status, hunting practices (number of hunting days, distances covered), species and number of animals harvested (including non-primate species), the main use of the hunted animal (subsistence, commerce, pets, medicine, including price), amount of game harvested, and location of harvests. Housewives and non-hunters in the localities were also interviewed, to obtain indirect information on which species are hunted and used for commerce, pets, food and medicine (Annex 1); particularly, we asked interviewees about the use of primates for any of these activities. All interviewees were informed of their anonymity status. Villagers were familiarized with me, as team members and I lived in the study area for several months during 2010-2011 when collecting data on primates and other species. Furthermore, villagers were aware I strictly conducted research and did not belong to any government organization which could penalize them if they admitted to hunting. This built trust and facilitated rapport with interviewed individuals. A summary of each interviewed village is provided in Annex 2.

A person was considered a “hunter” if they had carried out hunting activities in the last 3 years. A “non-hunter” was defined as a person who is able to hunt but chooses not to (e.g. due to religious beliefs). All villages that were visited performed hunting to some degree. These data were incorporated into a GLM to determine the level of threat that primates are exposed to in sites where wildlife hunting occurs and if the degree of usage of primates impact on their presence/absence in a site.

Table 3.1. Codes for hunting intensity, depending on number of villages hunting per plot

Hunting intensity	Number of villages impacting plot
Moderate	1
Medium	2
High	3 or more

Predation

All large feline scats from the Uxpanapa Valley were collected by J.M.W. Day and B. Solórzano during the dry season (March to June), in 2010 and 2011, within the 54 randomly selected sites mentioned in the Chapter 2. The sites were examined by at least two experienced researchers and a local guide, as well as canine trained in feline scat detection (Wasser et al. 2004). Dogs trained to locate scat of particular species detect carnivores more effectively than traditional methods, such as hair snares, scent stations, and camera traps (Wasser et al. 2004; Harrison 2006; Long et al. 2007b; Vynne 2011). In total, 124 scat samples were collected in 38 of the 54 plots. When a scat was located, geographic coordinates using a Global Positioning System (GPS) were registered, together with vegetation type. Scats were preserved and later used for genetic, parasitological and diet analysis (J.M.W. Day and B. Solórzano unpublished data).

Diet of the large felines (puma and jaguar) of Uxpanapa Valley were analyzed at the Universidad Veracruzana laboratories by B. Solórzano. The primate hairs found in the feline scat were identified and differentiated by their morphology, specifically by their medulla, as spider monkey's hair medulla is shaped with fragmented cells, while howler monkey hair lacks this structure (B. Solórzano, unpublished data).

Coordinates of the jaguar and puma scats (with and without primate remains) were added as a layer to the Uxpanapa Valley map with ArcMap 10.1. These scat data were incorporated into the GLM to determine if large cat predation was impacting primate presence/absence in our study site. The data were classified as shown in Table 3.2:

Table 3.2. Codes for large cat scat diet regarding primates

Predation intensity	Number of scats
Medium-High	2, scats with primate remains found
Low	1, scat with no primate remains
None	0, no scat detected

Fire

Fire data were initially obtained from a previous project in the area (PRONATURA, 2007), which categorized level of threat in the entire region due to forest fires. These data were added as a layer to the Uxpanapa Valley map created for the current project and ArcMap 10.1 was used to extract the data for each of our 54 sites from the PRONATURA fire layer. The data were then incorporated into the GLM. Nevertheless, we consider the results solely as a comparison point, as this PRONATURA data set was limited to 2003 and provided no background for level of threat ranking (Table 3.3).

Table 3.3 PRONATURA fire categories

Fire occurrence probability	Code
Low	1
Medium	2
High	3
Very high	4

More recent data on fire events (2009-2014) in the region were obtained through NASA´s Archive MCD14ML MODIS Active Fire Detections, downloaded from https://earthdata.nasa.gov/active-fire-data#tab-content-6.

MODIS stands for Moderate Resolution Imaging Spectroradiometer. The MODIS instrument is on board NASA’s Earth Observing System (EOS) Terra (EOS AM) and Aqua (EOS PM) satellites. The near real-time (NRT) active fire locations are processed by the Land, Atmosphere Near real-time Capability (LANCE) using the standard MODIS MOD14/MYD14 Fire and Thermal Anomalies product. Each active fire location represents the center of a 1km pixel that is flagged by the algorithm as containing one or more fires within the pixel (NASA/GSFC/ESDIS 2015). Data provided by NASA were incorporated into the study site map using ArcMap 10.1 and all fire events within the 54 plots were counted, and ranged from 0 (No fire) to 12 incidents. The two fire variables were incorporated separately into our GLM, to establish if historic or more recent fire incidence had an effect on primate presence in the area.

Statistical analysis

Descriptive statistics were used to report questionnaire outputs.

The effect of the different factors on the occurrence of *Alouatta palliata* and *Ateles geoffroyi* was analysed using generalized linear models (GLMs) with a logit link function and binomial error structure in R (Crawley, 2007). Predictor variables were the hunting, predation and fire events occurring in each sampled plot. Three analyses were conducted to examine the association between the variables and: 1) the presence of *A. palliata*, 2) the presence of *A. geoffroyi*, and 3) the presence of both species recorded within the same sampled plot. For each data set, I created a 0 - 1 response variable in which 0 represents the absence and 1 the presence of each primate species (in the case of the third analysis, 1 represents only those locations with both primate species). I first ran a full model with all predictors included, using the library MASS and then used the function 'dredge' in the package MuMIn to select the best model based on Akaike's Information Criterion (AIC). In order to determine the ability of the model to explain the variation in the data, I compared the fit of the best model selected against a null model that included only the intercept, using a likelihood ratio test. All statistical analyses were carried out in R 2.15.1(R Core Team, 2012).

I further analyzed the effect of the different factors on the total number of groups found of both *A. palliata* and *A. geoffroyi* using generalized linear models (GLMs) with a log link function and poisson error structure in R (Crawley, 2007). Predictor variables were the hunting, predation and fire events occurring in each sampled plot. I conducted two analyses to examine if the variables were associated to 1) the number of groups of *A. palliata*, 2) the number of groups of *A. geoffroyi*, within each sampled plot. For each data set, I created a 0 to 6 (maximum number of groups found in a site) response variable in which 0 represents the absence and the different numbers represent the total number of groups found for each primate species. I first ran a full model with all predictors included using the library MASS and then used the function ‘dredge’ in the package MuMIn to select the best model based on Akaike’s Information Criterion (AIC). In order to determine the ability of the model to explain the variation in the data, I compared the fit of the best model selected against a null model that included only the intercept, using a likelihood ratio test. All statistical analyses were carried out in R 2.15.1(R Core Team, 2012). Anova tests were performed, using SPSS V 2.0 to test the differences between landscape variables (Tall Forest (TF), Mature Secondary Forest (MSF), Secondary Forest (SF), Transformed Habitat (TH) and Human Setlement (HS)) within each group of factors (Hunting, Predation and Fire Incidents).

3.4 Results

Hunting

A total of 80 hunter interviews were collected from 35 villages within the Uxpanapa Valley. The villages correspond to 24 of the 54 windows previously sampled for primates. I collected 262 interviews from housewives/non-hunters from the same villages, which allowed me to obtain indirect data on wildlife hunting and additional information on which species were being used and for what purposes. All villages in which the questionnaires were applied presented hunting activities. Over 40% of hunters responded that they hunted more than twice a month (Fig. 3.1) and that their preferred species for hunting was the Lowland paca (*Cuniculus paca*) (33.14%), while primates were one of the least sought after species (0.58%) (Fig. 3.2).

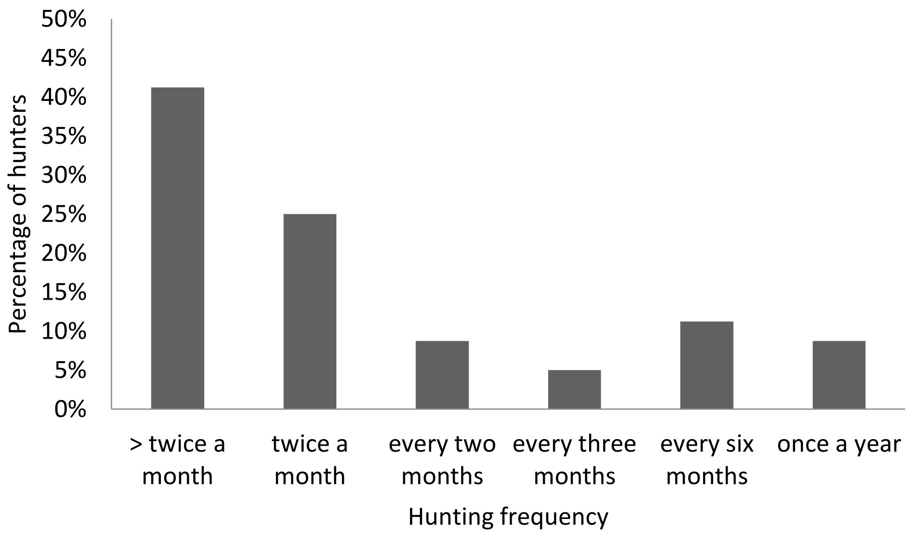

Fig. 3.1 Hunting frequency of all interviewed hunters from the 35 sampled villages.

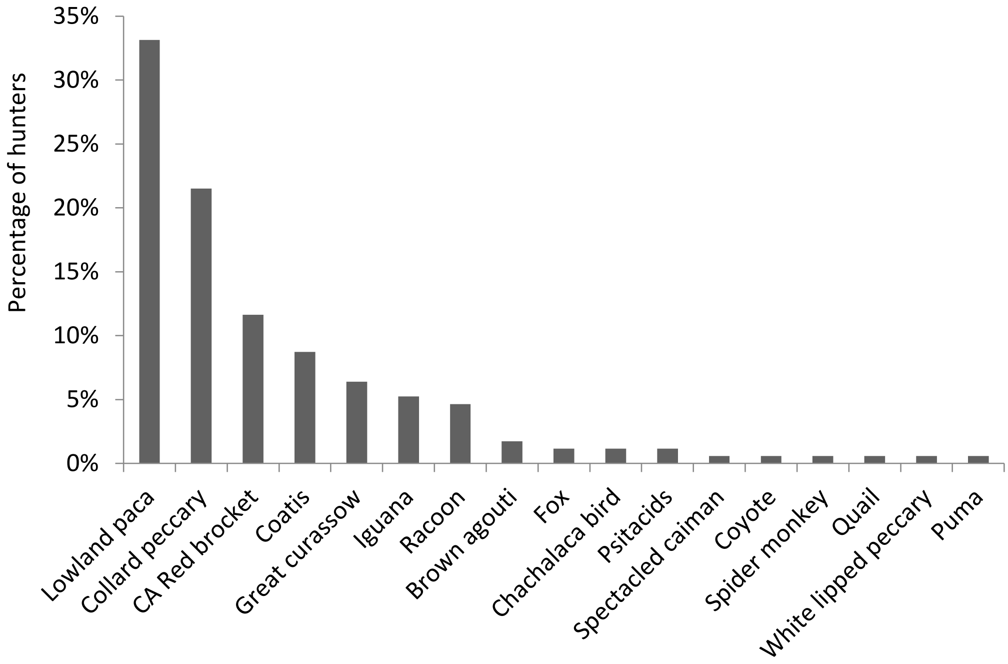

Fig. 3.2 Percentage of the total prey preferred by all interviewed hunters in the Uxpanapa Valley.

Results from the 262 housewife/non hunter questionnaires show 90% of interviewees used wildlife as a food source (Fig. 3.3) and 25.73% of people favoured Lowland paca for consumption (Fig. 3.4), while preference for primates was relatively low (0.40%).

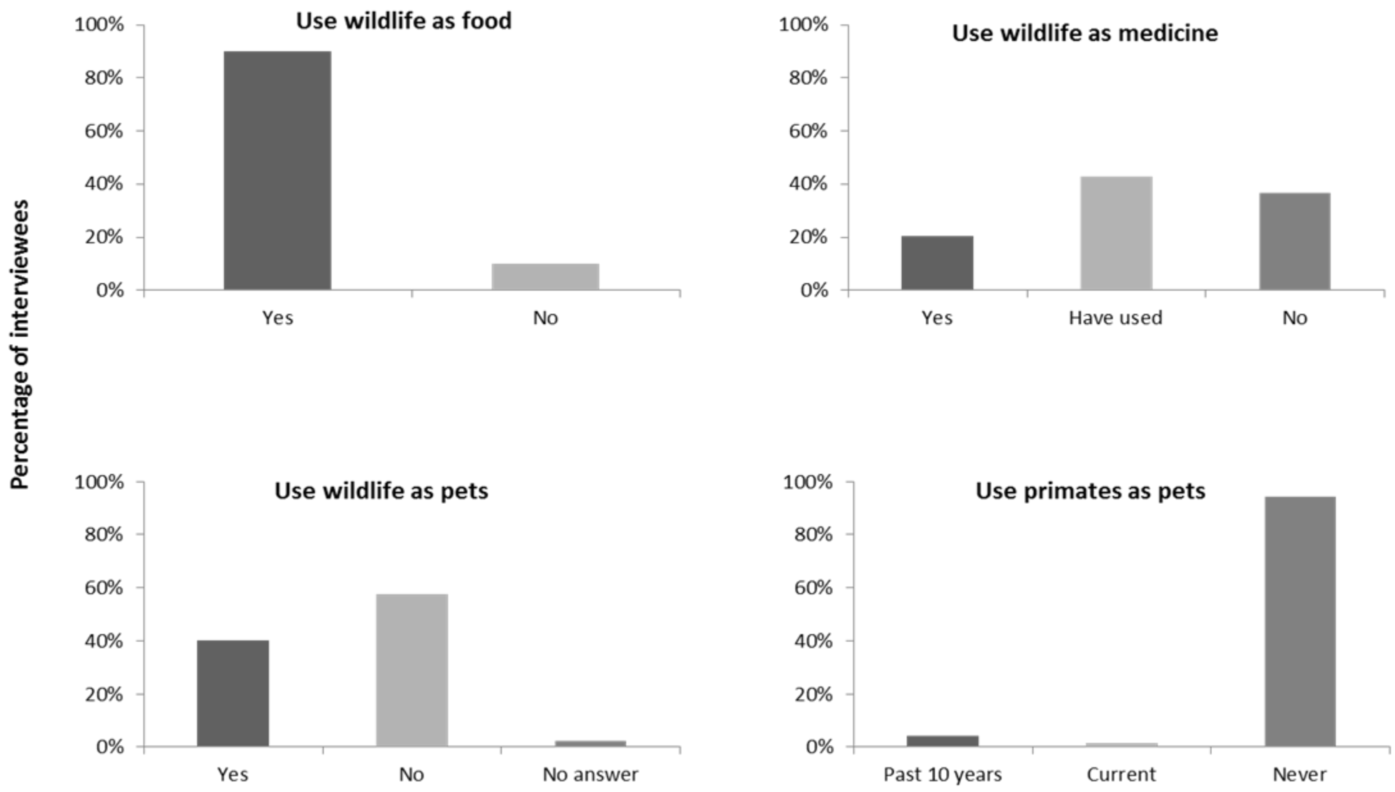

Fig. 3.3 Percentage of all interviewees (hunters and non-hunters) using wildlife for different purposes as well as percentage of interviewees that have had or currently have a primate as a pet.

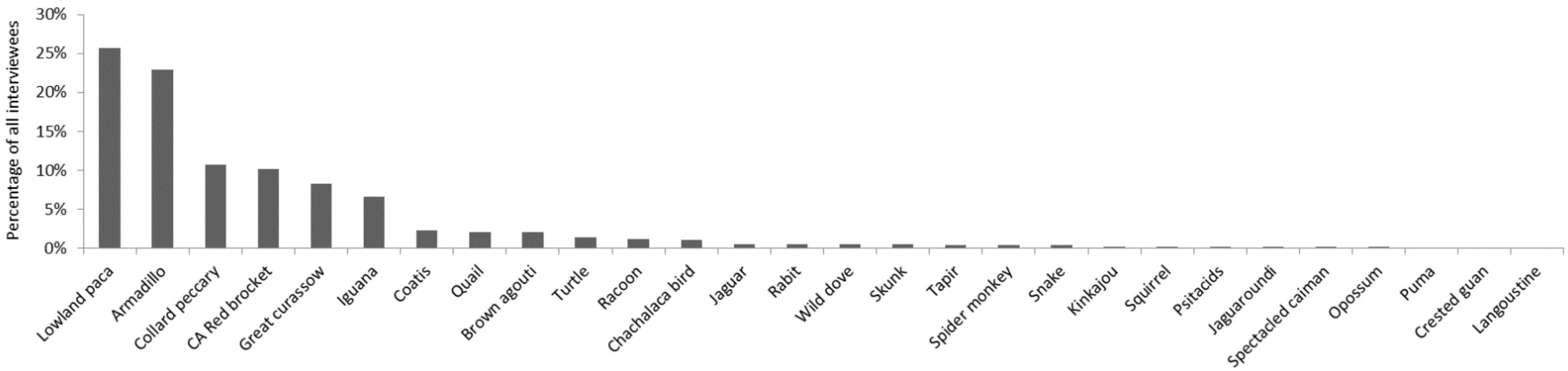

Fig. 3.4 Percentages of all interviewees (hunters and non-hunters) preferred species for food usage in Uxpanapa Valley

Some wildlife species are also used for pets, with 40% of households reporting to have at least one pet (Fig. 3.3). In this set of uses, primates appear to be ranked 4th as preferred species to have as a pet (2.76%) (Fig.3.5). However, most household have never had a primate as a pet (94%) (Fig. 3.3).

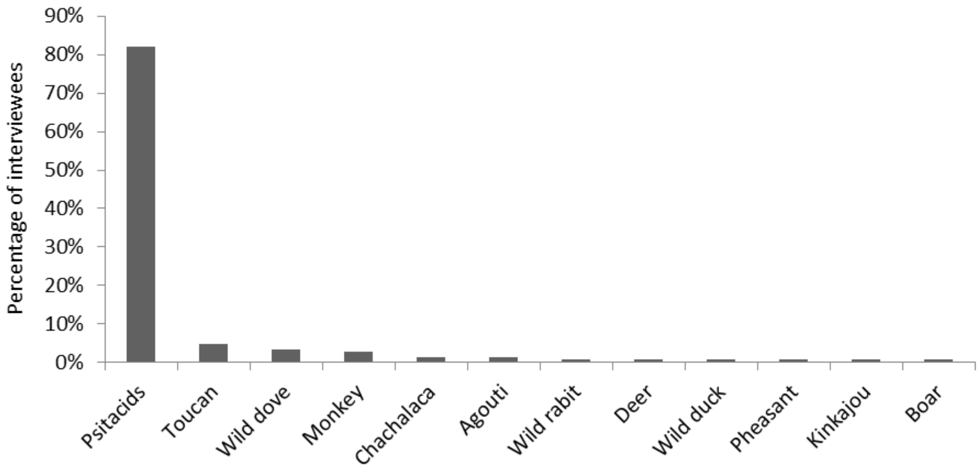

Fig. 3.5 Percentages of interviewees who owned wildlife pets in Uxpanapa Valley

Use of wildlife for medicinal or traditional purposes was also reported; 64% of households had used or were currently using wild animals as medicine or for other traditional purposes, such as making instruments for religious rituals (Fig. 3.3). The most used species for medicine was the Skunk (*Mephitis macroura*) (34.95%), while spider monkey ranked 7th in this category (3.46%) (Fig. 3.6).

On average, interviewees have been hunting for a total of 16.2 years (12 - 63 yrs) in the area. Overall, 4 (5%) hunters said they hunted for commercial purposes. A single plot could be hunted by more than one village. The distribution of the villages within the sampled plots can be observed in Fig. 3.7.

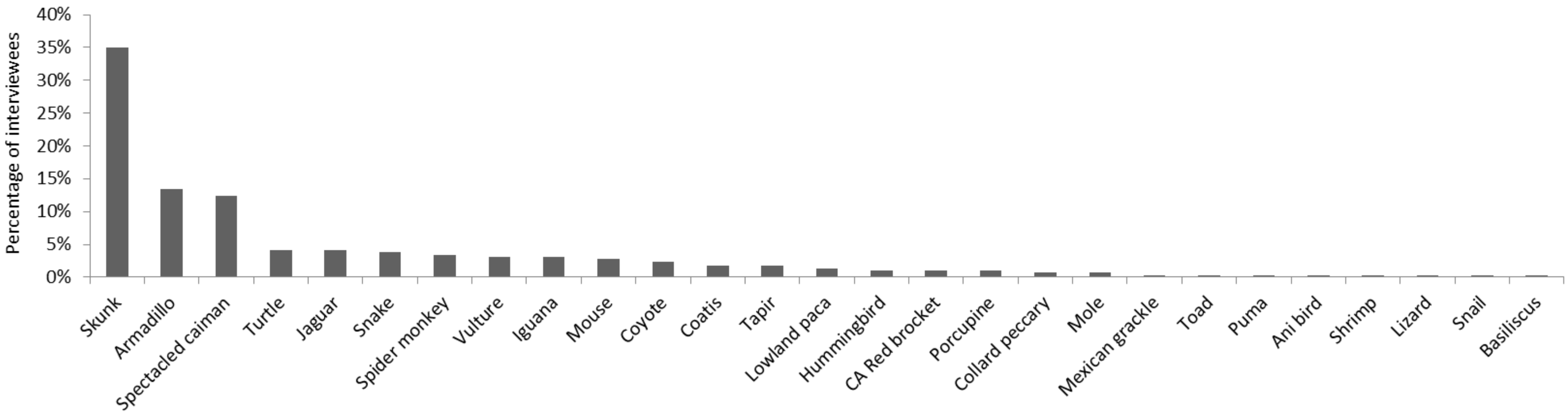

Fig. 3.6 Species commonly used by interviewees for medicinal or traditional purposes

Fig. 3.7 Distribution of villages where questionnaires were conducted (black triangles) and intensity of hunting per plot was based on number of villages hunting a single plot (NA- interviews not applied in area, 1-Low; 2-Medium; 3 or more-High). Dark grey plots represent high hunting intensity, medium grey represent medium intensity and white represent low.

Predation

Primate remains were found in the scat of both jaguar and puma, in 14 (26%) of the 54 plots that were sampled. In some cases, genetic markers were insufficient to differentiate between jaguar and puma individuals, so their scats were catalogued as belonging to “big cat”. When primate remains found in scats couldn´t be identified as belonging to either howler or spider monkey, they were catalogued as “primate” (B. Solórzano unpublished data) (Table 3.4).

Table 3.4. Frequency of appearance (%) of primate remains in big cat scats in Uxpanapa Valley.

	Jaguar	Puma	Big Cat
Alouatta palliata	20.8	15.4	29.1
Ateles geoffroyi	33.3	38.5	38.2
Primate	37.5	46.2	45.5

Eleven areas of Medium-High, and 10 of Low predation were found in the 54 sampled plots (Fig. 3.9). No evidence of scat was found in 30 plots.

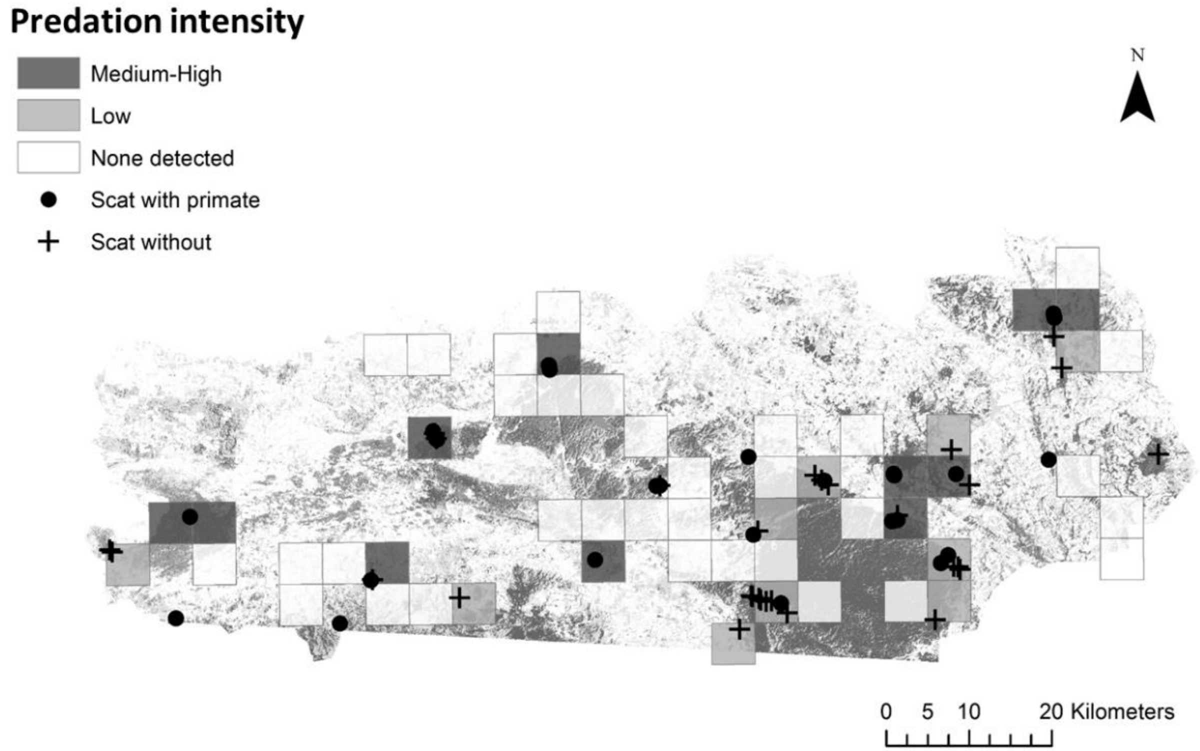

Fig. 3.9 Distribution of feline predation intensity on the primates of the Uxpanapa Valley. Dark grey plots indicate Medium-High predation - scats that presented primate remains in them, medium grey (low level)-scats without primate remains and None detected – no scats found in area during 2010-2011 inspection. Black circles represent individual scats with primate remains and black crosses represent individual scats without primate remains.

Fire

In a previous study, PRONATURA (2006), established areas of fire risk for the Uxpanapa Valley region (Fig. 3.10), but their criteria for establishing these categories were not clear. Furthermore, their data only comprises 2003 data and was not updated. Although we recognize this work, we considered it was necessary to have a clear definition of criteria selection, as well as updated information on fire occurrences.

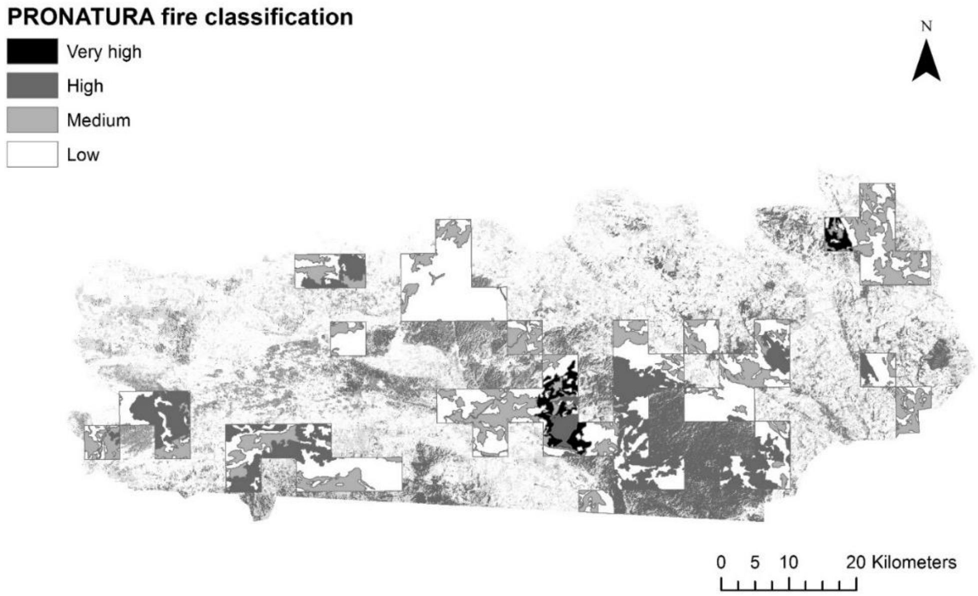

Fig. 3.10 Fire frequencies within the sampled plots, as established by Pronatura (2006).Black areas represent Very high fire risk, dark grey High risk, medium grey Medium risk and white Low risk.

The input data on fire events recorded by NASA (2009-2011) show a total of 100 fire events occurred within 29 of our 54 sampled plots. As our classification indicates, multiple fires could occur in a single plot (2-12) (Fig. 3.11).

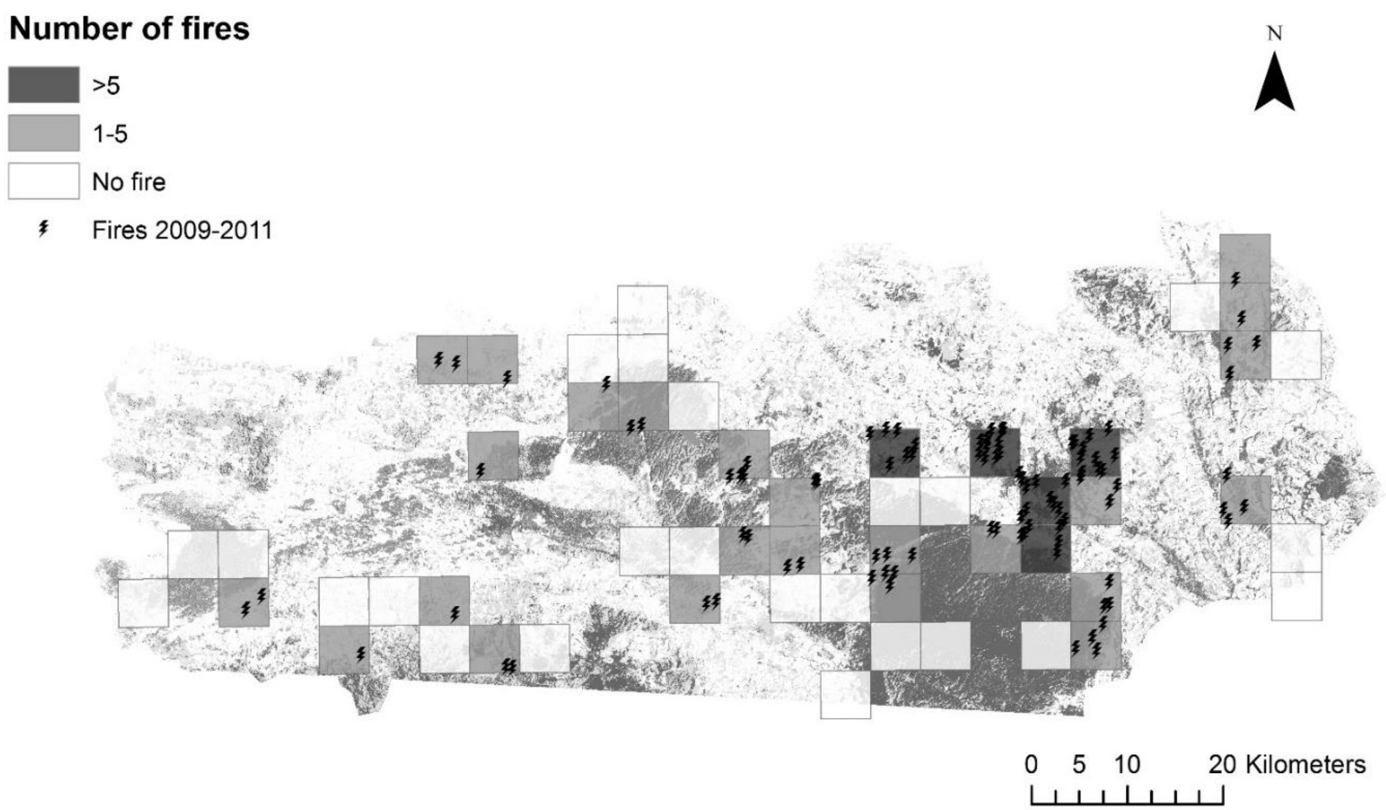

Fig. 3.11 Fires reported for Uxpanapa Valley from 2009 to 2011. To facilitate interpretation, fire incidents were classified as follows: dark grey plots indicate high incidence of fires (more than five), medium grey indicate 1-5 events and white the absence of fire incidents. Black symbols represent individual fires.

General GLM/tables

The general GLM analysis showed that none of the variables explained the presence/absence of spider monkeys (Table 3.5).

Table. 3.5 The general GLM for *Ateles geoffroyi* presence/absence

Ateles GLM	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.17838	1.17599	0.152	0.879
HUNTING.INTENSITYMedium	-0.54335	0.89812	-0.605	0.545
HUNTING.INTENSITYHigh	18.40385	2164.8	0.009	0.993
Number of fires	-0.05114	0.17627	-0.290	0.772
No predation	0.20068	1.26060	0.159	0.874
Predation on primates	0.76361	1.67887	0.455	0.649

Null deviance: 44.149 on 33 degrees of freedom. Residual deviance: 33.880 on 28 degrees of freedom.
AIC: 45.88

A GLM analysis using total number of groups present per site was also run, showing that the total absence of scat predicted spider monkey absence in the area (Table 3.6).

Table. 3.6 The general GLM for *Ateles geoffroyi* total group number

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	0.92524	0.30307	3.053	0.00227	**
HUNTING.INTENSITYMedium	-0.17739	0.39287	-0.452	0.65161	
HUNTING.INTENSITYHigh	0.54353	0.31188	1.743	0.08138	.
Number_of_fires	-0.03955	0.04826	-0.819	0.41254	
No predation	-0.76659	0.31064	-2.468	0.01360	*
Predation on primates	-0.14281	0.49796	-0.287	0.77428	

Null deviance: 67.484 on 33 degrees of freedom. Residual deviance: 52.968 on 28 degrees of freedom.
AIC: 124.04

Using the model selection criteria, Predation was selected as the best model. The selected model showed a significant result, where total absence of predator scat predicts less spider monkey groups in the site (Table 3.7).

Table 3.7. Best model selected for spider monkeys shows predation absence significantly predicts less spider monkey groups.

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	0.9694	0.1857	5.220	1.79e-07	***
No predation	-0.7463	0.2381	-3.134	0.00172	**
Predation on primate	-0.5174	0.3541	-1.461	0.14396	

Null deviance: 123.17 on 53 degrees of freedom.
Residual deviance: 114.04 on 51 degrees of freedom. AIC: 205.21

As with spider monkeys, the general GLM for howler monkeys indicated that none of the variables predicted presence/absence (Table 3.8).

Table 3.8. The general GLM for *Alouatta palliata*

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.0746	1.0383	1.035	0.301
HUNTING.INTENSITYMedium	0.7343	0.9313	0.789	0.430
HUNTING.INTENSITYHigh	-0.9781	0.9559	-1.023	0.306
Number_of_fires	0.1314	0.1427	0.921	0.357
No predation	-1.0232	1.0440	-0.980	0.327
Predation on primate	-0.7050	1.6078	-0.439	0.661

Null deviance: 45.234 on 33 degrees of freedom. Residual deviance: 41.487 on 28 degrees of freedom. AIC: 53.487

A GLM analysis using total number of groups present per site was also run, showing that none of the predictors influenced the number of howler monkey groups present at any site (Table 3.9).

Table 3.9 The general GLM for *Alouatta palliata* total group number

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.23434	0.39226	0.597	0.5502
HUNTING.INTENSITYMedium	0.67689	0.37069	1.826	0.0678 .
HUNTING.INTENSITYHigh	-0.43422	0.43243	-1.004	0.3153
Number_of_fires	0.07965	0.04849	1.643	0.1005
No predation	-0.27656	0.41528	-0.666	0.5054
Predation on primate	-1.04503	0.80175	-1.303	0.1924

Null deviance: 57.938 on 33 degrees of freedom. Residual deviance: 48.092 on 28 degrees of freedom. AIC: 114.69

For both species together, the general GLM showed none of the variables predicting both species presence (Table. 3.10)

Table 3.10. General GLM for both species

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.31821	0.92217	0.345	0.730
HUNTING.INTENSITYMedium	-0.47110	0.92355	-0.510	0.610
HUNTING.INTENSITYHigh	0.02890	0.89717	0.032	0.974
Number_of_fires	-0.01494	0.12714	-0.118	0.906
No predation	-0.80355	0.94104	-0.854	0.393
Predation on primate	-0.84979	1.51302	-0.562	0.574

Null deviance: 45.234 on 33 degrees of freedom. Residual deviance: 43.606 on 28 degrees of freedom. AIC: 55.606

Anova test results for differences between landscape variables

Overall, there were no statistically significant differences between group means as determined by one-way ANOVAs: No significant differences were found between the vegetation types encompassed within the high, medium and low hunting category plots (Table 3.11). No significant differences were found between the vegetation types encompassed within the medium-high, low and none predation category plots (Table 3.11). No significant differences were found between the vegetation types encompassed within the >5, 1-5 and none fire incident category plots (Table 3.11).

Table 3.11. Anova test results for differences between vegetation type within each group of factors (hunting, predation and fire incidents)

	Forest type				
	SF	MSF	TF	TH	HS
Hunting	F(2,31)=.81, *p*=.45	F(2,31)=2.3, *p*=.12	F(2,31)=.82, *p*=.44	F(2,31)=.28. *p*=.75	F(2,31)=.94 *p*=.4
Predation	F(2,51)=.27, *p*=.76	F(2,51)=.19, *p*=.82	F(2,51)=.32, *p*=.72	F(2,51)=.34. *p*=.71	F(2,51)=.59, *p*=.5)
Fire incidents	F(2,51)=.44, *p*=.64	F(2,51)=.5, *p*=.6	F(2,51)=.12, *p*=.88	F(2,51)=.28. *p*=.75	F(2,51)=.1, *p*=.9

High hunting intensity areas held the highest mean percentage of TF and HS, as well as the lowest mean percentages of SF and TH (Table 3.12). Medium hunting intensity areas were characterized by having the highest mean percentage of MSF and TH, as well as the lowest mean percentage of TF, while Low hunting intensity area had the highest mean percentage of SF, as well as the lowest mean percentage of MSF and HS (Table 3.12)

Medium-High predation intensity areas were characterized by having both the highest mean percentages of TF and lowest TH (Table 3.12). Areas with Low predation intensity held the highest mean percentages of TH and HS, while areas where no predation was detected held the highest percentages of SF (Table.3.12).

Areas in which >5 fires occurred hold the highest mean percentages of TH and HS as well as the lowest TF. Areas in which 1-5 fire incidents were recorded had the highest mean percentage of SF as well as the lowest mean percentages of HS and TH, while areas in which fire events weren’t registered held the highest percentage of TF and the lowest of SF (Table 3.12).

Table 3.12. Mean percentage of landscape attributes of areas per respective level of predation, fire and hunting intensity, as well as the mean number of howler (HM) and spider (SM) monkey groups detected.

	SF	MSF	TF	TH	HS	Mean number of HM groups	Mean number of SM groups	Number of sites
HUNTING INTENSITY								
High	21.02	19.14	31.55	27.54	0.51	.88	2.5	9
Medium	26.29	19.29	18.07	34.38	0.47	2	1	11
Low	28.41	9.56	29.88	30.14	0.23	1.21	1.57	14
PREDATION INTENSITY								
Medium-High	27.86	12.03	26.98	31.76	0.24	1.27	2.63	11
Low	24.57	15.30	17.88	39.15	0.53	.71	1.57	7
None	28.66	14.37	23.11	32.38	0.37	1.3	1.25	36
FIRE EVENTS								
> 5	31.41	8.75	19.50	39.73	0.46	1.4	1.4	5
1 to 5	29.06	14.61	22.44	32.10	0.34	1.29	1.29	24
None	26.24	14.48	24.71	32.80	0.37	1.12	1.88	25

3.5 Discussion

With this study, I was able to ascertain that hunting is a constant and current activity in the Uxpanapa Valley. Although interviews were not conducted in all the villages of the 54 sites, in all the 35 villages where questionnaires were applied, at least some residents undertook hunting activities. Furthermore, information on wildlife hunting was obtained by proxy, interviewing housewives and non-hunters. Only 10% of households denied currently using wild animals as food, while 40% use wild animals as pets and 64% use or have used wildlife for medicinal/traditional purposes. The animals are either obtained by members of their family or bought in the same village. Nevertheless, primate hunting is not widespread, with only 0.58% of hunters reporting them as prey and 0.40% of housewives/non-hunters using them for food. On the other hand, 2.76% and 3.46% of interviewees stated they used primates (specifically spider monkey) as pets and for medicine, respectively. This shows that primates can be a target in the Uxpanapa Valley, but the GLM results did not show hunting as a variable that explains primate presence/absence across the site. Several studies have established that hunting is detrimental for all species populations in the tropical forests, including primates (Peres 1997; Michalski and Peres 2005; Harrison 2011; Wilkie et al. 2011), but most studies on primate hunting have taken place in areas where primates constitute a diet staple (Peres 1990; de Thoisy et al. 2005; Ohl-Schacherer et al. 2007). The fact that primates are not typically used as a food source in this region (and in general in Mexico), may be one of the reasons for which hunting intensity is not directly linked to their presence/absence. Locals also mentioned recent changes in the Mexican law, which now include primate hunting and commercializing as a federal offense leading to a decrease in their hunting of primates (Pers. Com.).

Big cat predation on primates was another factor analyzed in this work. Specifically, the amount of primate remains found in jaguar and puma scat within our sample plots was examined. The frequency of appearance of howler monkey remains in jaguar scat was 20.8%, while spider monkeys appeared 33.3%. In puma scat, howler remains appeared 15.4% and spider monkeys 38.5%. Jaguar and puma predation have been shown to significantly impact primate groups in other areas (Peetz et al. 1992; Matsuda and Izawa 2008) but the GLM results showed that predation intensity was not an adequate predictor for howler monkey presence/absence in the Uxpanapa valley. On the other hand, there were significant results related to spider monkey presence, showing that in areas where predation was not recorded, the likelihood of presence of spider monkeys and the combined presence of the primates decreased (z-value= -3.134, p-value =0.0017). This might be explained by the fact that areas where no predation was recorded held the highest mean percentage of Secondary Forest, which has been linked to spider monkey absence in Chapter 2. In this sense, predator presence and spider monkey presence could be governed by the same landscape drivers. Additionally, as both jaguar and puma are considered to be opportunistic hunters (Hernández-SaintMartín et al. 2015), predation may be related to availability of both primates, but particularly spider monkeys, within certain areas. Medium-High predation took place in areas with the most TF percentages (26.98%), while the results also show that the felines are less active in areas with the highest mean percentages of TH (39.15) and HS (0.53). In this sense, we did expect big cats to show higher predation intensity in the most conserved areas due to their specific needs and to primate groups being more numerous in TF areas. Nonetheless, as these conclusions are based on a limited data set, perhaps long term studies would show a more direct link between big cats and primate distribution in the area.

This study also included Fire events and intensity as a possible variable affecting primate presence/absence in the Uxpanapa Valley, as wild fires can cause extensive damage to a habitat and the biodiversity in it (Kinnaird and O'Brien 1998), particularly to canopy dwellers (Barlow and Peres 2004; 2006). The general GLM showed that fire events and fire intensity could not explain primate presence/absence within the study site. High intensity fire areas had more SF (31.4%) than TF (19.5%), and areas with no fire events held the highest TF (24.7%). These areas were also where the most spider monkey groups were found, while the most howler monkey groups were recorded in sites with 1-5 fire events. Some studies have suggested howler monkeys may benefit from small wildfires, as they increase productivity of high-quality foliage (Michalski and Peres 2005, Michalski and Peres 2007) and this could be an explanation for these findings. Local inhabitants have formed voluntary fire prevention and contention brigades as a result of a widespread fire that occurred in 1998 and affected their homes and livelihoods (pers. Com.). This has greatly limited the spread of wild fires, even though traditional slash and burn practices still occur. By regulating the extent of wild fires, key primate habitat may be less susceptible and able to maintain current populations, and areas in which small fires are taking place could be supporting the howler monkey population in the Uxpanapa Valley. Nevertheless, this information must be viewed with caution, as it has also been shown that when constant fires take place, the most affected mammals are the canopy dwellers (Barlow and Peres 2006).

Overall, the GLM results only showed a significant relationship between spider monkeys and non-predation (i.e. there were fewer spider monkey groups in sites with no predation pressure compared to sites with predation of non-primates), but the rest of the threat variables were not adequate predictors for howler and spider monkey presence/absence or the number of groups. The one way-ANOVA showed no significant results when comparing mean landscape values within the areas that had different levels of hunting, predation and fire intensity. Nevertheless, when considering mean percentage of landscape attributes, there is an indication that in areas where these threat activities do not exist or are at their lowest, more primate groups were detected (Table 3.12). Interactions between the different threat variables were not explored in this study due to the limited number of replicates, but should be undertaken when more data is obtained, as they could possibly elucidate where factors act synergistically. Predator‑primate interactions remain understudied worldwide, particularly as they relate to forest loss and fragmentation, as a result of the challenges associated with investigating these relationships (Farris et al. 2014). This work is reporting the first assessment of the effects hunting, wildfires and natural predation have on primates in the Uxpanapa Valley, and is contributing towards understanding how and when they occur and the possible consequences for primates in the future. Unequivocally, further studies that can enhance our current knowledge on these variables need to be developed as a further step towards understanding what is determining howler and spider monkey distribution in the Uxpanapa Valley, and to enhance management policies in the area.

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3.7Annex 1

Participant information sheet, hunting questionnaire and non-hunter questionnaire

PARTICIPANT INFORMATION SHEET

Project: Hunting effects on Uxpanapa Valley primates

You are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

If you agree to answer the questions posed in this interview, you may at any time withdraw your participation. All interviewees will remain ANONYMUS, as the name of each person answering questions for this work will NOT be taken and thus will not be used in any way.

This project aims to obtain information on the number of animals that are hunted from forests and what these animals are used for (food or trade). This information will help us understand if there are sites in which this activity is more common than others and if that is related to animals being more present or absent.

This data collection forms part of a PhD research project, and the results will be published in a scientific journal, presented at congresses and will form part of a final PhD thesis.

You will answer questions on hunting and pet trade (e.g. what animals are hunted and in what quantity, if they are consumed or sold, where it is easier to find these animals, etc.).

Thank you for taking the time to read this information and if you wish to contact me in the future, you may write to Aralisa Shedden, email: arazitl@bournemouth.ac.uk

INTERVIEWS FOR OBTAINIG DATA ON HUNTING ACTIVITIES IN THE UXPANAPA VALLEY

Aralisa Shedden González
Bournemouth University
Centro de Investigaciones Tropicales

For hunters

1. Where do you originally come from?
2. What kind of monkeys are there near your land/in the forest nearest to you? (ID from photos)
3. What other animals are there in the forest where you find monkeys?
4. Do you consider there are many monkeys?
5. Is there the same amount of monkeys than before (5, 10 years ago)?
6. Do you have wild pets? What kind? How many?
7. Do you hunt?
8. Where did you learn to hunt?
9. How many times a week/month/year do you hunt?
10. What implements do you use to hunt?
11. Do you go by yourself or with other people?
12. What kind of animals do you hunt?
13. How many animals do you hunt?
14. If you go with other people, do they hunt as well? How many animals do they hunt?
15. What do you hunt them for?
16. If you sell them, how much do you get per animal? Where do you usually sell them?
17. If you eat them, what parts do you use?
18. Where do you usually hunt?
19. How far away is your hunting area?
20. Do you always use the same place?
21. Do you still find animals there?
22. Have you noticed a decrease in the number of animals you find?

For non-hunters

1. Where do you originally come from?
2. How many individuals are in your family?
3. Do you have wild pets? What kind? How many?
4. Do you eat bushmeat?
5. How many times a week/month/year?
6. What do you usually eat?
7. How many animals do you need to cook to feed your whole family?
8. Who hunts the animals you eat?
9. Have you ever bought bushmeat? If so, at what price?
10. Is it easy to buy bushmeat?
11. Do you own wild animal skins? Or do you use wild animals for any other purpose, such as medicinal?

3.8 Annex 2

Village	Population Size	Size (Km^2) Land owned by Village	Number of interviewees
5 DE MAYO	126	6.06	11
BENITO JUAREZ	178	9.06	16
BUENA VISTA	17	14.18	8
CONSTITUCION	73	17.67	4
DESENGANO	349	42.45	21
EL REMOLINO	257	17.75	14
FRANCISCO VILLA	105	9.10	12
HUEYAPAN	124	10.41	8
LAS BRUJAS (UX)	25	9.03	9
LAS MARGARITAS	80	15.52	8
LOPEZ RAYON	65	20.16	8
LOS CASTANOS/GALILEA	31	40.87	5
LOS LIBERALES	331	61.33	21
MURILLO VIDAL (CH)	72	34.82	18
NARCISO MENDOZA/NUEVO NARANJOS	130	10.33	10
NUEVO CORDOBA	118	18.49	10
NUEVO IXTACOMITAN/RIO PLAYAS	93	8.67	6
PASO DEL MORAL	104	22.34	14
PLAN DE IGUALA	278	37.02	12
POB 13	202	12.11	13
POB 15	241	41.41	14
POB 2	178	31.81	13
POB 3	39	10.86	9
PRIMITIVO (CH)	218	9.25	16
PRIMITIVO (UX)	74	22.87	10
PROGRESO 1	22	41.11	11
PROGRESO DOS (LOS CRUCES)	92	14.58	6
SALTA BARRANCA	73	23.19	11
SAN MIGUEL ALLENDE	357	28.22	12
SATURNINO CEDILLO	133	4.03	11

CHAPTER 4. Primates associated to bat indicator species: a potential for species-based conservation

Abstract

Indicator species are used to express biodiversity values within a region. To be considered as an "indicator species", a species must have a set of qualities that ensure that other taxa are represented, and also allow an assessment of ecosystem quality. In this sense, bats have been recognized as excellent indicators on a global level. However, bats are frequently perceived as undesirable by local villagers, so a species-based conservation approach centred on them would probably fail. Primates, on the other hand, are highly charismatic and have thus been considered as "umbrella species". By establishing the co-existence of bats and primates in specific sites, conservation efforts directed towards primates would benefit bats, as well as the biodiversity and ecosystems that bat species represent as indicators. In this study the main aim was to establish whether bats and primates were found in the same areas, and specifically, whether there was a relationship between endangered/highly habitat-specific bat species diversity and primates in my study site. Primate and bat data, such as presence, distribution and habitat type, were collected by different teams during 2010-2011 within 54 25km^2 plots in the Uxpanapa Valley. A series of GLM analysis were performed, and results show that bat species diversity was related to an increased number of spider monkey groups. Endangered bat species showed a much stronger positive association with spider monkey groups. Conversely, no association was found between bats and howler monkeys. The association between bats and spider monkeys could be due to their highly specific habitat requirements, and highlights the potential for primates to be used as umbrella species for bats and other taxa, both in Mexico and in the Neotropics.

4.1 Introduction

Finding appropriate taxa to indicate habitat quality is a complicated task, but using taxa as a conservation shortcut is common when conservationists need to prioritize areas with limited time and funds (Lambert 2011). In particular, where data on the distribution of species are inadequate, prioritization procedures must rely on surrogate measures of biodiversity (Tognelli 2005). Several definitions of "umbrella", "flagship", "keystone" and "indicator" species exist and their use is not always standardized (Verissimo et al. 2010), but their potential for conservation and management is undeniable. Primates have been considered as umbrella species due to their charismatic appeal (Mittermeier et al. 2005; Norconck et al. 2011), and recent studies have also shown their importance as seed dispersers and thus the role they play in forest composition, structure and regeneration (Chapman 2005; Link and di Fiore 2006; Nunez-Iturri and Howe 2007; Lambert 2011, Arroyo-Rodríguez et al. 2015), which links their conservation to forest maintenance. Additionally, primates are mostly large, easily observable, diurnal species (Meijaard and Nijman 2003), which makes the task of establishing their presence easier in comparison with many other taxa.

To maximize numbers of protected species across selected areas, the species richness of individual sites must also be accounted for (Arponen 2012). For example, a recent study revealed felids may be considered as umbrella species, benefiting primate conservation, due to overlap in distribution (Burnham et al. 2013). In Mexico, primates could potentially serve as umbrella species for species such as bats and jaguar, which are present in the Uxpanapa Valley, but have an unfavourable image with local inhabitants. While primates have been used to propose conservation sites in several countries (Smith et al. 1997; Hacker et al. 1998; Dinesen et al. 2001; Meijaard and Nijman 2003), their role as umbrella species has not yet been fully examined and this study provides an ideal setting to determine their potential.

Indicator species should be abundant, as well as ecologically, taxonomically and trophically diverse (Medellin et al. 2000) and in this sense bats comply.

Bats are the second most diverse Order of mammals and are characterized for being the only mammals that fly and use echolocation for locomotion navigation (Eisneberg, 1981; McSweeny et al. 2013). Bats have great ecological importance, due to their pollination activities as well as being natural pest control (McSweeney et al. 2013). Studies have also shown that bats can be indicators of habitat health, due to their taxonomic and functional diversity (Jones et al. 2009). Furthermore, their highly specialized needs in diet and habitat selection (Fenton et al. 1992) make them good indicators of the status of an environment (Medellin et al. 2000). The presence and abundance of specific bat species, such as *Lonchorhina* and *Lophostoma* from the Phyllostomidae family, provide information on habitat quality, as they are susceptible to habitat disturbance (McSwiney in prep.). The New World phyllostomids are recognized as important pollinators and seed dispersers for a number of ecologically and economically important plants (Jones et al. 2009). Bats can be suitable indicators of habitat disruption caused by deforestation, and one study showed that vegetation structure is related to the richness and diversity of bat communities in Mexican rainforests (Fenton et al. 1992). Species richness, the number of rare species and diversity were all positively associated with vegetation indices that were suggestive of low levels of forest disturbance. On the other hand, several studies have shown that transformed landscapes do not favour the richness or abundance of bats (Estrada 1993; Medellin et al. 2000; MacSwiney et al. 2007), while bat species richness and diversity (particularly Phyllostomidae) have been positively associated to larger fragment size and primary, undisturbed forests (Wilson et al. 1996; Gorresen and Willig 2004; Castro-Luna et al. 2009)

Frugivore bats that are found in tall evergreen forests show a marked preference for using *Ficus* species as their main feeding resource (Morrison 1980). This coincides with neotropical primates, including spider and howler monkeys (Wendeln et al. 2000). Bats have a significant effect on ecosystem processes through ecological interactions (Whittaker 1993). Bats disperse more seeds than birds (Medellin and Gaona 1999); they can also act as pest control for damaging insects and play a key role in pollination (Jones et al. 2009). Overall, bats are undoubtedly of great ecological importance, but also frequently have a negative public image (Mickleburgh et al. 2002). This study investigates whether howler and spider monkeys are associated to bat species, particularly those that are highly sensitive and endangered, within the Uxpanapa Valley, and also examines the potential for the use of these primates as umbrella species for bats, which are also important pollinators and seed dispersers within the forest (Jones et al. 2009). Nevertheless, bats have no conservation appeal to inhabitants of the Uxpanapa Valley (McSweeny, Pers. Comm.) and conservation efforts based on them might not be feasible. Generally, they are perceived as pests, mainly due to the presence of vampire bats that affect cattle (McSweeny, Pers. Comm.). Although education about bat importance might help, focussing conservation strategies on a charismatic species, such as primates, could be another way to tackle the issue. Associating the presence of specific bioindicator bat species to the presence of primates will further contribute to the selection of priority conservation sites within the Uxpanapa Valley and provide elements to develop species-based conservation projects. Furthermore, the association between specific bat guilds and primates will highlight how primates represent biological diversity, one of the most important factors to establish umbrella species.

4.2 Aims and objectives

Aim

Examine the distribution patterns of bat species present in the study site and compare with primate presence data. This will be addressed by analyzing the species and environmental information available for the Uxpanapa Valley.

Determine if the number of bat species and primate groups vary between the different vegetation types and climatic variables encompassed in the areas in which bats were found.

Objective

To test the hypothesis that primates can be effective umbrella species in the research area.

Specific activities

Determine if primate distribution and density correspond with bat species distribution and diversity.

Determine if areas with higher bat diversity hold higher number of primate groups.

Establish vegetation and climatological characteristics of areas in which bats are found.

Establish if endangered bat species diversity coincides with primate group presence.

4.3 Methods

Bats

All bat data from the Uxpanapa Valley were collected by Dr. Cristina McSwiney and her team, during the dry season (March to June), in 2010 and 2011, within a subset of 14 of the 54 randomly selected sites mentioned in the previous chapters. Each site was visited for three nights in a row, and two types of nets were used to collect the bats (5 mist nets at ground level, 1 mist net at canopy level), together with a harp trap; all bats were identified at species level and tagged before release (McSwiney et al. in prep.). Prior to 2010-2011, there were no data on bat species presences and distributions for the Uxpanapa Valley. McSweeny et al. (2013) captured 2014 individuals from 45 species which were classified in seven families during 2010-2011; eight of the captured species are considered to be threatened under the Mexican Endangered Species List (NOM-059) (Table 4.1). A full list of the bat species found can be viewed in Annex 1.

Table 4.1. Number of Uxpanapa Valley species found per vegetation category, and which are included within the Mexican Endangered Species categories: Pr (Endangered) and A (Threatened) (NOM-059-SEMARNAT-2010).

Family	Species	Habitat				Total	Status
		Secondary forest	Cave	Plantation	Tall forest		
Phyllostomidae	*Artibeus watsoni*	1		8	1	**10**	Pr
	Chotopterus auritus				1	**1**	A
	Lonchorhina aurita		6	14	10	**30**	A
	Lophostoma brasiliense			3	1	**4**	A
	Lophostoma evotis				2	**2**	A
	Mimon cozumelae	1			11	**12**	A
	Trachops cirrhosus	6		6	9	**21**	A
Thyropteridae	*Thyroptera tricolor*	1				**1**	Pr
Abundance		**9**	**6**	**31**	**35**	**81**	
Richness		**4**	**1**	**4**	**7**	**8**	

Bioclim and vegetation

BIOCLIM data were obtained from http://www.worldclim.org/ . Bat sample points were incorporated into the primate distribution map and 3 km buffers were established around these locations, to encompass both bat and primate home ranges. Percentage cover of the four vegetation types and the mean values of BIOCLIM variables for these 3 km buffers were calculated using ArcMap 10.1 and the Patch Analyst tool extension. BIOCLIM data were selected considering previous work has shown a relationship between species and these variables (Patten 2004) and consisted of BIO4 (Temperature

Seasonality (standard deviation *100)), BIO15 (Precipitation Seasonality (Coefficient of Variation)) and Altitude (mean per site); while vegetation consisted of mean percent cover of Secondary Forest (SF), Mature secondary Forest (MSF), Rubber Plantations (RP) and Tall Forest (TF).

Statistical analysis

I conducted analyses to establish 1) the relationship between bat diversity and primate group numbers, together with 2) the relationship between bat species diversity and BIOCLIM/vegetation type. For each data set, I created a 0 to 22 (maximum number of bat species found in a site) response variable in which 0 represents the absence of bats and the different numbers represent the total number of species found within each 3 km buffer. Species richness was then the dependent variable in the generalized linear models (GLMs) with a log link function and poisson error structure in R (Crawley, 2007), with number of primate groups, percent cover of the 4 vegetation types and the three BIOCLIM variables as the independent variables. A GLM with only environmental predictor variables was also run, to explore the effects these factors had, without the primate data. To account for multiple testing, the Bonferroni correction was used and only considered significant those results for which $P<0.025$.

The presence and diversity of bats was related to the number of primate groups, the landscape and the BIOCLIM data of the 14 sites where bats and primates were found using similar analytical methods as used in previous chapters.

A full model was run with all predictors included using the library MASS (Venables and Ripley, 2002) and then used the function 'dredge' in the package MuMIn to select the best model based on Akaike's Information Criterion (AIC). In order to determine the ability of the model to explain the variation in the data, I compared the fit of the best model selected against a null model that included only the intercept, using a likelihood ratio test. All statistical analyses were carried out R 2.15.1(R Core Team, 2012). Additionally, I examined the relationship between the abundance of the 8 endangered/indicator bat species found and the number of primate groups present at each site with the same GLM method mentioned above.

Endangered bat species were targeted in my tests, as they are highly sensitive to habitat alteration and have specific habitat requirements (Medellin et al. 2000).

4.4 Results

Relationship between bat species diversity and primate groups

Bats and primates were present in 14 plots, a total of 45 bat species were found and ranged from 2 to 22 species in the sampled plots (Figs. 4.1, 4.2). The general linear model showed that bat species diversity was positively associated with the number of Spider monkey groups (S.Groups) and negatively associated with the percent cover of Secondary Forest (SF) and Rubber Plantations (RP) (Table 4.2). However, when the Bonferroni correction for multiple analysis was applied, Secondary Forest was no longer significant.

Table 4.2. General GLM results show higher bat species diversity is positively linked to more Spider monkey groups (S.Groups), while the percentage cover of both Secondary Forest (SF) and Rubber Plantations (RP) negatively relate to the number of bat species in the sampled sites.

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	13.39908143	12.79854677	1.046922098	0.295135509	
H.GROUPS	0.100253168	0.104005199	0.96392458	0.33508374	
S.GROUPS	0.23903334	0.081357448	2.938063409	0.003302695	**
BIO4	-0.007280447	0.005209773	-1.397459462	0.162275449	
BIO15	0.082796275	0.068632095	1.206378369	0.227671632	
ALT	-0.000937158	0.002835594	-0.330498128	0.741023607	
SF	-2.135156217	1.061964161	-2.010572762	0.044370604	-
MSF	-2.037808663	1.435388622	-1.419691247	0.155697587	
RP	-12.87573555	4.820933355	-2.670797251	0.007567134	**
TF	-2.245814692	1.490600176	-1.5066513	0.131900061	

Null deviance: 49.153 on 13 degrees of freedom, Residual deviance: 15.845 on 4 degrees of freedom, AIC: 94.032. *Significant after application of Bonferroni correction.

The output of the best selected model confirms bat species diversity positively associated with the number of Spider monkey groups, such that higher bat species richness is found in sites with more Spider monkey groups. Bat species diversity is also positively associated to Rainfall Seasonality (BIO15), but negatively associated to the percentage cover of Mature Secondary Forest (MSF) (Table 4.3) (Figs. 4.3, Fig. 4.4, 4.5). All variables are significant after applying Bonferroni corrections.

Table 4.3. The best model output shows Spider monkey groups (S. Groups) and Rainfall Seasonality (BIO15) are significantly associated to bat species diversity while percentage cover of Mature Secondary Forest (MSF) is negatively associated to bat species diversity.

	Estimate	Std. Error	z value	Pr(>|z|)	Lower CI	Higher CI	
(Intercept)	-6.49559435	3.0469076	-2.13186457	0.03301798	-12.606	-0.609	-
S.GROUPS	0.18758538	0.04158092	4.51133331	6.44E-06	0.106	0.269	***
BIO15	0.15919739	0.05457984	2.91678034	0.00353665	0.053	0.268	**
MSF	-1.69587802	0.60130018	-2.82035178	0.0047971	-2.921	-0.560	**

Null deviance: 49.153 on 13 degrees of freedom. Residual deviance: 24.690 on 10 degrees of freedom. AIC: 90.877
*Significant after application of Bonferroni correction

The GLM run exclusively with environmental predictor variables showed that bat species diversity presented a significant negative association to Rubber Plantations (RP).

Table 4.4. The GLM without primate variables, shows higher bat species diversity are negatively associated to Rubber Plantations (RP).

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	3.619980089	14.02493271	0.258110336	0.796321755	
BIO4	-0.001518651	0.004860797	-0.3124285	0.754714893	
BIO15	0.057482171	0.099008162	0.580580123	0.561523472	
ALT	-0.001587011	0.003065624	-0.517679709	0.604681758	
SF	-1.852014856	1.085458369	-1.706205331	0.087969857	
YSF	6.376417464	26.51710583	0.240464306	0.809970331	
MSF	-2.669026169	1.53578844	-1.737886612	0.082230795	
RP	-10.99259395	4.851836691	-2.265656215	0.02347244	*
TF	0.395082376	1.451553606	0.272178977	0.785484406	

Null deviance: 49.153 on 13 degrees of freedom, Residual deviance: 28.214 on 5 degrees of freedom, AIC: 104.4. *Significant after application of Bonferroni correction

The best selected model which included only environmental variables, showed bat species diversity was positively associated to Tall Forest (TF).

Table 4.5. Best model selection output shows a high, positive association between higher bat species diversity and Tall Forest (TF).

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	2.213752542	0.118246413	18.7215197	3.31E-78	***
TF	1.070401753	0.305470674	3.504106431	0.000458142	***

Null deviance: 49.153 on 13 degrees of freedom, Residual deviance: 38.141 on 12 degrees of freedom, AIC: 100.33. *Significant after application of Bonferroni correction

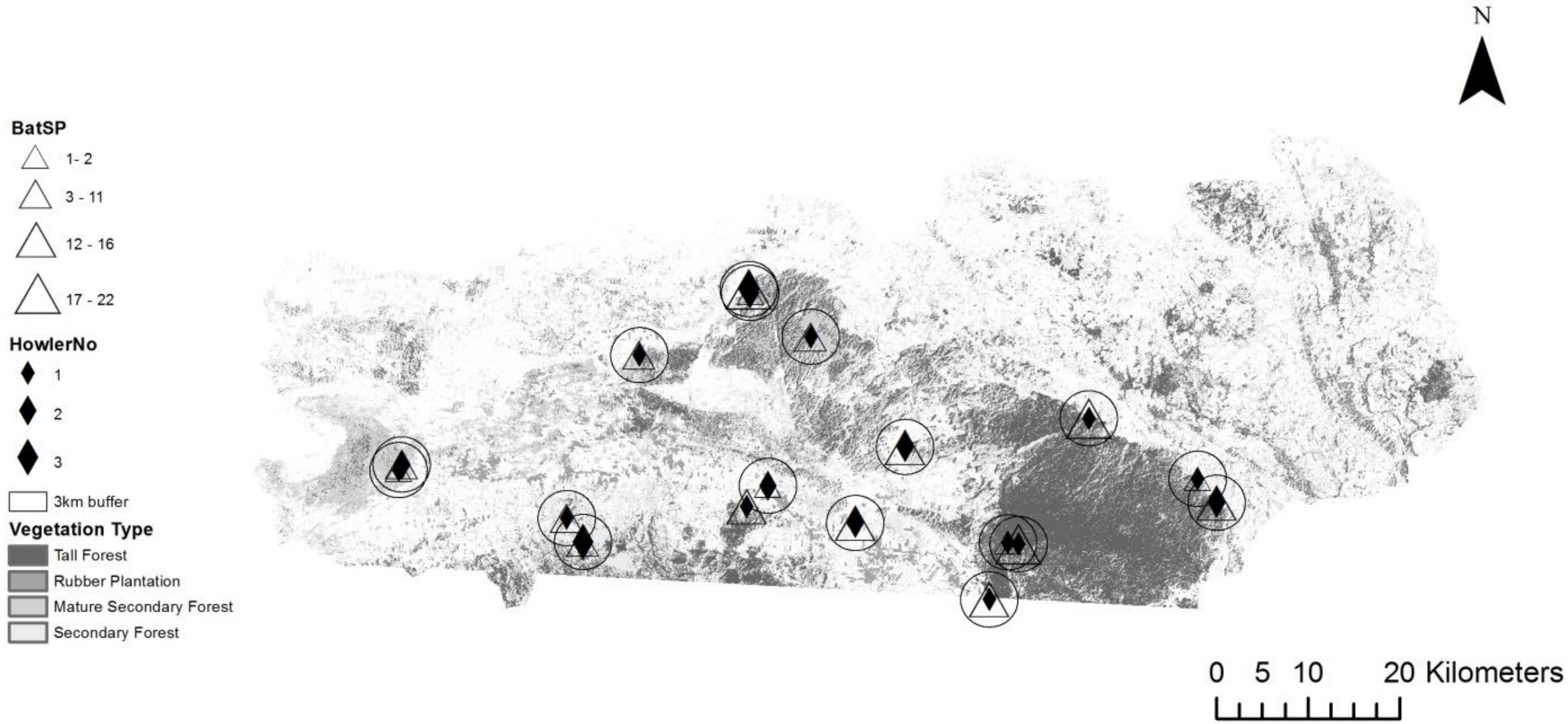

Fig.4.1 Location of bat capture sites, triangles indicate number of species recorded (range from 1-22), diamond shape indicate howler monkey groups present per site (range from 1-3) and transparent circles indicate the 3 km buffers. Forest type is represented by grey shades, darkest being most conserved forest and lightest the least conserved.

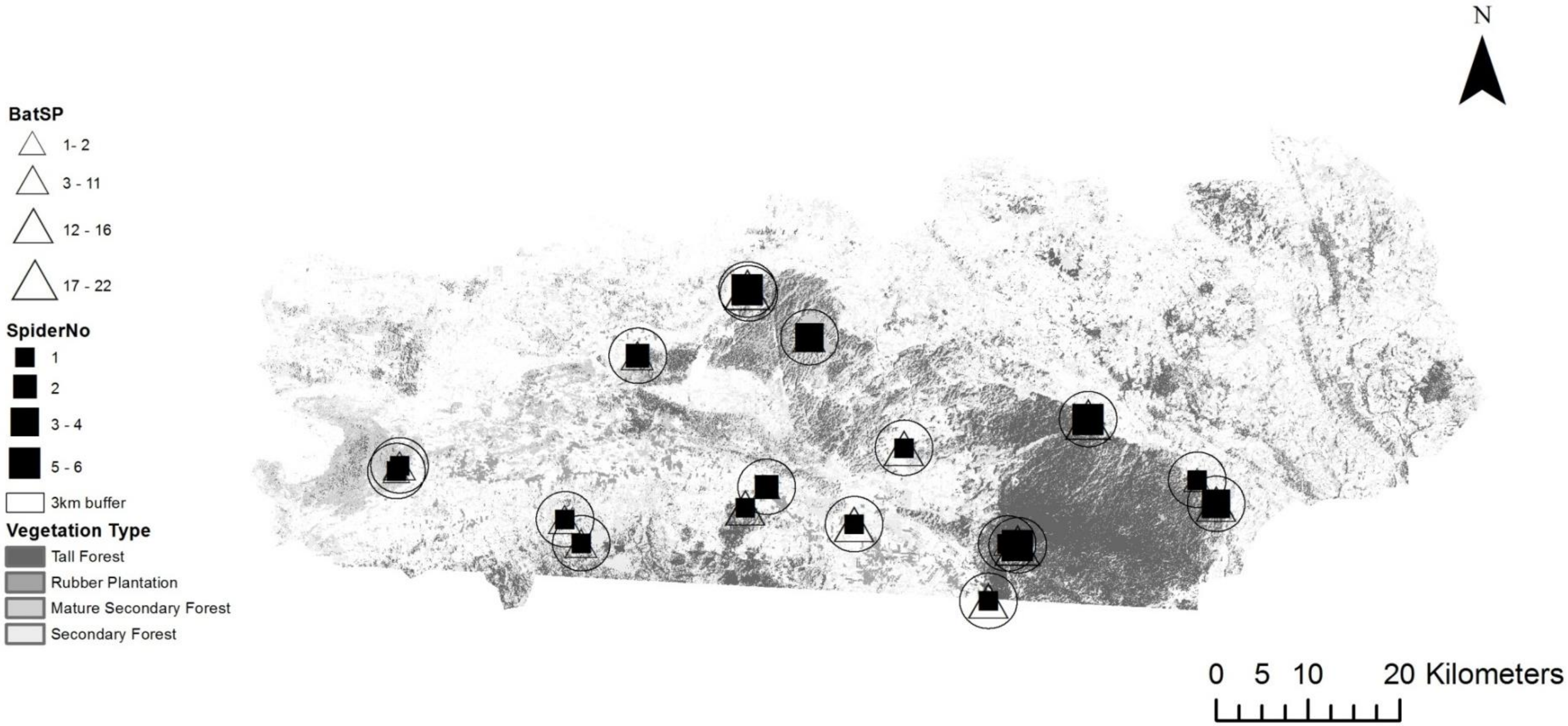

Fig.4.2 Location of bat capture sites, triangles indicate number of species recorded (range from 1-22), squares indicate spider monkey groups present per site (range from 1-3) and transparent circles indicate the 3 km buffers. Forest type is represented by grey shades, darkest being most conserved forest and lightest the least conserved.

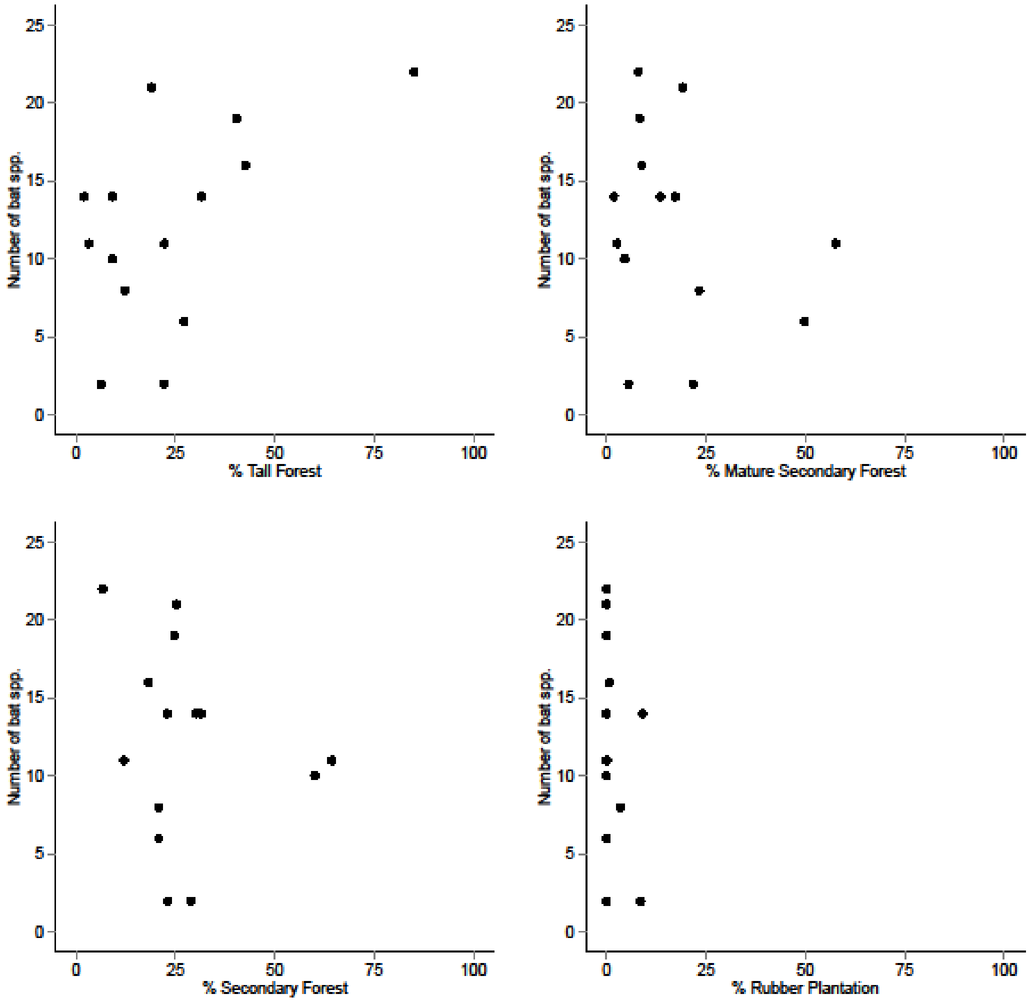

Fig. 4.3 Number of bat species distributed according to percentage of vegetation cover types in the sampled sites.

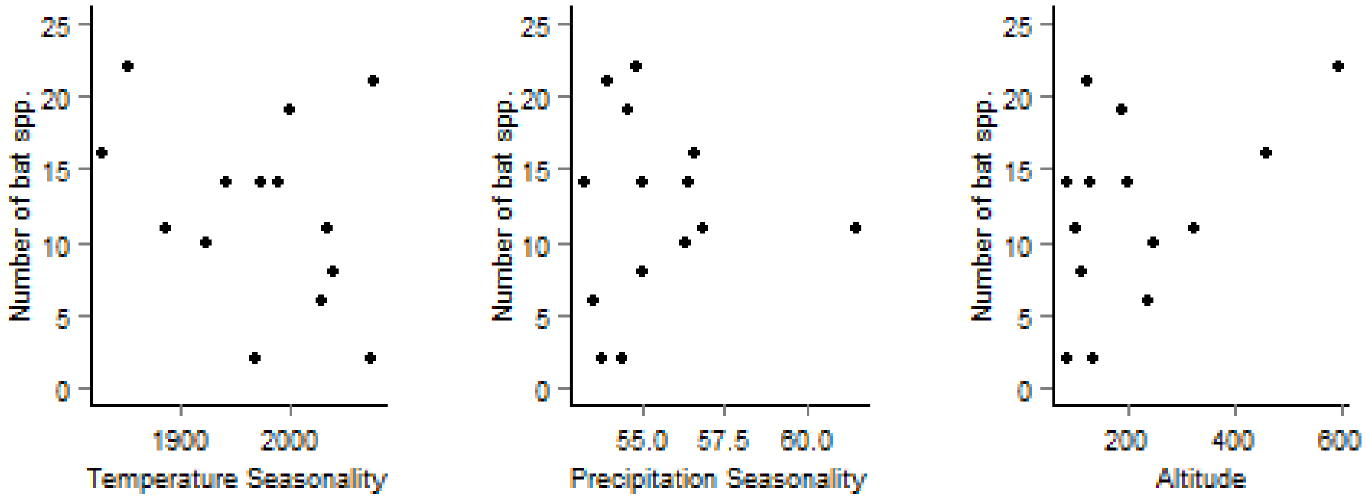

Fig. 4.4 Number of bat species distributed among the different BIOCLIM variables Temperature Seasonality (BIO4), Precipitation Seasonality (BIO15) and Altitude (ALT).

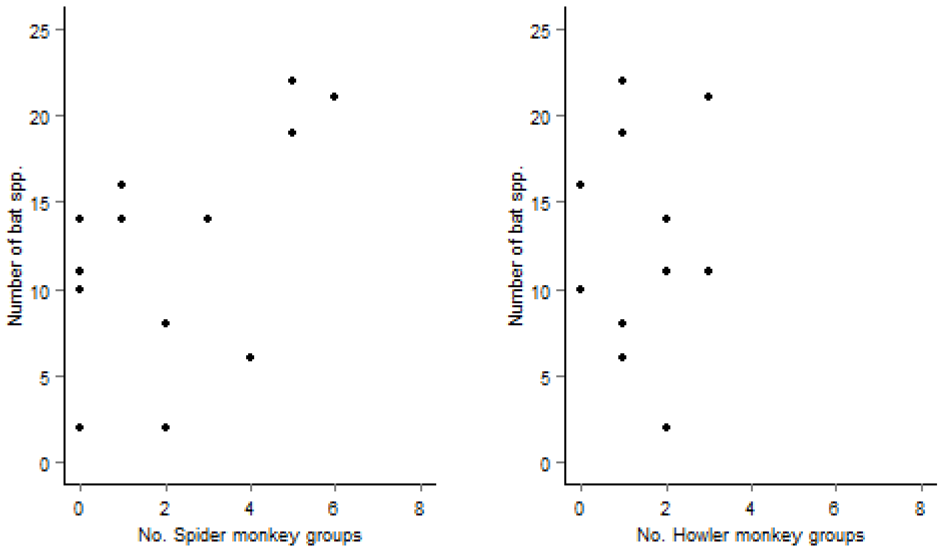

Fig. 4.5 Distribution of number of bat species plotted against the number of spider and howler monkey groups.

Endangered bat species and primate groups

A total of 8 endangered and indicator bat species were found distributed among 9 of the plots (Figs. 4.6, 4.7).

The endangered bat GLM showed a positive association between number of endangered bat species and Precipitation Seasonality (BIO15), as well as negative relationship with percent cover of Secondary Forest (SF) and Mature Secondary Forest (MSF) (Table 4.6). However, when the Bonferroni correction for multiple analysis was applied, only Mature Secondary Forest remained significant.

Table 4.6. GLM results show endangered bat species are associated to Precipitation seasonality (BIO15) and are negatively related to percentage cover of MSF (Mature Secondary Forest) and RP (Rubber Plantations).

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-45.56997638	27.27380626	-1.670833031	0.094754662	
H.GROUPS	0.767001274	0.534960894	1.433752042	0.151643035	
S.GROUPS	0.224092764	0.23236496	0.964399987	0.334845429	
BIO4	0.011275755	0.008391435	1.34372194	0.17903832	
BIO15	0.59910219	0.304052798	1.970388675	0.048793842	-
SF	-16.21635224	7.38540735	-2.195728884	0.028111354	-
MSF	-34.58530747	13.63139137	-2.537181021	0.011174915	*
RP	-44.65389935	24.08806562	-1.853776889	0.063771086	
TF	-4.717396571	3.520149788	-1.340112454	0.180208788	

Null deviance: 77.6425 on 13 degrees of freedom, Residual deviance: 7.0822 on 5 degrees of freedom, AIC: 53.271. *Significant after application of Bonferroni correction

The results of the best model for endangered bat species are similar to the general bat model, also showing a positive association between endangered bats species diversity and greater number of spider monkey groups present in the sampled sites. Percent cover of Mature Secondary Forest (MSF) was negatively associated with endangered bat species diversity (Table 4.8) (Fig. 4.8) (Fig. 4.9) (Fig. 4.10).

Table 4.7. The best model output for endangered bat species shows high association with greater number of spider monkey groups (S.Groups) and a negative relationship with percent cover of MSF (Mature Secondary Forest)

	Estimate	Std. Error	z value	Pr(>|z|)	Lower CI	Upper CI	
(Intercept)	0.63682	0.36638143	1.73813	0.08218	-0.135	1.308	
S.GROUPS	0.50208	0.079078528	6.34915	2.17E-10	0.354	0.666	***
MSF	-7.69170	2.396443842	-3.2096	0.00132	-12.960	-3.577	**

Null deviance: 77.643 on 13 degrees of freedom, Residual deviance: 17.250 on 11 degrees of freedom, AIC: 51.439. *Significant after application of Bonferroni correction

The GLM which examined only environmental predictor variables showed that endangered bat species diversity presented a significant negative association to Mature Secondary Forest (MSF) (Table 4.8).

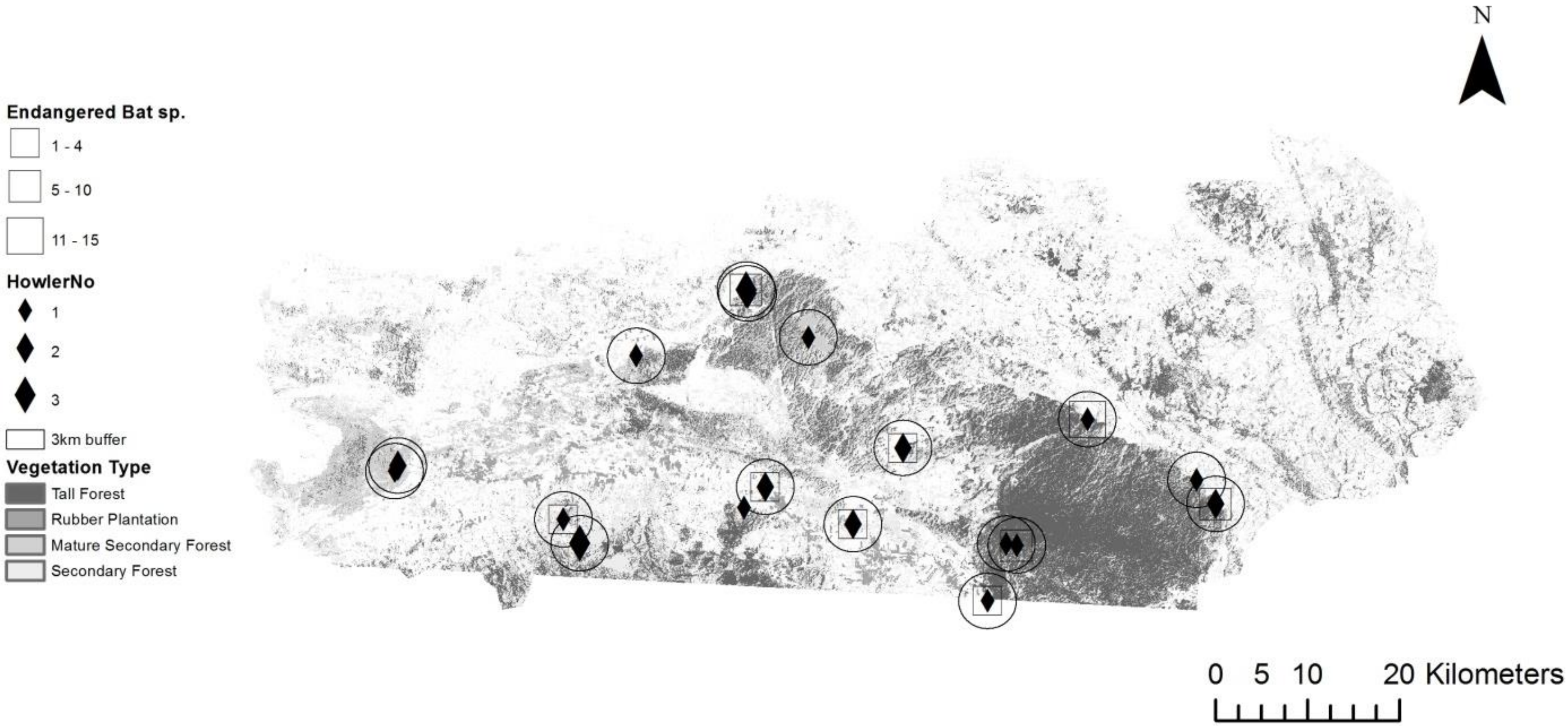

Fig.4.6 Location of endangered bat capture sites, squares indicate number of species recorded (range from 1-15), diamond shape indicate howler monkey groups present per site (range from 1-3) and transparent circles indicate the 3 km buffers. Forest type is represented by grey shades, darkest being most conserved forest and lightest the least conserved.

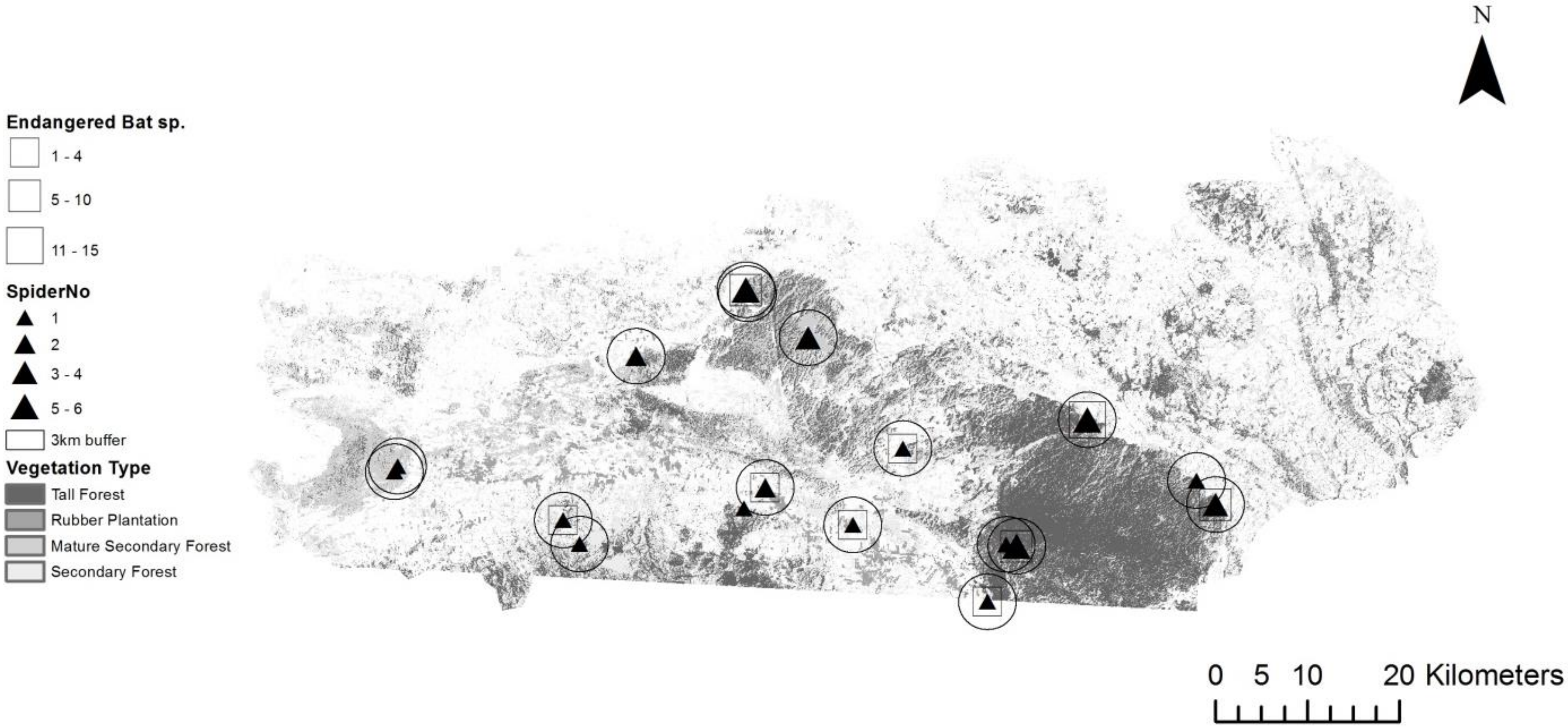

Fig.4.7 Location of endangered bat capture sites, squares indicate number of species recorded (range from 1-15), triangle indicate spider monkey groups present per site (range from 1-3) and transparent circles indicate the 3 km buffers. Forest type is represented by grey shades, darkest being most conserved forest and lightest the least conserved.

Table 4.8. The GLM without primate variables, shows higher bat species diversity are negatively associated to Mature Secondary Forest (MSF).

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-61.17627778	47.97233154	-1.275240869	0.202224	
BIO4	0.0215657	0.015459974	1.394937616	0.163034653	
BIO15	0.472719756	0.37222884	1.269970798	0.204095032	
ALT	0.001579411	0.007880426	0.200421993	0.841150561	
SF	-11.0311992	5.211039851	-2.116890201	0.034269167	-
MSF	-24.681111	9.65189694	-2.557125418	0.010554116	*
RP	-22.88035636	12.71959931	-1.798826818	0.07204608	
TF	-0.952459419	4.300826308	-0.221459634	0.824734564	

Null deviance: 77.643 on 13 degrees of freedom, Residual deviance: 15.268 on 6 degrees of freedom, AIC: 59.457. *Significant after application of Bonferroni correction

The best selected model which included only environmental variables, showed endangered bat species diversity was highly positively associated to Tall Forest (TF), but negatively associated with Mature Secondary Forest (MSF) and Altitude (ALT) (Table 4.9).

Table 4.9. Best model selection output shows a high, positive association between higher endangerd bat species diversity and Tall Forest (TF) and negative association to both Mature Secondary Forest (MSF) and Altitude (ALT).

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	1.884542096	0.386637727	4.874180562	1.09E-06	***
ALT	-0.01138087	0.002159544	-5.270033098	1.36E-07	***
MSF	-5.777972381	2.214332969	-2.609351196	0.009071409	**
TF	8.927450855	1.460882733	6.110997585	9.90E-10	***

Null deviance: 77.643 on 13 degrees of freedom, Residual deviance: 21.037 on 10 degrees of freedom, AIC: 57.226. *Significant after application of Bonferroni correction

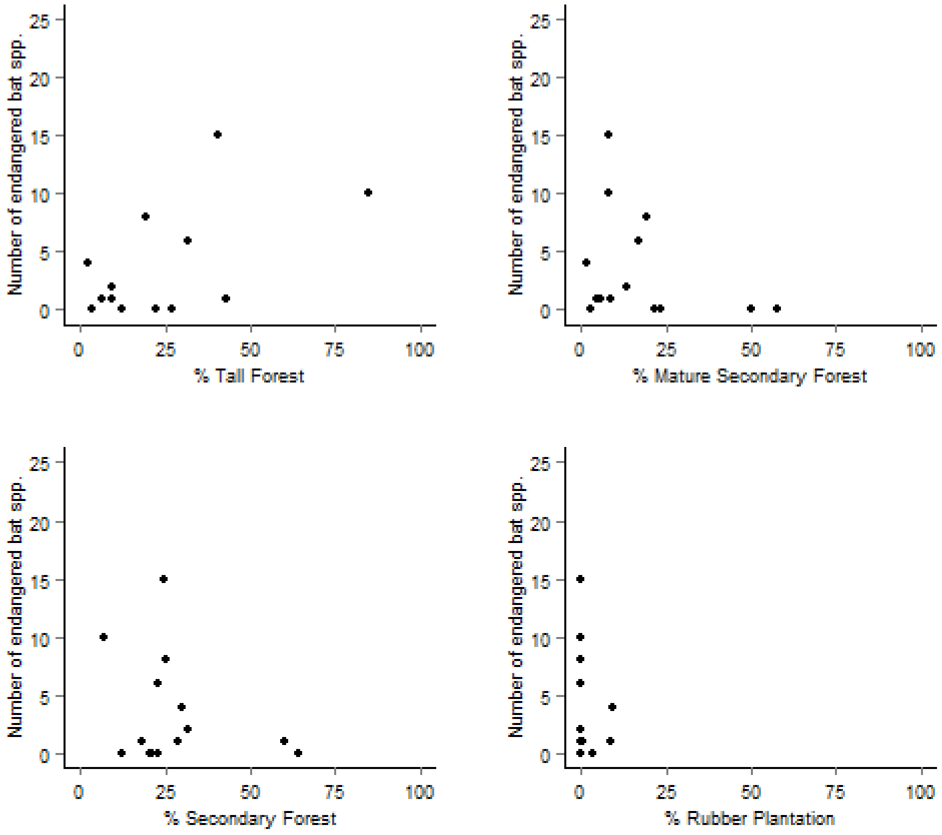

Fig. 4.8 Number of endangered bat species distributed according to percentage of vegetation cover types in the sampled sites.

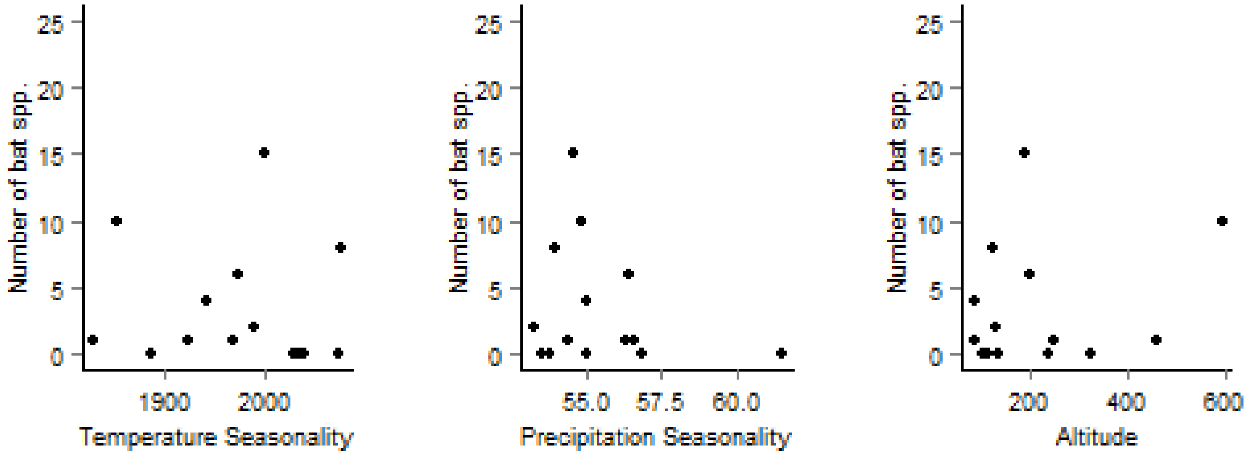

Fig. 4.9 Number of endangered bat species distributed among the different BIOCLIM variables Temperature Seasonality (BIO4), Precipitation Seasonality (BIO15) and Altitude (ALT).

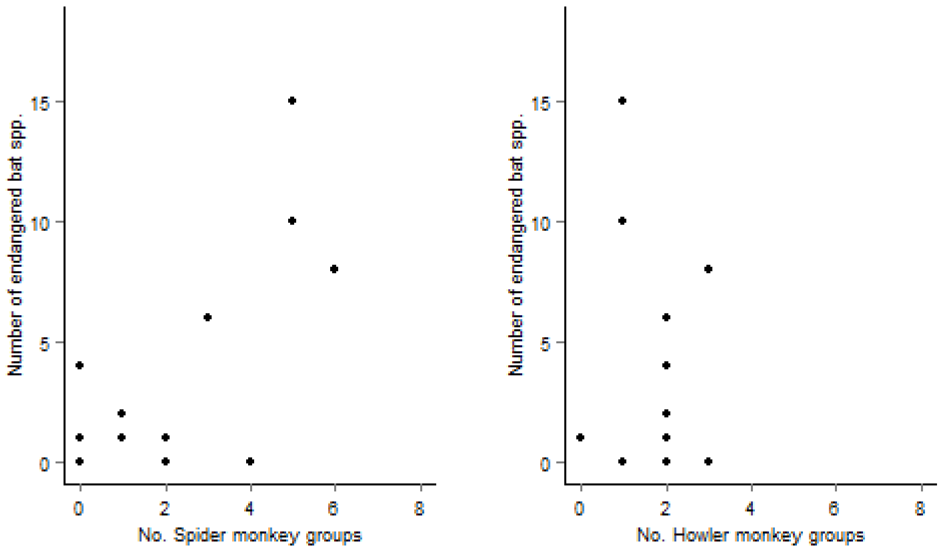

Fig. 4.10 Distribution of number of endangered bat species plotted against the number of spider and howler monkey group

Table 4.10. The number of bat species, endangered bat species, howler monkey groups and spider monkey groups found per each buffer within the study site.

Buffer No.	No. Bat Sp	No. Endangered Bat Sp	No. Howler Monkey Groups	No. Spider Monkey Groups
1	2	0	0	0
2	11	0	0	2
3	11	0	0	3
4	8	0	2	1
5	2	0	0	2
6	21	8	6	3
7	2	1	2	2
8	6	0	4	1
9	14	4	0	2
10	14	2	1	2
11	16	1	1	0
12	22	10	5	1
13	19	15	5	1
14	2	0	0	0
15	14	6	3	2
16	10	1	0	0

4.5 Discussion

With this chapter, I intended to establish whether Mexican primates can be used as umbrella species, by relating their distribution and group size to bat species diversity. Certain bats guilds are highly specialized regarding habitat preferences and are also considered excellent indicators of ecosystem health (Medellin et al. 2000; Jones et al. 2009). By identifying a relationship between bat species diversity and, particularly, endangered bat species with presence of spider and howler monkey groups, I can enhance the results I obtained in past chapters and provide conservation recommendations for specific sites within my study area (e.g. maintaining larger tracts of tall forest, promoting fragment connectivity with native tree species and develop educational workshops for local villagers on species conservation). This example may also contribute towards adding value to conservation efforts made towards Atelid primates in Mesoamerica and the Neotropics, also showcasing to what extent primates can represent biodiversity.

The analyses showed that areas with higher bat species diversity also had greater numbers of spider monkey group. However, no relationship was found between bats species diversity and the number of howler monkey groups. These findings further demonstrate the capacity of howler monkeys to live in a wide range of habitats and exploit a range of resources, even within small fragments that contain limited availability of tree species used for daily activities (Cristobal-Azcarate and Arroyo-Rodriguez 2007; Pozo-Montuy et al., 2008; Di Fiore et al., 2011). In contrast, spider monkeys heavily rely on larger trees, have a specialist fruit diet and need larger areas for movement (Chaves et al., 2012; Youlatos, 2002). Tall Forest was a clear driver for both endangered and general bat species diversity and the subsequent association found between bats and spider monkeys suggests that spider monkeys and bats have similar habitat requirements.

There was a negative relationship between bat species diversity and Mature Secondary Forest. On a broader scale, it has been established that relationships between bat species richness and either annual temperature range or vegetative cover do not conform to predictions as well as other variables, such as rainfall, did (Patten 2004). However, another study with a smaller sample size (12 sites) showed that bat species richness increased through the successional process in an additive manner, reaching greatest diversity in old-growth forest (Avila-Cabadilla et al. 2009). Bat assemblages with lower species richness, diversity and abundance were found in early and intermediate successional stages of vegetation, whereas greater species richness and abundance were found in old-growth forest (Pena-Cuellar et al. 2012). In our study site, MSF has not fully transitioned into Tall Forest, thus plant and tree species may be less diverse or smaller in size, causing certain fruit trees which either bats or their prey rely on, to either not be present or fully mature. Bats are also highly selective of habitats because of roost area characteristics and variations in humidity, temperature and air flow, among others, determine which sites they choose (Boyles 2007; Avila-Flores and Medellin 2004). In this sense, MSF may contain microclimatic features that are inadequate for bats. Furthermore, results of the environmental-specific GLM show that endangered and general bat species diversity is positively related to the percentage cover of Tall Forest. These results possibly corroborate how habitat-specific bat species can be, as well as highlighting the importance of Tall Forest maintenance for bat conservation. Nonetheless, additional studies should be carried out to examine on a finer scale what the drivers are behind bat species diversity in Uxpanapa Valley.

The endangered bat species showed a significant positive association with spider monkey groups and a negative association with MSF and Altitude. As mentioned above, this negative relationship between endangered bat species and Mature Secondary Forest may be due to the reduced size or diversity of certain plant and tree species which the bats or their prey use. Additionally, a specific set of microclimate variables may be occurring within MSF, forming a niche which doesn't favour bat presence or diversity. The endangered bat species were also found to be negatively associated to Altitude, suggesting that in areas in which there was higher elevation, it was less likely to find higher endangered bat species diversity. Elevation has been positively linked to bat species richness, but the relationship was moderate and did not fully explain variation in families such as Phyllostomidae (Patten 2004). On the other hand, bat species presence generally decreased as elevation increased in the Peruvian Andes, possibly due to reduction in temperature, foliage height diversity and food abundance (Graham 1990). Although the maximum altitudinal variation in my study site (500m) was much less than that of Graham's study (2800m), it is highly likely that slight temperature and rainfall variations occur within the altitude gradient of the Uxpanapa Valley, as it has been shown that even slight shifts in slope aspect can produce changes in temperatures of up to 7°C (Suggitt et al. 2011). Thus, bat presence and species diversity may be linked to micro-climatic variations within the region. Further studies on a finer scale should be conducted, in order to evaluate the impact climatic and topographical variables have on bat species richness and distribution in Uxpanapa Valley. Furthermore, these variables should also be examined on a finer scale for primates, as they could potentially be regulating their presence and distribution.

Overall, there was an undeniable relationship between bat species diversity and the number of spider monkey groups present, particularly for endangered and highly sensitive bats, despite the relatively small sample size. The broad vegetation classification used to establish forest cover type may not reflect distinctive characteristics, such as tree species diversity, which impact both these species, and it is likely that more refined analyses would uncover a particular set of variables which promote their presence and regulate their distribution. The Uxpanapa Valley is considered to be one of the most biodiverse areas in Mexico (WWF, 2007) and is the most northern part of the Selva Zoque forest extension. A recent survey determined that the mammalian fauna found in the Selva Zoque is composed of 149 species belonging to 99 genera and 30 families, further supporting that the region is the richest in the number of mammalian species in Mexico (Lira-Torres et al. 2012). In addition to bats, in our study site we found primates to be co-habiting with highly endangered species such as: tapir and large felines (e.g. jaguar and puma) (JMW Day unpublished data) and birds (e.g. blue headed parrot, Muscovy duck, scarlet macaw) (C Tejeda unpublished data). With these results I highlight the importance of conserving the areas in which spider monkeys are distributed, as a means for conserving other endangered species.

Although bats may be unsuitable for developing species-oriented conservation strategies in our study site, due to the ‘pest’ image they have with local inhabitants (C. McSweeny pers. com.), their importance and use as disturbance indicators is widely recognized and being adopted in other areas, including several Mexican Biosphere Reserves (Medellin et al. 2000). Using spider monkeys as an umbrella species provides possibilities not only for conserving bats and their habitat, but to ensure the protection of the biodiversity bats represent. This strategy could be useful for designing conservation programs within the distribution range of spider monkeys and for re-examining the role primates can play in conservation.

4.6 References

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4.7 Annex 1

Family	Species	Total captured	Diet
Emballonuridae	*Balantiopteryx io*	19	Insectivore
	Peropteryx macrotis	7	Insectivore
	Saccopteryx bilineata	2	Insectivore
Molossidae	*Molossidae* sp.	2	-
	Molossus rufus	1	Insectivore
Mormoopidae	*Mormoops megalophylla*	8	Insectivore
	Pteronotus davyi	7	Insectivore
	Pteronotus parnellii	69	Insectivore
	Pteronotus personatus	2	Insectivore
Natalidae	*Natalus stramineus*	13	Insectivore
Phyllostomidae	*Artibeus aztecus*	2	Frugivore
	Artibeus jamaicensis	217	Frugivore
	Artibeus lituratus	209	Frugivore
	Artibeus phaeotis	58	Frugivore
	Artibeus toltecus	9	Frugivore
	Artibeus watsoni	10	Frugivore
	Carollia perspicillata	51	Omnivore
	Carollia sowelli	349	Frugivore
	Centurio senex	14	Frugivore
	Chiroderma villosum	4	Frugivore
	Choeroniscus godmani	1	Nectarivore
	Chotopterus auritus	1	Carnivore
	Desmodus rotundus	130	Hematophag
	Diphylla ecaudata	8	Hematophag
	Glossophaga morenoi	6	Nectarivore
	Glossophaga soricina	91	Nectarivore
	Glossophaga sp.	3	-
	Hylonycteris underwoodi	10	Nectarivore
	Lonchorhina aurita	30	Insectivore
	Lophostoma brasiliense	4	Insectivore
	Lophostoma evotis	2	Insectivore
	Micronycteris microtis	9	Insectivore
	Mimon cozumelae	12	Carnivore
	Phyllostomus discolor	6	Omnivore
	Platyrrhinus helleri	6	Omnivore
	Sturnira lilium	397	Frugivore
	Sturnira ludovici	163	Frugivore
	Trachops cirrhosus	21	Omnivore
	Uroderma bilobatum	3	Omnivore
	Vampyrodes caraccioli	117	Frugivore
Thyropteridae	*Thyroptera tricolor*	1	Insectivore
Vespertilionidae	*Bauerus dubiaquercus*	2	Insectivore
	Lasiurus blossevillii	1	Insectivore
	Myotis keaysi	12	Insectivore
	Nycticeus humeralis	15	Insectivore

CHAPTER 5. Priority conservation site selection based on primate distribution

Abstract

Protected Areas (PAs) have become one of the most important tools for conservation over the past decades, and their establishment should ideally involve careful planning and include studies on species within the area. Nevertheless, and particularly in developing countries, PAs are often established without careful planning or analyses of their biodiversity potential/ worth. Systematic Conservation Planning is a method that helps in creating PAs to optimize resources and conservation efforts. Multi Criterion Analysis (MCA) is a tool that provides support in decision making and planning. In this study, an MCA based approach was used to a) identify priority conservation sites based on the combined spider monkey, howler monkey and bat species distributions, together with environmental data that was found to be associated with their presence, b) identify priority conservation sites based solely on howler monkey distribution and associated environmental factors, and c) identify priority conservation sites centred only on spider monkey distribution and the linked environmental data. Posteriorly, comparisons were performed between each of the outputs and found that when site selection was based on spider monkey distribution, the size and location of "High" priority areas remained the most constant despite user-defined changes in the factors that were used to select the sites. Conversely, when site selection was based on the combined species or howler monkeys data, output scenarios varied considerably. Additionally, spider monkey areas always intersected with howler monkey and bat species areas, showing spider monkeys can be effective species for site selection and zoning within a PA. Overall, the results from this work provide supporting evidence for developing species based conservation strategies for selecting priority conservation sites in tropical forests.

5.1 Introduction

During the past decade, a wide array of concepts and methods have been proposed to guide policies and prioritize conservation resources, generally using different taxa and/or criteria, but focussing mainly on species irreplaceability and vulnerability (Davenport et al. 2014). In the tropical forest regions, the establishment of Protected Areas (PAs) has been one of the most amply used tools for conserving biodiversity, with PAs currently covering around 27.1 % of the total tropical forest extension (Nelson and Chomitz 2011). Nevertheless, many PAs have been created opportunistically (González-Maya et al. 2015) in locations that do not necessarily contribute towards biodiversity conservation (Margules and Pressey, 2000). Systematic Conservation Planning (SCP) has been proposed to provide guidance to avoid this situation (Margules and Pressey, 2000). Over the last two decades, the application of SCP have expanded rapidly, widely influencing conservation priorities and government policy decisions (Botrill and Pressey 2012). Within the broader context of SCP, there is an essential biogeographic-economic analysis, frequently called spatial conservation prioritisation, which is used to identify where important areas for biodiversity are and how conservation goals might be attained (Kukkala and Miolanen 2013). Although spatial conservation prioritization by definition prioritizes locations for conservation actions rather than species, species occurrences determine the importance of each location-action-combination (Arponen 2012). Selection of priority sites for primate conservation has been used in Tanzania, by considering primates as an umbrella species to conserve biodiversity (Davenport et al. 2014, Dinesen 2001). Primates have also been considered as an umbrella species in Uganda (Lambert 2011) and as proxy for felid conservation in Africa, Asia and the Neotropics (Macdonald et al. 2012).

The availability and use of digital geographic data and decision-making tools have increased the development of geographic analyses that can assist in decision making and land-use planning (López-Marrero et al. 2011). Geographic Information Systems (GIS) and Multi-criteria evaluation (MCE), (also called multi criteria analysis, MCA), are two examples of tools that aid in the development of geographic data and maps for different conservation purposes (López-Marrero et al. 2011). MCA facilitates the implementation of decision-making rules to identify and enable the combination of many criteria, in the form of GIS layers, into a single map. For example, it has been found that the GIS-based MCA framework supports the objective identification of priority locations for conservation by integrating multi-source spatial data and providing visualisation capabilities to better understand how protected area networks might be developed (Wood 2007).

The capacity of GIS to handle spatial aspects of conservation has increased its use in the evaluation for prioritization and selection of potential conservation areas (Phua and Minowa 2005). The GIS-based multi-criteria decision making approach is simple and flexible and any number of criteria and indicators can be employed, although those involved in the weight assignment may face difficulty in assigning these weights (Phua and Minowa 2005). Thus, MCA provides a systematic methodology to combine varied inputs with cost/benefit information and stakeholder views to rank project alternatives (Huang et. al 2011). Many approaches identify as MCA, each involving different protocols for eliciting inputs, structures to represent them, algorithms to combine them, and processes to interpret and use formal results in actual advising or decision making contexts. In their review, Huang et al. (2011) showed that use of MCA has increased greatly over the past decade, and has been applied to areas such as management of natural resources, waste, water and air quality, as well as to restoration and strategy implementation, amongst others.

Although most GIS systems have limited capabilities for performing MCA, some notable exceptions include IDRISI, Common GIS, ILWIS and TNT-GIS (Malczewski 2010). ILWIS (Integrated Land and Water Information System) is a software tool that supports MCA. Some of the latest examples of the use of ILWIS for conservation purposes are: priority conservation site selection in Cameroon (Tchouto et al 2006), conservation planning and reforestation for an endangered pine species in Mexico (Leal-Nares et al. 2012), identifying priority sites for landscape restoration in southern Mexico

(Orsi and Geneletti 2010), landscape management in Italy (Geneletti 2007) and regional environmental quality assessment for recovery and protection of areas in China (Rahman et al 2014), amongst others. The spatial MCA process in ILWIS uses geographical data as an input and transforms it into a decision (output). In this sense, the input is a series of maps from the same area, representing all criteria/factors (both positive and negative) and a criteria tree which contains all the factors' weights and standardizations (Rahman et al. 2014). The output consists of one or more maps of the same area (composite index maps) that indicates the extent to which criteria are met or not in different areas, and thereby, supports planning and/or decision making (Rahman et al. 2014).

In this study, with the aid of systematic conservation planning, I aim to select priority sites for conservation based on primate data. In chapters 3 and 4, I found that primates coexist with large cats such as jaguar and puma, as well as with bats, and found a particularly strong association between endangered bats and spider monkeys. By selecting priority sites for conservation based on primates, I expect to ensure that other endangered species will also be protected. Furthermore, Uxpanapa Valley is considered a biodiversity hotspot (PRONATURA 2007; WWF 2007) and forms part of the biological corridor of the Selva Zoque, one of the largest pristine extensions of rainforests in North America (Asbjornsen et al. 2005).Through priority site selection I also aim to contribute towards the areas' zonation. Setting the zoning scheme is one of the most relevant processes in PA planning, as it helps to assign specific uses to land units (e.g. core areas zones, where strict nature conservation is enforced) (Geneletti and van Duren 2008). This is critically important, as the Uxpanapa Valley Protected Area was constructed without appropriate species or landscape studies. A GIS-MCA methodology was used for this analysis, providing multiple conservation scenarios that can potentially facilitate the PA establishment process.

5.2 Aims and objectives

Aims

Identify sites for priority conservation based on factors positively and negatively associated with primate presence and the number of groups.

Use previous chapters to develop maps to support conservation and comprehensive management for primates and biodiversity (e.g. Protected Area zonification).

Use the obtained results to provide stakeholders and decision makers with the necessary tools to develop conservation plans in the Uxpanapa Valley.

Objective 1

Generate a set of weighted maps based on both howler and spider monkey data, and also including bat species data, that will highlight and rank priority areas for conservation.

Objective 2

Generate a set of weighted maps based on howler monkey (*Alouatta palliata*) data, which will highlight and rank priority areas for conservation.

Objective 3

Generate a set of weighted maps based on spider monkey (*Ateles geoffroyi*) data, which will highlight and rank priority areas for conservation.

Objective 4

Compare the map outputs to determine whether spider and/or howler monkeys are effective umbrella species for conservation planning in this region.

5.3 Methods

MCA method

A Multi Criteria Analysis (MCA) was performed, using a modified version of that described by López-Marrero et al. (2011). The process to generate the maps involved two main procedures, a non-GIS based one and GIS one (Fig. 5.1).

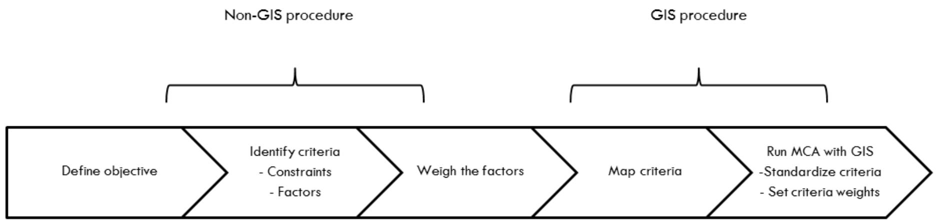

Fig. 5.1 The general process for conducting a MCA (López-Marrero et al. (2011)).

Following this process, the first step is to define the objectives, which in this case was establishing priority conservation sites based on a) the combined primate data plus bat species diversity, b) howler monkeys and c) spider monkeys. The successive steps are to identify the criteria and establish their order of importance. These criteria were derived from chapters 2 to 4, and were variously considered to be positively or negatively affecting the objectives based on the results of chapters 2-4. The criteria layers were produced using ArcMap v. 10.0, to convert the data into raster maps. These raster maps were then imported into R to be processed and converted into ASCII format, with identical resolution, coordinate system and number of rows and columns, as required by the Geographic Information System (GIS)-based MCA program ILWIS v. 3.08.04 in order to run the Spatial Multi-criteria Evaluation which outputs the final maps. The layer processing is described in detail in table 5.1. The MCA geographic analyses were done using ILWIS software (ILWIS 2001) and R package 'Raster' (Hijmans and van Etten 2012). The next step involved creating a pairwise matrix to prioritise and score the factors, to then derive the proportional weights for each of the factors. A detailed description of the method, which was adapted from López-Marrero et al (2010), is provided below, in order to assist with interpreting the matrix:

1) All the factors are listed on top (columns) and on the left side (rows) of the matrix.
2) The first factor listed on the left side of the matrix is compared against the second factor listed on the top side and users must identify which one is more important in determining the stated objective.
3) The factor deemed as most important is written down in the intersecting cell. For example, when comparing the factors "vegetation" and "transformed landscape" it was considered that "vegetation" was more important for the survival of primates and bats, thus, "vegetation" was then written into the intersecting cell. This process was repeated until each combination of factors was compared and the matrix was filled.
4) The sum of the times a factor appears in a cell is considered as the final score for that factor.
5) Finally, all the factors' scores are added, and the individual scores are divided by this total score to produce the weight

I generated a matrix for each of the objectives (Table. 5.2, 5.3, 5.4), and the following factors were included: species (spider monkey/howler monkey/bats), landscape (core size/forest type/transformed landscape) and threats (human population size/hunting/fires). I considered all species as positive (benefit) criteria, together with core size and forest type. Transformed landscape and all the threats I considered as negative criteria (cost). Each of their values were standardized through an interval method by the MCA program, which uses a linear function between minimum and maximum of the input value (Schouwenburg et al. 2007).

As part of standard MCA procedure, sensitivity analysis should be carried out to assess the robustness of the results (Wood 2007). This involves changing the weighting of selected criteria, which in this study was effected by a) using the results from the pairwise matrix, b) providing all criteria the same weight, c) assigning primate species a weight that doubled the value of all other criteria, d) using a higher weight for endangered species and e) assigning weight values based on the results from chapters 2-4 and literature, as well as first-hand knowledge of the study site. A full description of the considerations for weight selection and the values of these weights are found in tables 5.5, 5.6 and 5.7.Sensitivity analysis also helps to gain a good overview of the consequences of using different expert perspectives to rank the importance of factors (Geneletti and van Duren 2008).

The changes in weights were done using the Direct Method in ILWIS, in which user-defined weights were assigned to each of the criteria. These weights were entered manually and were automatically normalized to a standard scale of 0-1. The final step consisted of running the MCA with the GIS software (ILWIS) to produce the output maps with the varying weights. These were then imported into ArcMap 10.0 for final examination and processing, in order to provide an interpretation guide for these output maps. The output values for the Conservation Priority Level were classified as following: None= < 0.2, Low= 0.2- ≤ 0.5, Medium=0.5-$\leq$ 0.8 and High=≥ 0.8.

Table 5.1 Identification of each factor/criteria used for the analysis, their definitions, the detailed process for generating each map layer and the sources from which this data was taken.

	Factor/Criteria Layer ID	Definitions	Processes	Sources
Species	Howler monkey	The number of howler monkey groups (*Alouatta palliata*) occurring in each created buffer	3 km buffers were created around the point where the primate presence was detected, in order to represent the area in which the group or groups were potentially performing their daily activities. 3 km is suggested for this study, as it represents the maximum summed average of daily travel for both primate species (DiFiore and Campbell 2007). The buffers were converted to raster files and reclassified to express the number of primate groups within the buffer (1-3) and all areas outside the buffer were classified as 0*.	Data collected during 2010-2011 in the Uxpanapa Valley and analysed for chapters 2-4
	Spider monkey	The number of spider monkey groups (*Ateles geoffroyi*) occurring in each created buffer	This layer was processed in the same way as the howler monkey factor, only changing the range in the number of groups within a buffer to 1-4. All areas outside the buffers were also classified as 0.	Data collected during 2010-2011 in the Uxpanapa Valley and analysed for chapters 2-4
	Bats	Number of bat species found per buffer	3 km buffers were created around the points in which bats were captured, as 3 km is considered to be the minimum at which one bat population can be considered different from another (McSwiney and Pech-Canche, pers. com.). The buffers were converted to raster files and reclassified to express the number of bat species within the buffer (2-22) and all areas outside the buffer were classified as 0.	Data collected during 2010-2011 by McSwiney and collegues in Uxpanapa Valley. This data was analysed as part of chapter 4.

	Endangered bats	Number of endangered bat species found per buffer	This layer was processed in the same way as the bat factor, only changing the range in the number of groups within a buffer to 1-15. All areas outside the buffers were also classified as 0.	Data collected during 2010-2011 by McSwiney and collegues in Uxpanapa Valley. This data was analysed as part of chapter 4.
Landscape	Vegetation	The forest types found within Uxpanapa Valley, classified as Tall Forest (TF), Mature Secondary Forest (MSF) and Secondary Forest (SF)	The TF, MSF and SF forest types were extracted from the original raster containing forest types together with non-forested types, and a forest-only layer was created. The raster was reclassified to 1=TF, 2=MSF+SF, as it was important to fully distinguish pristine, undisturbed forest from those which have some degree of perturbation.	The original Uxpanapa Valley map created for this project is fully described in chapter 2.
	Core size	Areas of vegetation (Tall Forest, Mature Secondary Forest and Secondary Forest) which measured a minimum of 1 km^2	The "Vegetation" raster layer was converted into polygon features and the size of forested areas were computed in ArcMap using "Calculate field". The areas that were ≥ 1 km^2 were then selected by using "Select" tool. This selected area layer was transformed back into raster and reclassified into 1= 1-15 km^2, 2= 15.1-35 km^2, 3=35.1-197 km^2 and 4= >197.	"Vegetation" layer created from original map.
	Transformed landscape	All areas in which species cannot inhabit, classified as pastureland, farm land, clearings and human settlements.	The non-forest types were extracted from the original raster and a non-forest layer was created. The non-forested areas were reclassified into 1, while remaining areas were reclassified into 0.	The original Uxpanapa Valley map created for this project is fully described in chapter 2.
Threats	Population density	Human population density occurring per pixel	Point data representing each village's population size were transformed into a raster. Areas with no village were reclassified as 0, while the actual population number per village were kept (11-6453), as no more than one village was found within the same pixel.	PRONATURA-Veracruz, Mexico (2008)

	Hunting	The presence of hunting villages per pixel	The point data representing the hunting villages were transformed into a raster and were posteriorly reclassified as 0 for areas without hunting village and 1 for areas containing hunting village.	Data collection method during 2014 and corresponding analysis are fully described in chapter 3.
	Fires	Intensity of the number of fires occurring in the same year within a 500 m buffer	The number of fires that occurred in the same year per pixel were counted and the average of their Fire Radiative Power (FRP) was computed. The fire point data was used to generate buffers of 500 m, which were dissolved if found within that distance of each other. Each fire buffer layer from each year was merged to form a single layer. The Integrate tool was used to clump fire point data that was 500 m from each other and then the Collect Event tool was used to generate the sum of all incidents at each unique location. The buffers were converted into raster file and the fire intensity average of the clumped fires found within the buffer was added, so that each buffer represents the strength of the fire. The areas with no fire were reclassified as 0 while the areas with fire represent the actual FRP value per buffer (6.4 to 535). A buffer around the fires was considered important to consider the potential damage a fire may have (Nelson and Chomitz 2011), which could not be expressed with point data. The 500 m buffer is suggested, as it falls within the range of "small" fire category (Roman-Cuesta et al. 2004) of fires that occur in Southern Mexico. No large fires have been reported in the	Data on fire events (2009-2013) in Uxpanapa Valley were obtained through NASA´s Archive MCD14ML MODIS Active Fire Detections, downloaded from https://earthdata.nasa.gov/active-fire-data#tab-content-6. The data were processed and analysed for chapter 3.

			Uxpanapa Valley over the past five years, possibly due to fire control training of local inhabitants after an extensive fire destroyed thousands of hectares in 1998 (PRONATURA 2008).	
*All factor layers were initially processed using ArcMap v. 10.1. The resolution for all layers was .25 km x .25 km (.062 km^2). The second processing part was performed using R v. 3.2: all rasters were imported into R, where the extent, resolution and number of columns and rows were homogenized so all factor layers matched and were then transformed into an ASCII format.				

Table 5. 2 Pairwise matrix for establishing weights based on scores for Objective 1 (combined primate and bat data). Each factor is given an individual score based on the number of times it appears in an intersecting cell and divided by the total score. This result is considered to be the weight of each factor. Also included is a description of whether the criterion is positive or negatively affecting the Objective.

	FACTOR	***Species***				***Landscape***			***Threats***			**SCORE**	**WEIGHT**	**CRITERIA CONSIDERATION**
		HM	SM	Bats	En. bats	Core size	Vegetation	Transformed landscape	Population density	Hunting	Fires			
Species	HM		SM	Bats	En. bats	Core size	Vegetation	HM	HM	HM	HM	4	0.088	Positive
	SM			SM	En. bats	SM	SM	SM	SM	SM	SM	8	0.177	Positive
	Bats				En. bats	Core size	Vegetation	Bats	Bats	Bats	Bats	4	0.088	Positive
	En. bats					En. bats	En. bats	En. bats	En. bats	En. bats	En. bats	9	0.2	Positive
Landscape	Core size						Core size	Core size	Core size	Core size	Core size	8	0.177	Positive
	Vegetation							Vegetation	Vegetation	Vegetation	Vegetation	6	0.133	Positive
	Transformed landscape								Transformed landscape	Transformed landscape	Transformed landscape	3	0.066	Negative
Threats	Human population density									Human population density	Fires	1	0.022	Negative
	Hunting										Hunting	1	0.022	Negative
	Fires											1	0.022	Negative
											TOTAL	45	1	

Table 5.3 Pairwise matrix for establishing weights based on scores for Objective 2 (howler monkey data). Each factor is given a score and weighted accordingly, also describing whether it is considered a positive or negative criterion. Weights were selected based on results from previous chapters and published reports.

	FACTOR	***Species***	***Landscape***			***Threats***			**SCORE**	**WEIGHT**	**CRITERIA CONSIDERATION**
		HM	Core size	Vegetation	Transformed landscape	Population density	Hunting	Fires			
Species	HM		HM	HM	HM	HM	HM	HM	6	0.285	Positive
Landscape	Core size			Vegetation	Core size	Core size	Core size	Core size	4	0.190	Positive
	Vegetation				Vegetation	Vegetation	Vegetation	Vegetation	5	0.238	Positive
	Transformed landscape					Transformed landscape	Transformed landscape	Transformed landscape	3	0.142	Negative
Threats	Human population density						Hunting	Human population density	1	0.047	Negative
	Hunting							Fires	1	0.047	Negative
	Fires								1	0.047	Negative
								TOTAL	21	1	

Table 5.4 Pairwise matrix for establishing weights based on scores for Objective 3 (spider monkey data). Each factor is given a score and weighted accordingly, also describing whether it is considered a positive or negative criterion. Weights were selected based on results from previous chapters and published reports.

	FACTOR	***Species***	***Landscape***			***Threats***					
		SM	Core size	Vegetation	Transformed landscape	Population density	Hunting	Fires	**SCORE**	**WEIGHT**	**CRITERIA CONSIDERATION**
Species	SM		SM	SM	SM	SM	SM	SM	6	0.285	Positive
Landscape	Core size			Core size	Core size	Core size	Core size	Core size	5	0.238	Positive
	Vegetation				Vegetation	Vegetation	Vegetation	Vegetation	4	0.190	Positive
	Transformed landscape					Transformed landscape	Transformed landscape	Transformed landscape	3	0.142	Negative
Threats	Population density						Hunting	Population density	1	0.047	Negative
	Hunting							Fires	1	0.047	Negative
	Fires								1	0.047	Negative
								TOTAL	21	1	

Table 5.5 Variations in weights for each of the scenarios created for Objective 1 (combined primate and bat data) as well as the description of the considerations for the weight selection.

	FACTORS/CRITERIA											CONSIDERATIONS FOR WEIGHT SELECTION
		SPECIES				LANDSCAPE			THREATS			
		HM	SM	Bats	En. bats	Core size	Vegetation	Transformed landscape	Population density	Hunting	Fires	
WEIGHTS	Scenario 1	0.088	0.177	0.088	0.2	0.177	0.133	0.066	0.022	0.022	0.022	For this scenario, I used the weights derived from the pairwise matrix described previously.
	Scenario 2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	This scenario considers all criteria of equal importance, in order to provide another measure of comparison for the sensitivity analysis.
	Scenario 3	0.167	0.167	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	In this scenario primates were ranked highest, double the weight of the other criteria. This was to show how the focus on primates for establishing conservation sites compares to a non-primate based approach.
	Scenario 4	0.095	0.119	0.095	0.119	0.095	0.095	0.095	0.095	0.095	0.095	In this scenario the most endangered and highly sensitive species (spider monkeys and endangered bats) were ranked higher than the less sensitive species (other bats and howler monkeys) and the landscape and threat factors, but these were also assigned high weights, to establish if a focus on sensitive species provides a better selection of conservation sites than one based solely on primates.

	Scenario 5	0.099	0.123	0.099	0.123	0.123	0.111	0.111	0.062	0.062	0.086	This final scenario is weighted according to the importance I perceived for each of the factors. Usually, in the MCA method, a group of experts provide their opinions and establish the weights (López-Marrero et al. 2011) but in this case, I used literature, the results from my previous chapters and my knowledge of the site to simulate an "expert opinion". Spider monkeys and endangered bats were given the highest weight, as they are extremely sensitive to habitat depletion and are considered good indicator species. General bats and howler monkeys were given a slightly lower weight, as they can be generalists and survive in degraded habitat. Core area and vegetation were also weighted as high as the sensitive species, since these attributes ensure the species' presence. Transformed habitat was weighted highly, as the survival of the species I am considering is null within this factor. Population density, fires and hunting were assigned low weights as they did not show direct effects on the species I am considering when tested in chapter 3. Nevertheless, these weight are just an exploration of an alternative which contributes to the overall sensitivity analysis and are by no means definite.

Table 5.6 Variations in weights for each of the scenarios created for Objective 2 (howler monkey data) as well as the description of the considerations for the weight selection.

		FACTORS/CRITERIA							CONSIDERATIONS FOR WEIGHT SELECTION
		SPECIES	LANDSCAPE			THREATS			
		HM	Core size	Vegetation	Transformed landscape	Population density	Hunting	Fires	
WEIGHTS	Scenario 1	0.285	0.190	0.238	0.142	0.047	0.047	0.047	For this scenario, I used the weights derived from the pairwise matrix described previously.
	Scenario 2	.143	.143	.143	.143	.143	.143	.143	This scenario considers all criteria of equal importance, in order to provide another measure of comparison for the sensitivity analysis.
	Scenario 3	.250	.125	.125	.125	.125	.125	.125	In this scenario howler monkeys were ranked highest, at double the other criteria. This was to show how the focus on primates for establishing conservation sites compares to a non-primate based approach.
	Scenario 4	.204	.137	.196	.137	.098	.098	.137	In this scenario howlers and other factors were weighted according to my perceived importance. Howlers and vegetation were weighted the highest as the focus is on HM and without forest they cannot survive. Core size is less

important for howlers, they are known to live in smaller groups and have smaller home ranges than spider monkeys (DiFiore and Campbell 2007). Hunting, fires and population density were not found to have a significant impact on howler monkey presence or number of groups in chapter 3, so their weight was less. As I mentioned in chapter 3, further studies are recommended to fully understand the interaction these factors have with primates in the region.

Table 5.7 Variations in weights for each of the scenarios created for Objective 3 (spider monkey data) as well as the description of the considerations for the weight selection.

WEIGHTS	FACTORS/CRITERIA							CONSIDERATIONS FOR WEIGHT SELECTION
	SPECIES	LANDSCAPE			THREATS			
	SM	Core size	Vegetation	Transformed landscape	Population density	Hunting	Fires	
Scenario 1	0.285	0.238	0.190	0.142	0.047	0.047	0.047	For this scenario, I used the weights derived from the pairwise matrix described previously.
Scenario 2	.143	.143	.143	.143	.143	.143	.143	This scenario considers all criteria of equal importance, in order to provide another measure of comparison for the sensitivity analysis.
Scenario 3	.250	.125	.125	.125	.125	.125	.125	In this scenario spider monkeys were ranked highest, the double of the rest of the criteria. This was to show how the focus on primates for establishing conservation sites compares to a non-primate based approach.
Scenario 4	.161	.161	.161	.161	.113	.129	.113	In this scenario spider monkeys and other factors were weighted according to my perceived importance. Spider monkeys, core size and vegetation were weighted the highest as the focus is on SM and their need of high quality vegetation, their use of large home ranges and their susceptibility to habitat transformation (DiFiore and Campbell 2007). Hunting, fires and population density were not found to have a significant impact on

spider monkey presence or number of groups in chapter 3, but because their susceptibility to these factors is higher than that of howlers, and they have been known to be used for pet trade, these factors were weighted higher than for howlers. As I mentioned in chapter 3, further studies are recommended to fully understand the interaction these factors have with primates in the region.

5.4 Results

Overall, as was expected, I found considerable variations between and within the different scenarios that were created for each objective. In general, the variations within Objective 3 (spider monkey) were the least pronounced when compared amongst each other, while both the Objective 1 (both primates and bats) and 2 (howler monkeys) had at least one scenario that differed greatly from the rest.

Objective 1 (combined primate and bat data)

The conservation priority maps produced with ILWIS from the combined primate data, and which also included bat data, show that the Scenario 1 map holds the highest percentage of "None" priority level (55.60%) while the Scenario 2 map holds both the most extension of "High" Priority Level Areas (13.29%) and the lowest percentage of "None"(1.38%) (Fig. 5.2). These percentages represent 2662.06 km^2, 636.33 km^2 and 65.94 km^2, respectively (Table 5. 8). Sc1 was produced from the weights that resulted from the pairwise matrix approach, described in methods (Table 5.1). Sc2 weights were considered equal across negative and positive factors (Table 5.5). Overall, differences in weights had a marked effect on size of the total extension of the areas within each Priority Conservation Level, but Sc2 differed the most from the rest of the Scenarios (Fig. 5.3).

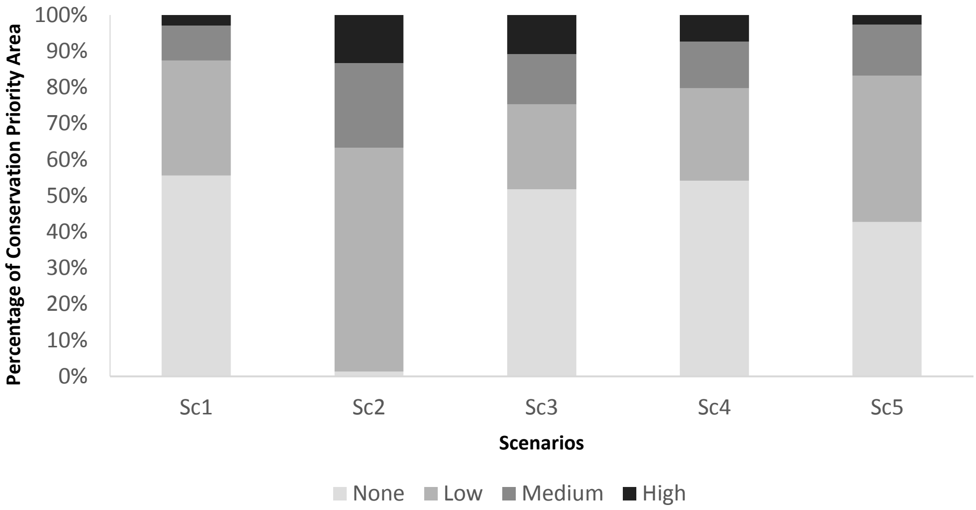

Fig. 5.2 The percentages of total the area of Conservation Priority Levels found for objective 1 (primate and bat data), per each of the tested scenarios (Scenario 1-Scenario 5). This test held the combined primate data, together with bat data.

Table 5.8 Total area (km^2) of Priority Conservation Levels within each scenario generated for the combined primate data, together with bat data in the Uxpanapa Valley.

		Scenarios				
		Sc1	Sc2	Sc3	Sc4	Sc5
Priority Conservation Levels	None	2662.05	65.94	2479.84	2595.78	2046.03
	Low	1524.80	2967.05	1125.03	1225.54	1939.26
	Medium	461.73	1118.40	665.01	613.38	678.44
	High	139.62	636.33	518.46	353.19	124.61

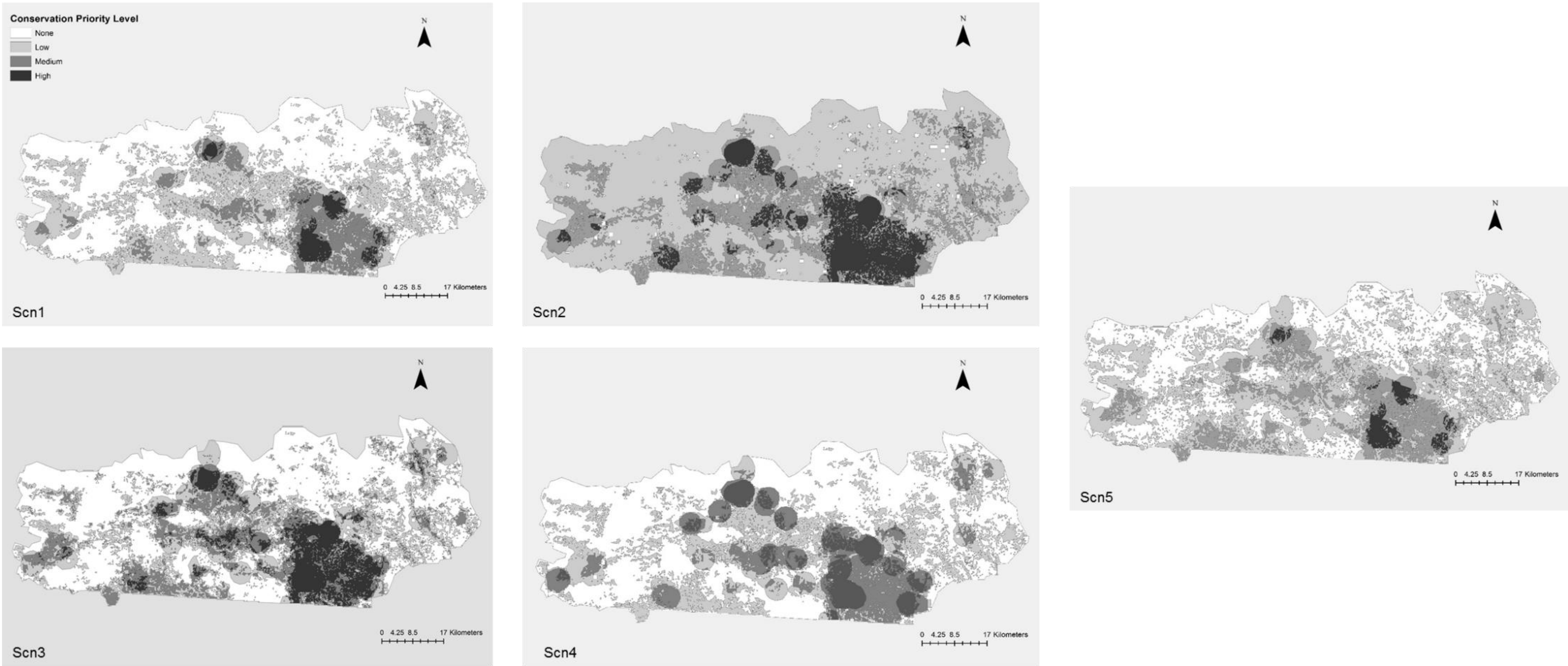

Fig. 5.3 Conservation Priority maps for Objective 1 (primate and bat data), showing the colours coded according to the Conservation Priority Level, where white is None= < 0.2, light grey is Low= 0.2- ≤0.5, dark grey is Medium=0.5-≤ 0.8 and black is High=≥0.8.

Objective 2 (howler monkey data)

The results for objective 2, which focused exclusively on howler monkeys, showed that Scenario 4 (Sc4) presented the most area of "None" Priority Area Level (43.32%) while Scenario 2 (Sc2) had the least amount of "High" Priority Area Level (8.80%) and Scenario 3 (Sc3) held the highest percentage of "High"(25.74%) (Fig. 5.4). This corresponds to 2073.89 km^2, 421.40 km^2 and 123259.63 km^2 respectively (Table 5.9). Sc1 and Sc4 maintain a similar distribution in the distribution of the area size, differing greatly from Sc2 and Sc3.

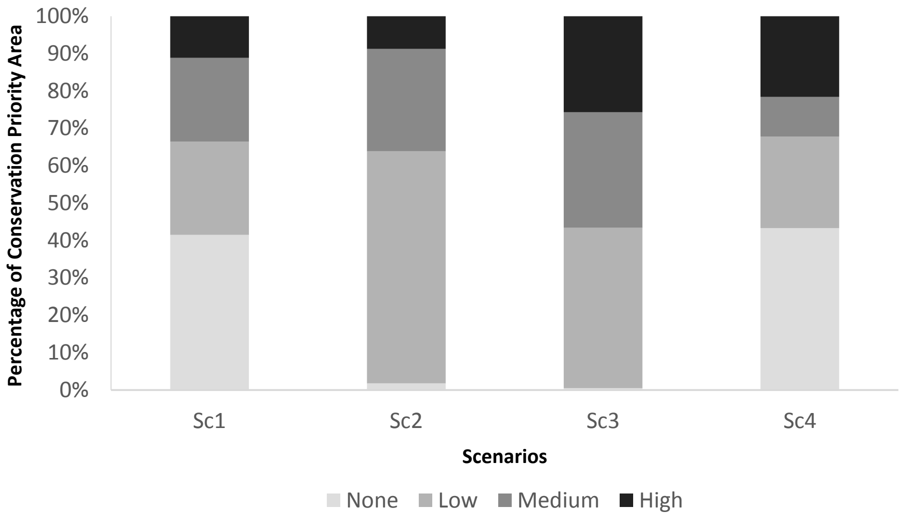

Fig. 5.4 The percentages of total the area of Conservation Priority Levels found for objective 2 (howler monkey data), per each of the tested scenarios (Sc1-Sc4). This test was performed exclusively with howler monkey data.

Table 5.9 Total area (km^2) of Priority Conservation Levels within each scenario generated for the howler monkey data of the Uxpanapa Valley.

		Scenarios			
		Sc1	Sc2	Sc3	Sc4
Priority Conservation Levels	None	1984.90	84.64	21.25	2073.89
	Low	1193.35	2971.10	2057.45	1171.79
	Medium	1076.04	1311.04	1476.55	509.21
	High	533.50	421.40	1232.59	1032.92

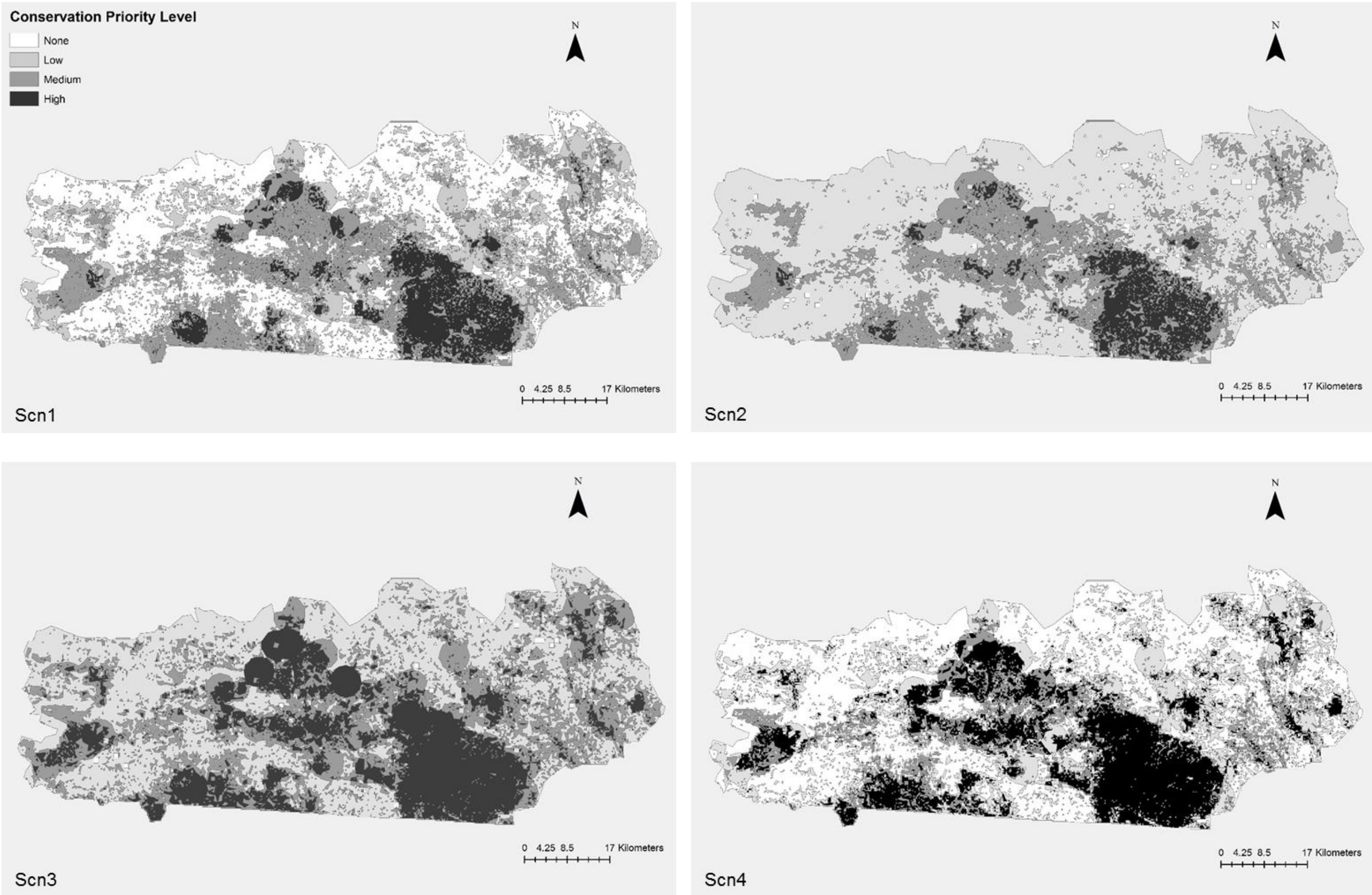

Fig. 5.5 Conservation Priority maps for Objective 2 (howler monkey data), showing the colours coded according to the Conservation Priority Level, where white is None= < 0.2, light grey is Low= 0.2- ≤0.5, dark grey is Medium=0.5-≤ 0.8 and black is High=≥0.8.

Objective 3 (spider monkey data)

The maps resulting from inputting spider monkey data show less variation between scenarios, in the percentages of all the Priority Conservation Level areas. Scenario 1 (Sc1) presented the most "None" area (67.03%) than any of the other tested scenarios, and also presented the least area of "High" (2.46%) Priority Conservation Level. Sc3 presented the highest percentage of "High"(8.8%). This corresponds to 3209.36 km^2, 117.78 km^2 and 421.46 km^2 respectively (Table 5.10).

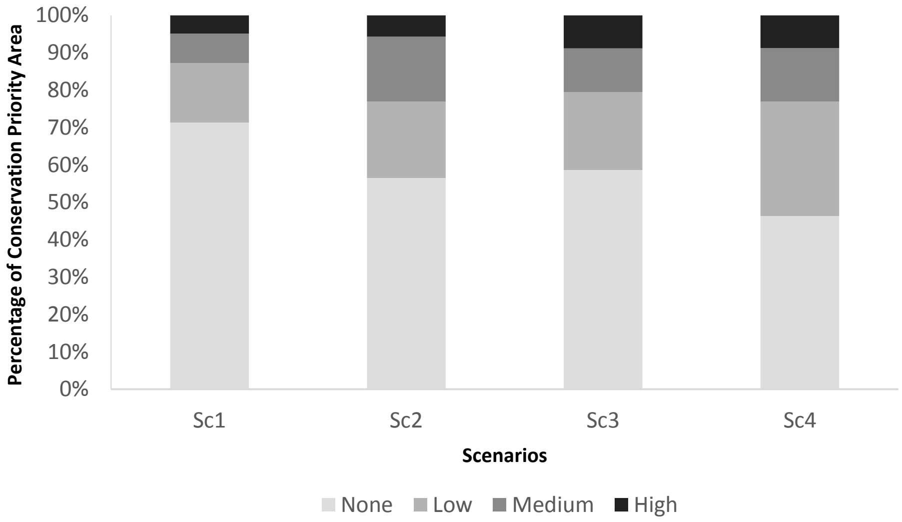

Fig. 5.6 The percentages of total the area of Conservation Priority Levels found for objective 3 (spider monkey data), per each of the tested scenarios (Sc1-Sc4). This test was performed exclusively with spider monkey data.

Table 5.10 Total area (km^2) of Priority Conservation Levels within each scenario generated for the spider monkey data of the Uxpanapa Valley.

		Scenarios			
		Sc1	Sc2	Sc3	Sc4
Priority Conservation Levels	None	3413.73	2707.39	2807.44	2218.07
	Low	765.78	976.58	998.95	1465.83
	Medium	375.81	832.34	560.39	684.72
	High	233.01	271.98	421.46	419.29

Lastly, I selected all the "High" outputs for the same Scenario for each of the Objectives and combined them in a single map, to facilitate the identification of the areas that are high priority regardless of Scenario or Objective (Fig. 5.7, Fig. 5.8).

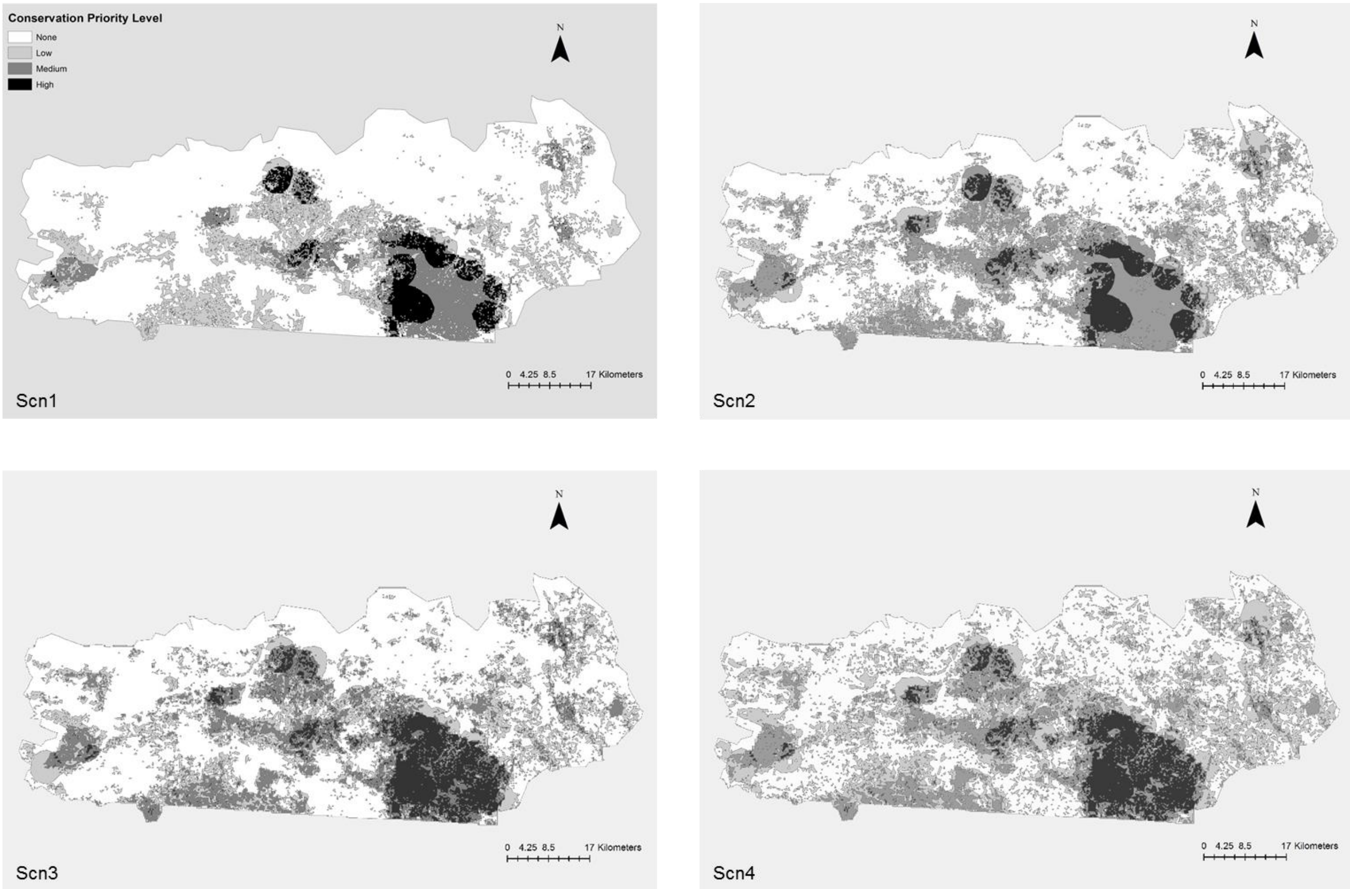

Fig. 5.7 Conservation Priority maps for Objective 3 (spider monkey data), showing the colours coded according to the Conservation Priority Level, where white is None= < 0.2, light grey is Low= 0.2- ≤0.5, dark grey is Medium=0.5-≤ 0.8 and black is High=≥0.8

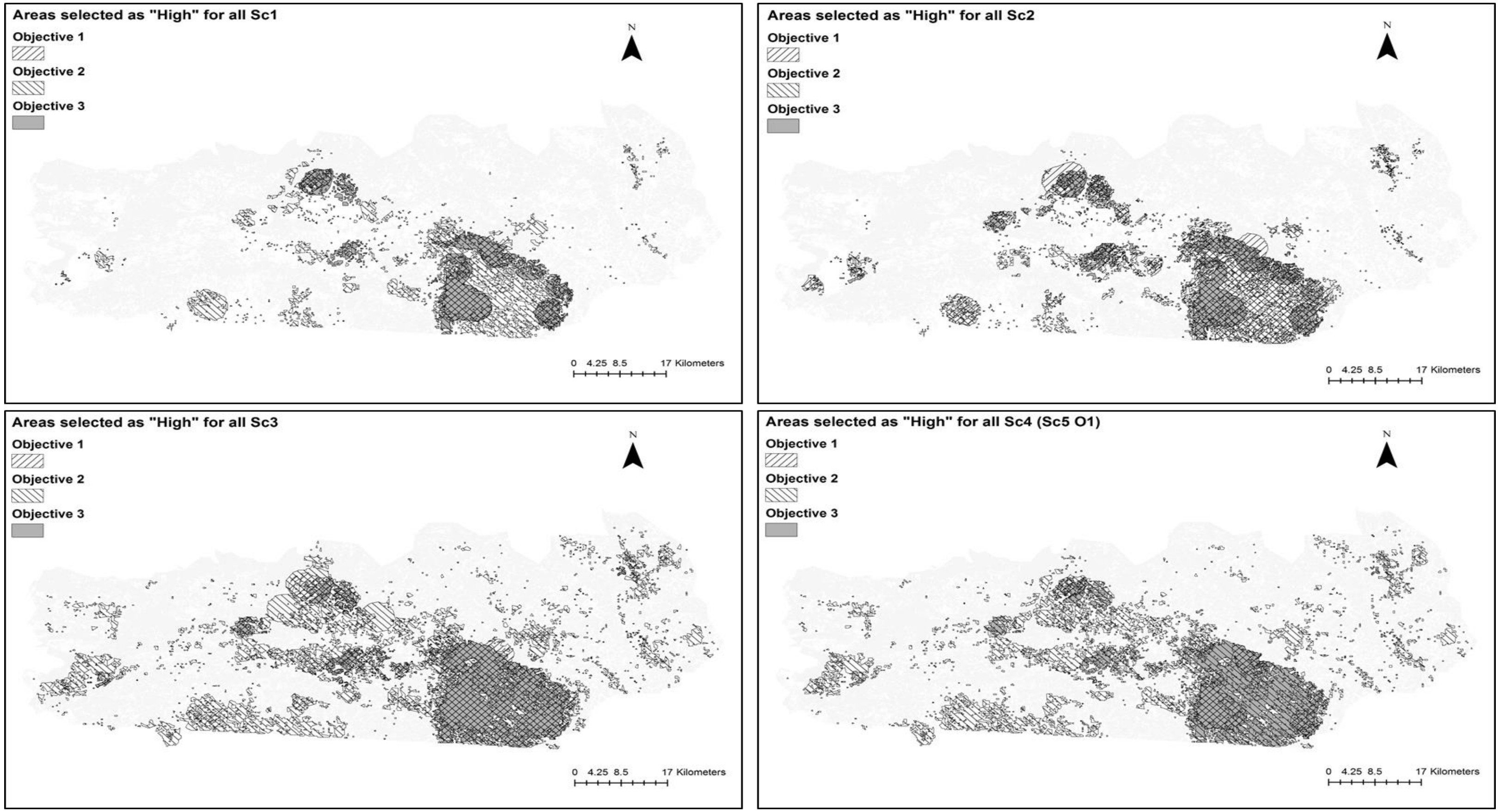

Fig. 5.8 Areas that were marked as "High" priority for all Objectives in each of the Scenarios. Objective 1 is represented by a simple hatch to the right, Objective 2 by a simple hatch to the left and Objective 3 by a solid grey colour. General background is represented by a light grey colour. Areas in which crosshatch is observed indicates intersection of both simple hatches. Overall, the "High" areas remain the same no matter what Scenario or Objective.

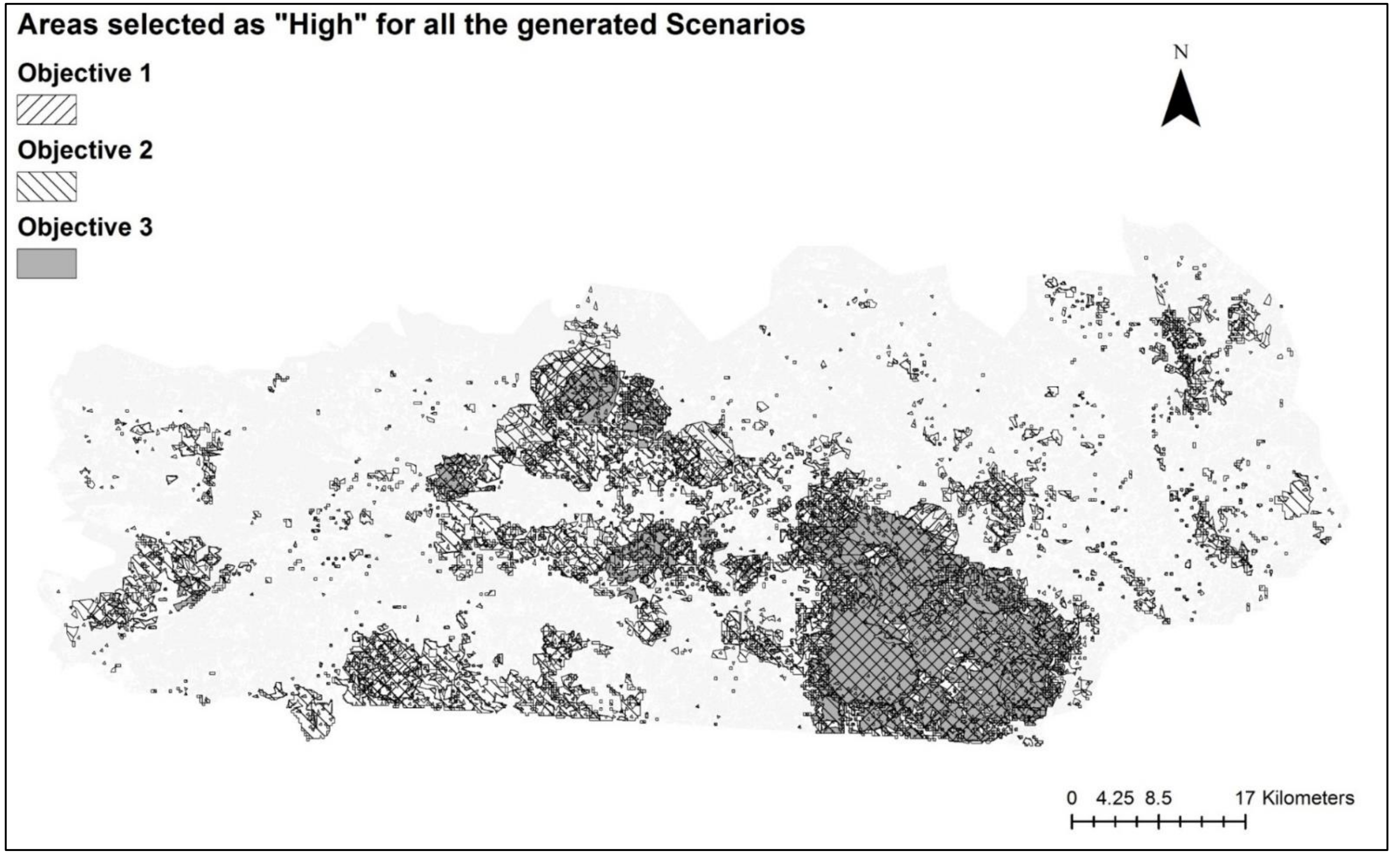

Fig. 5.9 Areas that were marked as "High" priority for all Scenarios combined. Objective 1 is represented by a simple hatch to the right, Objective 2 by a simple hatch to the left and Objective 3 by a solid grey colour. General background is represented by a light grey colour. Areas in which crosshatch is observed indicates intersection of both simple hatches

5.5 Discussion

Overall, I found that regardless of Objective or Scenario, the main sites considered as "High" priority were sites with the largest, connected extensions of Tall Forest. This result coincided with several studies that mention bigger fragments and higher quality forests are vital for species conservation (Lasky and Keitt 2013; Tscharnke et al. 2012; Fahrig 2003). These areas also held the most number of groups of primates or bat species. By comparing the outputs from the primate specific Objectives (O2 and O3) against Objective 1 (which included bat species) I can conclude that conservation recommendations based on O3 (spider monkeys) would also be protecting howler monkeys and bat species, particularly endangered ones. A detailed description of the comparison between Scenarios and Objectives is provided below.

The first scenario (Sc1) for all of the objectives, which was developed using a pairwise matrix, shows Objective 3 (spider monkey data) has the most extension of the "None" Priority Conservation Level (PCL) area (3413.73 km^2), as well as the least of the "High" PCL area. On the other hand, Objective 2 (howler monkey data) has the most of the "High" and "Medium" PCL areas (533.5 km^2 and 1076.04 km^2, respectively). Objective 1 (combined primate and bat data) held the most amount of "Low" PCL area (1524.8 km^2). These results are possibly due to howler monkeys being generalists (Bicca-Marquez 2003), and having a potentially more widespread distribution in less conserved forests, while spider monkeys and bats are usually reliant on larger tracts of well conserved forest (Medellin et al. 2000; Wendeln et al. 2000; Sorensen and Fedigan 2000). Thus, the presence of any of the forest types would be considered as potential areas to conserve for howler monkeys, while only a reduced amount of forest areas would be considered for spider monkeys and bats.

Scenario 2 (Sc2) for all of the objectives was executed using equal weights for all of the criteria (both positive and negative), which provides an additional basis to observe how the different weights affect each of the scenarios. For Objective 1 and Objective 2, the distribution of PCL areas was very similar, where the smallest areas corresponded to the "None" (64.94 km^2 and 84.64 km^2, respectively), followed by "High" (636.33 km^2 and 421.4 km^2, respectively) and "Medium" (1118.4 km^2 and 1311.04 km^2, respectively), while the largest extensions were of the "Low" classification (2967.05 km^2 and 2971.1 km^2, respectively). On the other hand, Objective 3 presented a different distribution of the PCL areas, as the least amount of area was of the "High" (271.98 km^2), followed by "Medium" (832.34 km^2), "Low" (976.58 km^2) and "None"(2707.39 km^2) was the most extensive PCL area. This finding is interesting, as it shows that even with equally weighted factors, the high priority areas for spider monkeys are still very focalized/localized. This can potentially be highlighting the importance of mapping distributions and selection priority conservation sites based on species' needs and traits.

Scenario 3 (Sc3) for each of the objectives was constructed to prioritize howler and spider monkeys. The outputs for this scenario are particularly important for my study, as they emphasize the selection of areas that should be considered as priority based on primate data. In this Scenario, Objective 1 and Objective 3 shared the same distribution of PCL areas, the lowest extension corresponding to the "High" (518.46 km^2 and 421.46 km^2, respectively), followed by "Medium" (613.38 km^2 and 560.39 km^2, respectively), "Low" (1225.54 km^2 and 998.95 km^2, respectively) and "None" (2595.78 km^2 and 2807.44 km^2, respectively). Objective 2 presented a different distribution of the PCL areas, where the "None" level was the least extensive in area (21.25 km^2), followed by "high" (1232.59 km^2), "Medium" (1476.55 km^2) and "Low" having the most extensive PCL area (2057.45 km^2). The causes for the observed differences, particularly between the "Low" areas, are probably similar to the explanations in Sc1, where howler monkey distribution is more widespread (although with less number of groups) due to their characteristics, while spider monkeys presented higher concentration of group numbers within the same sites (see chapters 2 and 4). Core size could also be one of the main drivers behind the differences between spider and howler monkey PCL area sizes, as size of the forest fragment can largely influence the presence or absence of spider monkeys (Michalski and Peres 2005), but not necessarily that of howlers. Spider and bat distributions were highly correlated and share similar habitat needs, so their occurrence would have a very similar distribution of PCL areas.

Scenario 4 (Sc4) for Objective 1 weighted endangered/highly sensitive species the highest. Endangered species in this case, refers to spider monkeys and endangered bats found within the study site. Sc4 was used to determine if by using endangered bat data, the output would differ highly from those using all species. The output showed a PCL area distribution similar to Sc3, where "High" has the least amount of area (353.19 km^2), followed by "Medium" (613.38 km^2) and "Low" (1225.54 km^2), while "None" has the most extension (2595.78 km^2). When compared to Sc3, in Sc4 there is a slight increase in the PCL areas "None" and "Low" and a slight decrease in the values for "Medium" and "High", suggesting that the selection of Priority Conservation Sites based solely on both primates would also offer protection for endangered bats and is slightly more inclusive in terms of extensiveness and other species, than the one based on only endangered ones.

Scenario 5 (Sc5) for Objective 1 (as well as Scenario 4 (Sc4) for Objectives 2 and 3) was produced employing user defined weights. This scenario was included as a means to observe how the weights based on "specialist" opinions fare against ranked or randomly selected weights. Again, Objective 1 and 3 followed the same distribution of PCL area sizes, and while Objective 2 was also very similar, the difference lay in the "High" area being more extensive than the "Medium". For all three Objectives, the highest extension was of the "None" PCL area (2026.03 km^2, 2073.89 km^2 and 2218.07 km^2, respectively), followed by the "Low" (1939.26 km^2, 1171.79 km^2 and 1465.83 km^2, respectively). Objectives 1 and 3 had the following "Medium" areas: 678.44 km^2 and 68.72 km^2, respectively, while Objective 2 had 509.21 km^2. The "High" areas for Objectives 1, 2 and 3 measured 124.61 km^2, 1032.92 km^2 and 419.29 km^2, respectively. The scenarios for Objective 1 and Objective 3 did not differ greatly from the outputs of other scenarios and greatly resembled Sc 3, probably due to primates being allocated the highest weights. In general, the results from this scenario did not contain any values that could be considered extremes in any of the PCL. This could potentially validate that opinions based on previous studies, current data and knowledge of the study area, may be important when deliberating on weight assignment.

But extreme care must be taken to not solely rely on an experts viewpoint, as opinions, though valuable, should not be the sole contribution when weighting, but form part of the sensitivity analysis.

Overall, the largest extension of "High" priority PCL area was found for Objective 2, in Sc 3 and the highest amount of "None" PCL area was found in Objective 3 Sc 1. These outputs further suggest that the howler and spider monkey distributions found within Uxpanapa Valley are expressing the plasticity of howlers to inhabit different vegetation types and to persist in small fragments (Cristobal-Azkarate and Arroyo-Rodriguez 2007), while spider monkeys are highly restricted by core size and vegetation quality. The Priority Conservation Sites based on howlers encompass larger areas due to the inclusion of small forest fragments, while the sites selected for spider monkey conservation tend to concentrate in areas with Tall Forest and larger core size (Figs. 5.5 and 5.7). Using the results from Objective 2 (HM) would imply conserving larger extensions of land than Objective 3 (SM), but the land extensions would likely be composed of high proportions of secondary forest as well as more fragmented areas. In the face of total forest cover loss, the value of secondary forests for species conservation is undeniable (Barlow et al. 2010). Nevertheless, conservation of primary forests remains a top priority as they are irreplaceable for sustaining tropical biodiversity (Gibson et al. 2011). Under this assumption, the remaining tracts of primary forest in the Uxpanapa Valley should be considered as part of the central conservation targets, which coincides with the output for Objective 3 (SM). An effective system for conservation on a landscape scale is ideally composed of core areas, which are protected by surrounding buffer zones and connected through ecological corridors (Boitani et al. 2007). Applying this system's layout through SCP, primary forest and large core areas where spider monkeys (as well as other highly sensitive species) are found would be considered as the "core areas" from which corridors could be built to connect to the secondary forest tracts, benefiting howler monkeys and other resilient species. This layout would be highly replicable in tropical forests where canopy dwelling or forest dependant species co-habit with less specialized species.

Another aspect to be considered, is that all of the Objectives overlap in the large core areas highlighted as "High" priority for conservation. These areas are deemed of particular importance in each Objective, regardless of which species the focus is on. These results in themselves are interesting, as they lead towards concluding that the species applicability can be extensive. The overlapping areas, should, without a doubt, be one of the pivotal features to be considered when planning the PA zonation in Uxpanapa Valley. Furthermore, some of these overlap areas are situated on a karst platform, making them highly rugged and inaccessible (PRONATURA 2009; Day-White in prep.). Unaltered conditions and limited access to humans are important attributes of core areas (Noss et al. 1999), which would make the overlap areas ideal for conservation, as local villagers cannot use them for agricultural activities and tend to stay out of them because of difficult terrain (A Shedden, pers. obs.). Several of the larger core areas within the overlap are also established National Properties, which means they are owned by the government. This would mean no private owners would be displaced if they are designated for strict conservation purposes.

Overall, I consider that the best scenario to direct conservation efforts would be Sc3 of Objective 3, which is the output based on spider monkey data. This scenario assigned 8.8% of the total area as "High" PCL, 11.7% as "Medium", 20.86% as "Low" and 58.63% as "None". The reasons for choosing this scenario are a) no extremes in the values are found (i.e. does not contain the lowest or highest extension for any of the PCL, which could lead to over or underestimation), b) would encompass howler monkey and bat habitat, ensuring their protection and potentially other species too, c) would target the larger core areas and best quality vegetation that still remains, while maintaining some of the smaller core areas, and d) would facilitate delimitation of the Protected Area nucleus, by focusing on the above mentioned factors. Furthermore, an interesting output from the application of this GIS-MCA, is that despite changes in weights the distribution of PCL areas remained the same (smallest areas of "High" through to largest areas of "None") for Objective 3 (spider monkey data) and values presented little variation between scenarios. This consistency validates the use of spider monkeys as an umbrella species and the potential for this species to be used to select priority conservation sites throughout its distribution range, both in Mexico and the rest of the Neotropics. It is clear that MCA provides the necessary structure to identify, organize and select the most important factors influencing the problem of priority site selection, as well as to understand the relationship between all the criteria. In this sense, the application is not limited to a single species and can be used as a conservation tool combining two or more species within any given site.

Although the use of the GIS-MCA method provided decision support throughout the site selection process, it is important to acknowledge there is an element of subjectivity in the weighting and ranking, even when based on published data and researcher's knowledge of the area. Nevertheless, performing a sensitivity analysis provides insights into the potential causes behind a particular outcome, as well as an indication of the robustness of the results of the MCA (Wood 2007). Sensitivity analysis is most often performed on the criterion weights to test the robustness and veracity of a decision solution subject to changing the weights for a predetermined set of criteria across alternatives (Malczewski 2010).

The output of this work is not a final, inflexible solution to the problems related to primate/biodiversity conservation based on the allocation of priority status to certain areas in Uxpanapa Valley, but rather a layout of the different scenarios resulting from a range of perspectives on the same issues. Future monitoring of the selected areas would be important, to determine whether the suggested conservation actions were successful. Finally, with the results from this chapter I also aim to contribute towards the zoning of the Uxpanapa Valley PA, which is currently lacking. This situation is common for most protected areas in developing countries and, as a consequence, many PAs are not effective in achieving the goals for which they were created (Sabatini et al. 2007). Overall, MCA results provide a visual and quantifiable aid for decision-makers to explore different solutions (Possingham et al. 2000; Wood 2007) and in this case, could also provide data that would help with the administration and management of the PA, based on primate data.

5.6 References

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CHAPTER 6. General Discussion

6.1 General discussion

Arguably, the most serious aspect of the global environmental crisis is biodiversity loss, and incontrovertible evidence indicates that recent extinction rates are unprecedented, due to human pressures (Ceballos et al. 2015). Despite the rapid changes in climate and other environmental factors induced by human activities, Protected Areas (PA) still remain as an essential means for species conservation (Gillingham et al. 2015). Systematic conservation planning (SCP) is the prevalent approach for designing protected areas (PA), and includes stages that deal not only with the technical aspects of laying out a PA, but also with the socio-economic and political aspects which are important for implementing conservation action (Di Minin and Miolanen 2012). Identifying priority sites for species conservation is crucial, as well as understanding the factors and processes that drive the spatial distribution of these areas (Albuquerque and Beier 2015). Thus, data on geographical ranges are essential when defining the conservation status of a species, for evaluating levels of human disturbance and for selecting sites that will optimize conservation tactics (Thorn et al. 2009). Identifying priority sites at finer scales should now be the primary concern for conservation planning (Brooks et al., 2006). In this sense, smaller "hotspots" (areas of exceptional concentrations of endemic species which are undergoing exceptional loss of habitat (Myers et al. 2000)) within larger "hotspots" at different scales have been proposed for various taxa (Cañadas et al. 2014). With this work, I aimed to provide information of the effectiveness of using primates, particularly spider monkeys, for selecting priority conservation sites and their potential to be used as a proxy for ensuring tropical forest maintenance. Additionally, I specifically aimed to contribute towards structuring an effective management plan, with the use of SCP, for the PA of the Uxpanapa Valley that will ensure maximum protection for biodiversity in the region.

The Selva Zoque (Zoque Forest) in Mexico is comprised of forested areas belonging to the states of Oaxaca, Chiapas, Veracruz and Tabasco. It is the largest remaining tract of tropical rainforest in Mexico and is one of the most important areas for biodiversity within the Mesoamerican "hotspot" (Lira-Torres 2012), but is also one of the areas that has the highest deforestation rates in southern Mexico (Vaca et al. 2012). The Uxpanapa Valley, Veracruz, forms part of the Selva Zoque extension, but has been widely ignored and no broad-scale information existed about the spatial distribution species within the valley or their conservation needs. The overall aim of this work was to establish whether using primates as a species-based approach for conservation purposes, either by using them as a proxy for biodiversity conservation or for establishing priority conservation sites, is feasible and to use my results to contribute towards the zonation of the Protected Area that is being developed. The first step in this process was to determine where in my study site both primate species were distributed, how many groups/sub-groups we could detect within the plots and the basic demographics for bot species. This was particularly important as no studies had been performed in this site before and a PA proposal had already been set in motion. Uxpanapa Valley stands in the largest forest extensions of Mesoamerica (considered as one of the most endangered ecosystems in the tropics) (Harvey et al. 2008). This area is also key to accurately estimating the overall population of howler and spider monkeys in Mexico, as well as generating data to further evaluate their conservation status (they are currently listed as Critically Endangered in the IUCN Red List). Scarce data from previous years make it impossible to fully understand how past events shaped present species distribution in the area. Nevertheless, my results showcase what is currently happening in the Uxpanapa Valley, and provide invaluable information which can be used to make future conservation decisions and which can also serve as a research model for other tropical forest systems in which primates are found. Finally, expert consensus has recommended that primate studies in Mesoamerica should be oriented towards obtaining key data (e.g. species distribution and demography, genetics, habitat status) in areas with information voids, in order to promote effective conservation efforts (Rodríguez-Luna et al. 2013). Subsequent research in the Uxpanapa Valley should continue with data collection both on the species and the human impacts found in the area.

In Chapter 2, the main goal was to determine the presence of mantled howler and spider monkeys in this area, and most importantly, if their distribution was associated with specific vegetation types. This survey constitutes the first demographic report of the primate populations inhabiting the Uxpanapa Valley, Mexico. The results show that in the Uxpanapa Valley, the presence of spider monkeys and the combined occurrence of both howler and spider monkeys were related to the increased area of tall evergreen forest (i.e. the most pristine habitat present in the valley). In contrast, as areas of secondary forest increased, the presence of *Ateles* decreased. Howler group size and composition was similar across vegetation types and their presence was not significantly related to any vegetation types or measure of disturbance. These findings confirm the hypothesis that howler monkey distribution is not strongly associated to a particular vegetation type, possibly due to their adaptive behavioural and physiological traits. On the other hand, a strong negative association was expected between primates and the increased percentage of Transformed Habitat, but none was found. These results may be showing that the remaining habitat is sufficient at the moment to maintain both primates' populations.

In this study, I was not able to follow the usual transect method used for primate surveys, due to the limitations imposed by the topographic characteristics of my site. Nevertheless, I used local knowledge of villagers (particularly hunters who were active in the forest) who lived near or within the sampling plots to obtain information on whether my sampling plots were known to have or not have primates. This information was coupled with my intensive examination of the plots, aided by a team of researchers and local guides. Although this method may not be widely utilized, it has been applied in areas where environmental conditions limit accessibility/visibility (Ortiz-Martínez and Rico-Gray 2007; Urbani 2005; Heyman et al. 2002) and contributes to assess primate populations in poorly researched sites.

Furthermore, my results follow the main trend established for spider and howler monkeys throughout their distribution in the Neotropics: spider monkeys are highly associated and dependant on large tracts of well-preserved forest, while howler monkeys can persist in less optimal areas, such as secondary forests with smaller patch sizes. Nevertheless, my results also show that howler group size was below the number reported for the same subspecies in a severely transformed area Los Tuxtlas, Mexico (Estrada and Coates-Estrada, 1996; Cristóbal-Azkarate et al., 2005). The reason for this small group size escapes our understanding at the moment, and further studies are vital to fully comprehend the trends of primate populations in this site. Moreover, the distribution and demographic data I obtained reflect the habitat transformation history over the past three decades in the Uxpanapa Valley. Howler and spider monkey populations have been known to remain stable for over ten or more years in areas that are severely altered (Fedigan et al 1998; Solorzano-Garcia and Rodriguez-Luna 2010) and in this sense, my results may be showcasing the changes in distribution patterns brought on by human activities in the area. In general, these outcomes further corroborate the need to ensure tropical forests are protected and the dependency certain species, particularly arboreal species, have on them for their survival (Barelli 2015). Finally, although important information on group sizes and distribution were obtained, questions remained on the factors that are impacting on them.

This was addressed in Chapter 3, where the effects that hunting, predation and wildfires had on the primates in my study site were analysed. The main objectives were to establish if a) hunting, wildfires and natural predation were occurring within the distribution of howler and spider monkeys in my study site and b) the effects these variables were having on the distribution and number of groups of these primates. I found that hunting, natural predation and wildfires are ongoing in the Uxpanapa Valley, but do not appear to have a significant effect on the primates. With this study, it was ascertained that hunting is a constant and current activity in the Uxpanapa Valley, which is valuable information in itself, as the number of studies on hunting in Mexico are restricted. Regarding predation, in areas where the activity was not recorded, the likelihood of presence of spider monkeys and the combined presence of the primates decreased. Preventative measures implemented by locals have limited the spread of wild fires, even though traditional slash and burn practices still occur (Pers. Obs.). By regulating the extent of wild fires, key primate habitat may be less susceptible and therefore more able to sustain current populations.

The effects of hunting on primate populations have been mainly studied in African countries (Fa and Brown 2009), while in the Neotropics, this subject has been primarily examined in Brazil (Cullen et al. 2000). In Mexico, very few projects have addressed the issue of wildlife hunting and particularly, how this activity impacts primates. In my study site, I found no evidence that hunting activities are currently affecting primate distribution. Nevertheless, it is important to consider that future, longer term studies in the area may show a different trend, especially if deforestation rates and expansion of human settlements continue unrestrainedly. For example, in Republic of Congo, areas in which human population was low and anti-poaching enforcement was active, hunting still reduced primate populations by 30% (Poulsen, Clark & Bolker, 2011). Continuous monitoring of both primates and hunting are vital to determine future outcomes.

Predation on primates is another understudied topic, not only in Mexico but in most of the countries in which primates are found (Farris et al. 2014). However, it has been ascertained that predation can influence primate behaviour, population dynamics, spatial distribution and group size (Farris et al. 2014). The results of my study do not show any direct effect on howler monkeys, but do relate lack of predation to spider monkey absence. This relationship could potentially be explained by jaguar and puma habits, as they tend to be opportunistic hunters (Hernández-SaintMartín et al. 2015), implying that where there are more monkeys they will ingest them more frequently. Even though I did not find a strong indicator of predation effects on primate distribution in my study site, my results are contributing towards understanding large cat-primate interactions in the Neotropics, as well as the first description of jaguar and puma incorporating primates in their diet in the Zoque Forest extension. This data can be used to model Mexican primate viability and also encourage further studies on primate predation throughout their distribution range.

Fires are known to severely affect canopy dwelling species (Barlow and Peres 2004; 2006), but I found no direct links between present-day fire occurrences and primate distribution in the Uxpanapa Valley. Historical fire incidents have probably defined species distribution in this area, as records show that a widespread fire in 1998 affected 255,000 ha that included portions of

Uxpanapa Valley forests (Asbjornsen and Hernandez 2004). Nevertheless, there is insufficient data to examine to what extent this fire event impacted primates and their distribution at the time. Fires are now highly controlled in the area by special brigades formed by local inhabitants (Pers. Obs) and no other large scale fires have been reported for over a decade. Although my results do not show current fires affected primate distribution, these species would be highly vulnerable if a similar event to that of 1998 would occur.

Overall, contrary to what was expected, the current distribution of primates in the Uxpanapa Valley is not noticeably correlated to the threats that surround them, but these factors should be further examined, particularly on a smaller scale and for a lengthier period of time, as it has been shown that their long term effect on primate populations can be highly damaging (Mugume et al. 2015; Farris et al. 2014; Marsh 2013), and exacerbated within a transforming landscape (Laurance et al. 2012; Lande 1998). Finally, continued research that involves multifactorial explanations is key to understanding the determinants of primate distribution and abundance (Chapman et al. 2005).

In Chapter 4 the main aim was to establish whether bats and primates were found in the same areas, and specifically, whether there was a relationship between endangered/highly habitat-specific bat species diversity and primates in my study site. Primates are considered to be highly charismatic and can function as “umbrella species”, whereas other species which have high ecological and economic value, such as bats, are not usually considered as conservation emblems because of their lack of appeal for the general public. Establishing whether primates and highly sensitive/indicator species (such as bats) co-exist, would confirm conservation efforts directed towards primates benefits the biodiversity and ecosystems that bat species represent as "indicators" (meaning a species that is abundant, as well as ecologically, taxonomically and trophically diverse (Medellin et al 2000)). The first general linear model showed that overall, in areas with higher bat species diversity, the probability of finding greater numbers of spider monkey groups was increased. This result provides insight on a finer scale approach to understanding the environmental characteristics which may be influencing spider monkey distribution, and is relevant to establish the environment conditions in which these two species (spider monkeys and bats) are coinciding. However, no relationship was found between bats species diversity and the number of howler monkey groups. The association between bats and spider monkeys could be because both groups have highly specific habitat requirements, and points towards a great potential for primates to be used as umbrella species for bats and other taxa, both in Mexico and in the Neotropics. Primates represent good ecological indicators in tropical rainforests, being highly sensitive to habitat changes, hunting and other forms of disturbance (Cavada et al. 2016). In several countries, primates have been used to propose conservation sites (Smith et al. 1997; Hacker et al. 1998; Dinesen et al. 2001; Meijaard and Nijman 2003), but have been less used as umbrella species (Lambert 2011; Davenport et al. 2014). One of the most recent reviews on primate conservation, mentions that primates, for their seed dispersal capabilities alone, are essential components in tropical ecosystems worldwide and that because of their kinship with humans they have become a lightning rod for protection (e.g. umbrella species) (Norconck et al. 2011). Overall, my results indicate that using spider monkeys as an umbrella species provides possibilities not only for conserving bats and their habitat, but also as a means of selecting priority conservation sites to benefit biodiversity as a whole.

In Chapter 5, priority conservation sites were identified based on the factors that are linked to primate presence/number of groups, in order to provide information and develop maps to support conservation and comprehensive management for primates and biodiversity. In this sense, this works' aim is to provide stake holders and decision makers (e.g. Mexican government officials from the Secretariat of Environment, local municipality authorities and university researchers) with the necessary knowledge on the area, providing information that can aid in both the Protected Area zonation (which is currently lacking) and biodiversity conservation in the Uxpanapa Valley. This situation is common for most protected areas in developing countries, which hinders the PAs effectiveness in achieving the goals for which they were created (Sabatini et al. 2007). Overall, results show that priority site selection based on spider monkey data is a suitable approach for establishing conservation priorities within the Uxpanapa Valley, as large core areas, tall forest and coincidence with other species are highlighted in the results. Conversely, an approach based on howler monkey data appears to overestimate the extent of sites that are high priority for conservation, due to all forest types in the area (tall forest, mature secondary forest and secondary forest) being equally viable for their persistence, especially if they remain untouched. Howler monkeys are known to be resilient and inhabit a wide array of habitats throughout their distribution range (Bicca-Marques 2003) and to survive where other primates cannot (Estrada & Coates-Estrada, 1996). A clear example of this is shown in Nicaragua, where three species of primates (howler monkeys, spider monkeys and capuchin monkeys) co-habit within a habitat of varying degrees of transformation and protection; and overall howlers fared the best out of the three species, both in protected, good quality forest fragments and in unprotected, transformed ones (Williams-Guillen et al. 2013). Another example is found in the region of Los Tuxtlas, Mexico, where over 80% of habitat has been transformed or depleted and in which spider monkeys have almost gone locally extinct, while howlers continue to persist despite reduced forest fragment size and increase in secondary forest (Cristóbal-Azkarate and Dunn 2013). In this sense, where the aim is to prioritise areas to spend limited conservation resources, the scatter-gun approach based on such a plastic species is not particularly helpful. Furthermore, howler presence shows no association to bats as well as a high tolerance for disturbance, which would not favour conservation activities for less resilient species. Overall, my results show that integrating biological and geographical information through a SCP approach is useful to examine the different possibilities for conservation in an area. The flexibility of the SCP system also allows contributions from stakeholders and decision makers, including local inhabitants, which would potentially enrich the outcome of my work. This particular point would be one of the elements I would strive to incorporate in my future studies.

Recommendations

At a regional scope, the recommendations for the study site that stem from the obtained results are: a) prioritize resources and conservation actions for sites in which the Critically Endangered spider monkeys (*Ateles geoffroyi*) are present, which translates into protecting the larger, high quality vegetation areas also holding other endangered species (e.g. bats and large cats), b) designate the sites identified as high priority as core ‘no take’ zones within the Protected Area's zonation scheme, which will contribute to maximize conservation efforts within the area, c) develop further studies on human activities and their impacts at a landscape and species level and finally, d) work on connecting the large fragments within Uxpanapa Valley which will also lead to building and maintaining connectivity with adjacent forested areas of the Zoque Forest, ensuring habitat conservation and the maintenance of primates in the region. On a broader scale, using spider monkeys for selecting sites could be advantageous for developing species-based conservation strategies in the Neotropics, since throughout their distribution range, spider monkeys are associated quality habitat and are considered to be highly susceptible to habitat transformation and all the associated threats that come with it. Following this system, this approach could be implemented globally, as primates that have certain attributes (e.g. arboreal, frugivorous, dependant on high quality forest, seed dispersers, etc.) could potentially be used as a proxy for biodiversity conservation.

Lastly, this work could contribute towards enhancing management decisions, resource allocation and most importantly, the layout of the Uxpanapa Valley PA that would guarantee primate and biodiversity conservation. I intend to show the final outcome of my research to stakeholders (particularly government agencies directly linked to PA establishment in Mexico) through a series of workshops and meetings organized in collaboration with the state University (Veracruz University). I would also pursue presenting my results to local authorities in the Uxpanapa Valley and developing an educational campaign which would be offered to local inhabitants. This would constitute a further step to provide an applicable procedure for creating efficient Protected Areas, not only in Mexico, but also in those countries where forest maintenance is essential.

6. 2 References

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