

Does Population Increase Equate to Conservation Success? Forest Fragmentation and Conservation of the Black Howler Monkey

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Abstract

The Community Baboon Sanctuary (CBS) in Belize is a community reserve for the endangered black howler monkey (*Alouatta pigra*). This study assessed the performance of the CBS as an International Union for Conservation of Nature (IUCN) Category IV protected area through deforestation and forest fragmentation of the CBS and 500 m river buffer, and impacts on black howler monkey habitat over 15 years (1989–2004). Using satellite imagery remote sensing and landscape metrics, this study helps fill the gap in our understanding of forest fragmentation processes and habitat provision, using the black howler monkey as a specific example. Increased fragmentation resulted in decreased forest cover by 33% within both the CBS and river buffer. However, connectivity between habitat patches has remained high, indicating that dispersal and colonising potential between most forest patches has not been jeopardised. We conclude that conservation within the CBS may be more complex than simply equating forest conservation with black howler monkey conservation. One could say the CBS has been successful at black howler monkey conservation, as documented by population increases over the past 20 years. However, if the conservation objective is forest preservation, one could conclude conservation failure and may signal that the CBS should not be managed for a single outcome as assigned by an IUCN Category IV designation.

Keywords: Community Baboon Sanctuary, Belize, black howler monkey, forest fragmentation, landscape metrics

INTRODUCTION

Anthropogenic activities have led to forest cover loss worldwide, with forest fragmentation within developing tropical regions increasing rapidly (Rudel & Roper 1997;

Lamb *et al.* 2005; Abdullah & Nakagoshi 2007). Although an increasing body of literature provides valuable information on the ecological impacts of fragmentation, there is a gap in our understanding of the complicated relationship between forest patterns and habitat (Harrison & Bruna 1999; Haila 2002). This study helps in addressing this gap and examining the effects of an on-going, long-term community conservation effort on both habitat and wildlife, using the black howler monkey (*Alouatta pigra*) as an example.

Fragmentation, defined as the “breaking up of a habitat or cover type into smaller, disconnected parcels” (Turner *et al.* 2001: 3), affects forest habitat when large, continuous forests are divided into smaller blocks, either by roads, clearing for agriculture, urbanisation, or other human development (Kupfer

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et al. 2006). Fragmentation affects a variety of population and community processes over a range of temporal and spatial scales, with significant implications for biodiversity conservation (Saunders *et al.* 1991; Fahrig 2003; Vergara & Simonetti 2004). The concern with extensive deforestation is the resulting ‘forest island’ habitats within the fragmented landscape that can be more easily accessed for further degradation, such as over-hunting, ground fires, and logging (Cayuela *et al.* 2006). Habitat area loss and patch isolation can change predator-prey dynamics, competitive interactions, and species composition, which may affect community structure (Bollen & Donati 2006), reduce species diversity (Hill & Curran 2001), or lead to extinction of vulnerable species (e.g., Burkey 1995; Weaver *et al.* 1996). Smaller forest fragments can also result in the ‘empty forest’ syndrome (and often from human activity) where trees are still standing but the species that make up the complex ecosystem are not (Redford 1992; Robinson 1996). Characteristics that determine the principal effects of fragmentation are isolation (connectivity, surrounding landscape change, distance from other remnants, and time since isolation) and microclimate change (wind and edge effects, radiation, water fluxes). In addition, remnant size and shape, and position within the landscape can also influence the effect of fragmentation (Marsh 1999).

Landscape ecology seeks to understand spatial arrangements and their ecological effects, examining interactions between the spatial landscape structure, function, and temporal change. It is through the identification and quantification of landscape patterns that our understanding of these interactions between landscape structure and ecological processes develops (Turner *et al.* 2001). Studies on forest fragmentation have used island biogeography theory (within the landscape ecology discipline) to estimate species survival within fragments (Saunders *et al.* 1991; Redford 1992; Bierregaard & Dale 1996), the optimum size of fragments for species conservation (e.g., SLOSS; Single Large Or Several Small: Gilpin & Diamond 1980; Shafer 1995), and to predict species numbers (MacArthur & Wilson 1967; Wilcox 1980; Shafer 1995). Another theoretical framework for studying forest fragmentation out of landscape ecology—metapopulation theory—assesses the impact of habitat fragmentation on population viability.

Here, the focus is on a network of small patches and a single species, specifically dispersal among habitat fragments where inadequate dispersal and habitat loss past a certain critical threshold will lead to extinction (Harrison & Bruna 1999).

CONSERVATION OF FRAGMENTED FORESTS AND PRIMATES

Forest fragmentation has become a principal focus of conservation and ecological research on organisms in tropical regions, including primates (e.g., Clarke *et al.* 2002; Laurance *et al.* 2002). Research on the effects of deforestation on primates has largely focused on habitat degradation, reduction, and isolation (Andren 1994; Marsh 2003). When primate populations are isolated from each other because of habitat

fragmentation, continued habitat decline further endangers these populations (Estrada & Coates-Estrada 1996; Crockett 1997; Estrada *et al.* 1999). The severity of the effects of disturbance on a primate species depends on the composition and spatial layout of remaining habitat patches, such as shape, size, isolation from other habitat patches, and amount of edge habitat (Saunders *et al.* 1991; Collinge 1996).

The black howler monkey is found in Belize, northern Guatemala, and Mexico (Campeche and Quintana Roo, northern Chiapas, and parts of Tabasco states) (Horwich & Johnson 1986). Initial concern for the black howler monkey was stimulated by Smith (1970: 365), who suggested they prefer “extensive, undisturbed and mesic tropical forest” and were thought to be found primarily in low altitude areas that are below 1,000 ft (300m) above msl. However, more recent data suggest *A. pigra* also occur in high altitude areas (Baumgarten & Williamson 2007; Renner *et al.* 2007) and inhabit a wider range of evergreen and semi-evergreen forests, including disturbed and riparian forests (Horwich & Lyon 1990; Crockett 1997; Silver *et al.* 1998). In fact, Marsh (1999) regularly observed *A. pigra* using forest edges for feeding, travelling, resting, and howling.

For primates in general, body size and habitat specialisation have been considered the most important parameters related to extinction. However, diet requirements and social structure are also important survival factors, considering black howler monkeys are still found in small forest fragments despite being one of the largest New World primates (Marsh 1999), weighing between 6–7 kg (Horwich & Lyon 1990). Black howler monkeys are best described as a ‘folivore-fruitivore’ species (Crockett & Eisenberg 1987), and their adaptability in response to fragmented environments has been attributed to their flexible diets (e.g., Bernstein *et al.* 1976; Jones 1995). Combined, the black howler monkey’s ability to minimise energy expenditure through small home ranges (and short day ranges), relatively small troop size, and highly folivorous and flexible diets improves conservation likelihood (Milton 1980; Estrada *et al.* 1999; Bicca-Marques 2003; Fuentes *et al.* 2003). Nevertheless, concern for the black howler monkey stems from substantial habitat loss (56%) within the black howler monkey’s range, and their restricted geographic distribution in habitats that are being rapidly fragmented and converted for agriculture and pasture (Estrada *et al.* 2006). The black howler monkey is currently classified as endangered under the International Union for Conservation of Nature Red List of Threatened Species, with a predicted 60% population decline over the next 30 years if trends continue (IUCN 2010).

Belize Forests

In 1980, forests covered 75.9% of Belize’s land territory (Cherrington *et al.* 2010). During 1990–2000, however, Belize’s deforestation rate (2.3% per year) surpassed the Central American average (1.2% per year) (DiFiore 2002). By 2010, forest cover had declined to 62.7% of Belize’s land territory, representing an average annual deforestation rate

(over this 30 year period) of 0.6% and accounting for a decline of 17.4%, about fifth of the forest that covered Belize's territory in 1980 (Cherrington *et al.* 2010). Belize's northern districts showed the highest relative rates of deforestation between 1980 and 2010 with only a little over 50% of the original forest cover remaining by 2010 (Cherrington *et al.* 2010). The main driver encouraging deforestation and fragmentation of remaining forests in Belize is large-scale agriculture (Programme for Belize 2000; Cherrington *et al.* 2010). Other activities contributing to deforestation and fragmentation include cattle ranching, milpas (small-scale slash and burn farming), urban growth, and logging (Horwich & Lyon 1990).

Remote Sensing and Landscape Metrics

Along with retaining certain habitat areas, conservation strategies are increasingly focusing on the spatial configurations of habitats across landscapes (Pulliam *et al.* 1992; Schumaker 1996). Considering that some of the most threatened primate communities now survive only in fragmented forest habitats (Cowlshaw & Dunbar 2000; Marsh 2003), the quality and spatial characteristics of forest fragments plays an important role in understanding how to best conserve and manage current populations (Harcourt 2002; Fahrig 2003; Marsh 2003). To understand the tolerance of black howler monkeys to habitat fragmentation, information on forest fragmentation and rates of forest loss, along with population demographic information is needed (Estrada & Coates-Estrada 1996; Cuarón 2000). In addition, the potential for tools to link data from sources such as satellite imagery, forest cover, habitat fragmentation, and human land-use patterns is also needed to better understand fragmentation (Harrison & Bruna 1999), and the relationships between areas of human population and primate survival (Garber *et al.* 2006).

Remote sensing data provide information on the differences in land-cover characteristics on spatial and temporal levels and have been used on a wide range of analyses, one of which is forest change detection (e.g., Foody *et al.* 1996; DiFiore 2002; Southworth *et al.* 2004). Simply monitoring forest loss, however, will not detect distinct landscape configurational changes (Mertens & Lambin 1997). Quantification of landscape patterns improves our understanding of these interactions between landscape structure and ecological processes (Turner *et al.* 2001). Measuring fragmentation (e.g., habitat and forest fragmentation) is one way to quantify landscape pattern, and forest fragmentation studies commonly apply landscape metrics (e.g., Nagendra *et al.* 2006; Gillanders *et al.* 2008; Serra *et al.* 2008). Specific spatial characteristics of patches, classes of patches, or entire landscape mosaics can help interpret the effects of forest loss and fragmentation (McGarigal *et al.* 2002; Long *et al.* 2010). The sensitivity of landscape metrics to changes in levels of forest loss demonstrates their importance in assessing and monitoring forest fragmentation (Trani & Giles 1999; McGarigal *et al.* 2002). Not all fragmentation metrics can capture the entire extent of forest fragmentation in a particular landscape (Cain *et al.* 1997). One major reason

for this points to high correlation and redundancy between some metrics (McGarigal & Marks 1994; Turner *et al.* 2001). Another issue with the use of multiple metrics has been a perceived lack of interpretability (Haines-Young & Chopping 1996). In large part, this is because there have been few attempts to analyse associations between land-cover level and processes at a land-use level, or even between land-cover and the biophysical structure of the landscape (Griffiths & Mather 2000).

This study assessed forest fragmentation within the Community Baboon Sanctuary (CBS) in Belize, a community reserve that has existed since 1985 with little monitoring of deforestation and, more specifically, fragmentation of forest habitat of the black howler monkey, the impetus for the creation of the CBS. This study focuses on the following objectives: 1) to examine forest cover change of the CBS landscape and 500 m river buffer from two time periods over 15 years (1989 and 2004); 2) to assess how forest habitat for the black howler monkey has changed over this 15 year time period and how much suitable habitat exists (in 2004, the last image date used in this study), based on minimum patch size and distance requirements; and 3) to assess the performance of the CBS as an IUCN Category IV protected area in terms of forest cover and fragmentation results and black howler monkey populations (from past population surveys).

MATERIALS AND METHODS

To assess the overall conservation status of the CBS as an IUCN Category IV protected area, the following methods were incorporated to address study objectives: remote sensing of satellite imagery was used to examine forest cover change of the CBS landscape and 500 m river buffer (objective 1). Landscape metrics, algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics were employed to assess forest fragmentation and habitat change for the black howler monkey, as well as the amount of remaining suitable habitat in 2004 (objective 2). Lastly, results from remote sensing and landscape metrics were combined with past surveys of black howler monkey populations and population densities within the CBS to assess CBS conservation performance (objective 3).

Study Site: The Community Baboon Sanctuary

The CBS in Belize (17° 33'N, 88° 35'W), an IUCN Category IV protected area, totals approximately 8700 ha (this comprises the greater CBS area to include the actual village townships) and was established in 1985 to protect black howler monkey populations and their forest habitat (Figure 1). An IUCN Category IV protected area aims to "... ensure the maintenance of habitats and/or to meet the requirements of specific species" (IUCN 1994). The creation of the CBS was the effort of two scientists and a local non-governmental organisation that worked with private landowners within seven villages to protect riparian forest landscapes (Horwich & Lyon 1990). Located in the

climatic region of north-central Belize, the forests of the CBS are classified as lowland, semi-deciduous rainforest (Horwich & Lyon 1990). Today the CBS is a patchwork of secondary forests from 10 to 75 years old, interspersed with cleared areas and secondary growth from 300 years of periodic logging (Horwich & Lyon 1990). There is concern that residents have realised few financial benefits from tourism and a conservation pledge intended to deter deforestation (see Wyman & Stein 2010). Despite this general dissatisfaction by residents, black howler monkeys are not threatened by local residents. Black howler monkeys only occasionally damage crops and are rarely killed as agricultural pests (Crockett 1997). Furthermore, past studies show positive views towards black howler monkeys and their protection, with residents recognising their local abundance and tourism attraction (e.g., Hartup 1994; Bruner 1993). Additionally, black howler monkeys are the only primate species within the CBS with little hunting or predation threats (Silver *et al.* 1998; Jones & Young 2004).

Remote Sensing

Image Pre-processing

Remote sensing enables an assessment of the CBS to protect the forest habitat of the black howler monkey and offers a unique opportunity for long-term assessment. Remote sensing was used to address the study's first objective to conduct a change detection analysis from a 1989 Landsat TM image and a 2004 Landsat ETM+ image, to evaluate rates and trends of forest change within the CBS and 500 m Belize River buffer over 15 years. To decrease errors associated with seasonal variations on biophysical properties and subsequent change detection analyses, both images were taken between November (10 November 2004) and December (27 December 1989), corresponding with the study site's dry season, as most of the year's rainfall occurs from May to October (Belize National Meteorological Service 2005). Dry season images are favourable for the region for many reasons, including less cloud cover and soil and vegetation moisture, which is advantageous for discriminating forest. Preceding year/month climate information of the area, in particular precipitation levels, were obtained and considered for the change analysis process, considering that extremely wet or dry conditions on one of the dates can cause serious change detection issues (Jensen 2005).

For the ETM+ image, the Scan Line Corrector (SLC off) malfunction originally left data 'stripes' across the scene. Because the study area was located in the centre of the image, it was not necessary to replace any missing image pixels with one or more 'fill' scenes acquired on a separate date (as is the case with other sections of the image). Image processing and spatial analyses were performed in Erdas Imagine and ArcGIS. Radiometric calibration and atmospheric correction procedures (Green *et al.* 2000) were conducted to correct each Landsat band for sensor, illumination, and atmospheric sources of variance (Jensen 2005). Geometric correction of the 2004 image was performed using a 1:50,000 scale map of the study area from the Land Information Center in Belize (UTM

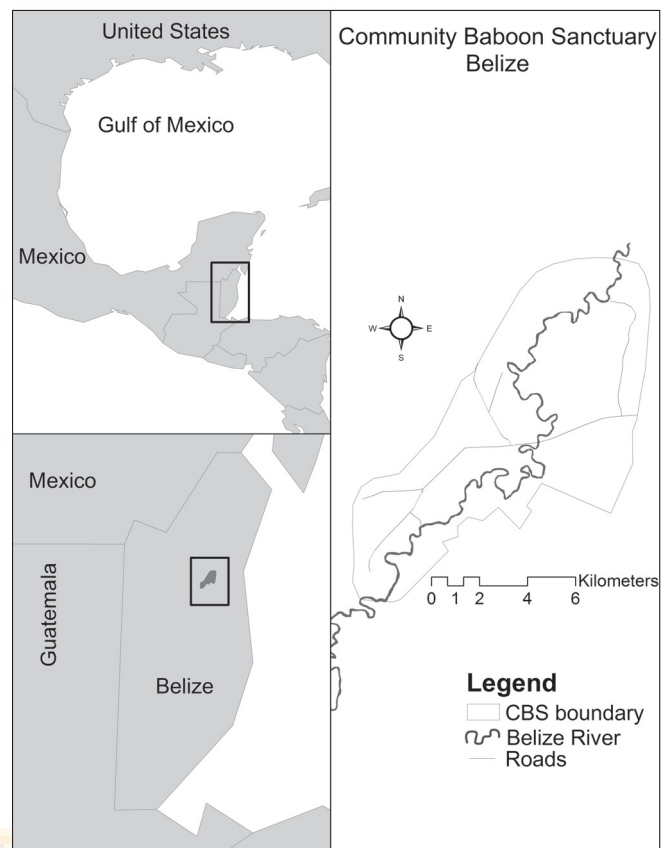


Figure 1

Map of the Community Baboon Sanctuary in Belize, Central America

Zone 16, WGS 1984). Image-to-image registration was then performed using points from the already rectified 2004 image to register the 1989 satellite image. The root mean square error of each registration was maintained below 0.5 pixels (<15 m).

Image classification

A hybrid supervised/unsupervised classification was conducted on the satellite images. In a supervised classification, the identity and location of some of the land-cover types (e.g., forest, agriculture, wetlands) are known a priori through a combination of fieldwork, map analysis, and personal experience (Hodgson *et al.* 2003); these are commonly referred to as 'training samples' because their spectral patterns are then used to train the computer to recognise such patterns in the image data for the unsupervised classification. The unsupervised classification evaluated the separability between classes represented in the Landsat imagery to provide guidance for the supervised classification (Jensen 2005). This procedure generated 60 initial classes on the 2004 image, separating the pixels with similar spectral characteristics and spectral clusters.

To begin with, ground truthing of the 2004 image was conducted from October to December, 2005 within the CBS. Other qualitative descriptions, including photographs, were recorded for reference and comparison with classified maps and satellite imagery. Informal interviews with landowners and personal observations added information on land-cover

and land-use. Sixty-six training sample points (31 for 'forest' and 35 for 'non-forest'), including as many different types of land-cover in and around the CBS were taken as possible. The forest class was defined as having a canopy cover of 25% or above, which was based on the following information: Belize's Designated National Authority to the UN Framework Convention on Climate Change's Clean Development Mechanism defines forests as having at least a 30% crown cover (UN Framework Convention on Climate Change 2010), data from a study conducted within the CBS that estimated deciduous forest habitat to have between 40–75% canopy cover and riparian forest habitat to have between 65–100% canopy cover (Jones unpubl. data), knowledge that black howler monkeys inhabit a wide range of evergreen and semi-evergreen forests including disturbed and riverine forests (Crockett 1997), and an estimate based on our assessment and knowledge of the black howler monkeys' tolerance within the CBS to some fragmentation and less dense forests. The qualitative analysis (e.g., training sample points, map analysis, photographs, etc.) allowed separation into the following classes: bare soils/built, forest, pasture, agriculture, water, and wetlands. Using reference data collected training samples and GPS point data, the spectral clusters from the unsupervised classification were re-labelled and combined for each of the six land-cover classes. After classification, non-forest classes (both natural and anthropogenic non-forest areas) were merged into a final non-forest class (NF). The other class was a forest (F) class (Figure 2). An accuracy assessment on the 2004 classified image resulted in a producer's accuracy of 86% (F) and 84% (NF) and a user's accuracy of 81% (F) and 89% (NF) for an overall classification accuracy of 85% and an overall Kappa Statistics of 69%. Thomlinson *et al.* (1999) set as a target an overall accuracy of 85% with class accuracy not less than 70%.

The 1989 image was then classified through comparison with signature mean plots of 2004 classes, and also contrasting vegetation in ArcGIS using the NDVI (Normalized Difference Vegetative Index) and the thermal band. A NDVI is a vegetation index used to indicate the relative abundance and activity of green vegetation using the normalised ratio of the near-infrared and red bands (Jensen 2005), and was used to better distinguish between forested and non-forested vegetation to assist with the supervised classification. NDVI is an important vegetation index because it can be used to monitor seasonal and inter-annual vegetation growth and reduce noise that may be present in an image, including topographic variations, cloud shadow, and sun illumination differences (Jensen 2005). Changes in NDVI values from vegetation re-growth or forest clearing can also be detected between two or more time period images (Sader & Winne 1992). The result of the classification process was the creation of 'forest' and 'non-forest' classifications for the two image dates (Figure 2).

Landscape Metrics

Landscape metrics have several important applications in conservation, including the investigation of scale effects in describing landscape structure (O'Neill *et al.* 1996; Turner *et*

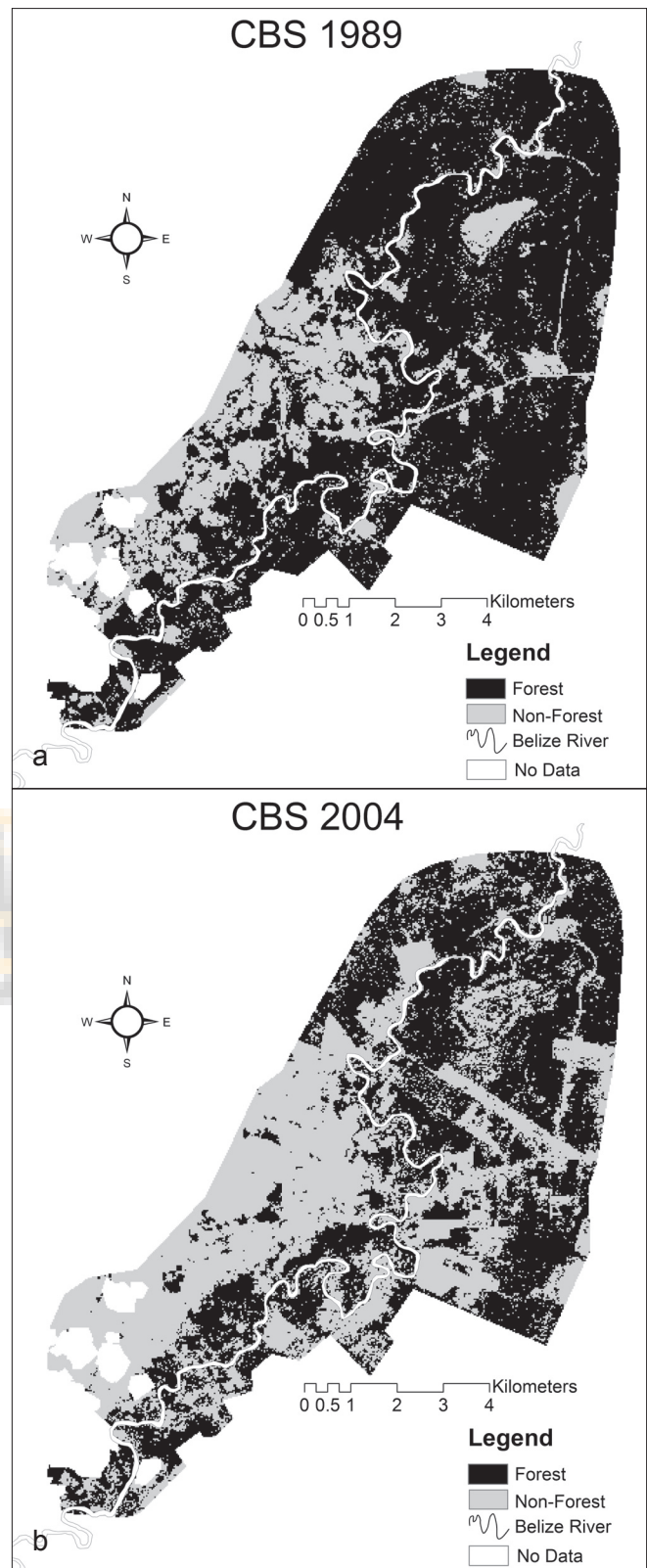


Figure 2
CBS forested and non-forested landscape in: a) 1989 and b) 2004

al. 1989), other landscape change descriptions (Dunn *et al.* 1991; Frohn *et al.* 1996), and detecting habitat fragmentation, biodiversity, and landscape pattern (Gardner *et al.* 1993; Keitt *et*

al. 1997). Measuring fragmentation (e.g., habitat fragmentation and forest fragmentation) is one way to quantify landscape pattern. The effects of forest loss and fragmentation can be interpreted with landscape metrics, algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics (McGarigal & Marks 1994). This study's second objective was addressed using Fragstats software (McGarigal *et al.* 2002) to conduct landscape metrics on the 1989 and 2004 classified images. Fragstats provides a comprehensive set of spatial statistics and descriptive metrics of pattern at the patch, class, and landscape levels (Haines-Young & Chopping 1996). When working with landscape metrics, one is confronted with the question of selecting indicators that are not repetitive and those that are relevant for the area and the research question under investigation (Lausch & Herzog 2002). Given the important habitat needs of black howler monkeys, i.e., size, number of patches (Saunders *et al.* 1991; Collinge 1996), and their dispersal needs, i.e., distance between patches, patch aggregation (e.g., Onderdock & Chapman 2000; Pozo-Montuy & Serio-Silva 2003), the following metrics were analysed: patch size, total patch count, mean patch area, median patch area, ENN (Euclidean Nearest Neighbor distance, a patch-level analysis), and Clumpy metrics (class-level analysis). These are functional metrics that explicitly measure landscape pattern relevant to the species under consideration and the developed research objectives. Complete descriptions of these metrics, and equations for their calculation, are provided in McGarigal & Marks (1994).

The ENN metric measures distance (in m) to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance, and is used extensively to quantify patch isolation. The clumpiness index (Clumpy) metric measures pixel adjacencies (the frequency that a patch type appears next to another similar patch type on the map) (McGarigal *et al.* 2002). With a range between -1 and +1, '-1' indicates the focal patch type is maximally disaggregated, '0' indicates the focal patch type is distributed randomly, and '1' indicates the patch type is maximally aggregated. To assess the suitability of black howler monkey habitat using fragmentation metrics, the following criteria were used: 1) A forest patch must be greater than or equal to 1.21 ha (Horwich 1998; Belize Zoo 2006), and 2) To be considered connected, forest patches must be less than or equal to 60 m apart. Although 50 m appears to be the

more appropriate distance, based on studies by Onderdock & Chapman (2000), Pozo-Montuy & Serio-Silva (2003), and our own data, 60 m was chosen as the distance because of the 30 m pixel size of the satellite images used. For statistical analysis, Chi-square tests were conducted to assess whether ENN (using the proportion of patches that met this requirement) differed significantly ($P \leq 0.05$) across dates.

To address this study's third objective, remote sensing and landscape metrics results were compared with past surveys of black howler monkey populations and population densities within the CBS. Black howler monkey surveys were conducted using the following methodology: surveys were carried out within a 4.05 sq. km study area (1985) and in a 0.63 sq. km primary study site (from 1990 to 1999, except for 1993) (Horwich *et al.* 2001a, 2001b). For our study, the actual counts of black howler monkeys have been multiplied by the CBS area considered black howler monkey habitat (47 sq. km), as well as by only forested areas, to make a more accurate estimate of the total population (Table 1). A survey conducted in 2003 was carried out in a similar manner: 1581 individuals were counted covering a portion of each of the seven CBS villages. Since the exact area surveyed in 2003 is unknown, we have not used that data. For our 1985 extrapolation, we used the 1989 and 2004 percent forest loss to get an average percent forest loss per year. For our 2004 extrapolation, we used the start (1985) and end (1999) densities from Horwich *et al.* (2001a, 2001b) to get an average yearly density increase, then multiplied this times the hectares of forest in 2004 to get our 2004 population estimate.

RESULTS

CBS Landscape

Forest cover has decreased within the CBS landscape and the 500 m river buffer over the 15 year time period. Despite increased forest fragmentation, there is still high connectivity between forest patches. In 2004, 47.61% of the CBS landscape was forest, a 33% relative decrease in forest cover from 1989 (70.87%) (Table 2; Figure 2). The results were similar for the 500 m river buffer, decreasing from 74.34% in 1989 to 50.64% in 2004 (Table 2; Figure 3).

The total number of forest patches within the CBS landscape in 2004 (n=1323) was more than twice the number found in

Table 1
Population estimates of black howler monkey population for 47 sq. km area within the Community Baboon Sanctuary

Year	^b 1985	1988	1990	1991	1992	1993	1995	1996	1997	1998	1999	^c 2004
Density (individuals per sq. km)	31.85	33.33	103.17	98.41	96.83	89.52	166.67	142.86	171.43	163.49	178.19	230.45
% forest	75.52	70.87							57.80			47.61
sq. km forest	35.5	33.3							27.2			22.4
Population estimate 47 sq. km	1497	1567	4849	4625	4551	4207	7834	6714	8057	7684	8375	10831
^a Population estimate (forested areas only)	1130	1110							4657			5162

^aThe 'forested area only' population estimates are based on densities from Horwich *et al.* 2001a, 2001b. ^bEstimates for 1985 are based on % forest in this study.

^cEstimates for 2004 are based on extrapolations from earlier data.

1989 (n=628), with the mean patch area in 2004 decreasing to one-third (Table 3). The number of forest patches that met the 1.21 ha or greater size requirement was 48 of 628 (7.64%) in 1989 and 102 of 1323 (7.71%) in 2004. Although the mean patch area in 2004 decreased by one-third, the median patch size for both years was the same (0.09) (Table 3). This can be explained by several large patch sizes in 1989 that acted as outliers and adjusted the average mean patch size.

Considering forest patches must be less than or equal to 60 m apart to be considered connected, the ENN metric result indicates that in 1989, 510 of 628 of CBS forest patches (81.2%, covering 76.95 ha) met this requirement. In comparison, in 2004, 1025 of 1323 forest patches within the CBS (77.5 %, covering 141.84 ha) were within this 60 m distance from other forest patches (Table 3). For patches greater than or equal to 1.21 ha in size, 44 of 48 patches within the CBS in 1989 (91.7%, covering 6041.52 ha) and 96 of 102 patches within the CBS in 2004 (94.1%, covering 69.93 ha) met this criteria (Table 3). A Chi-square test confirmed that the proportion of CBS forest patches greater than or equal to 1.21 ha in size that had other forest patches within 60 m did not differ significantly ($P = 0.57$, $df = 1$) across dates.

CBS River Buffer

The patch-level analysis of the river buffer shows patterns comparable to the CBS landscape. The total number of forest patches within the river buffer in 2004 (n=669) was greater than twice that amount in 1989 (n=267). Although the mean patch area in 2004 decreased by over two-thirds, the median patch size for both years was the same (Table 3). As within the CBS, this can be explained by several large patch sizes in 1989 that adjusted the average mean patch size.

The ENN metric result indicates that in 1989, 233 of 267 (87.3%, covering 17.37 ha) forest patches within the river buffer were within this 60 m distance from other forest patches. In comparison, 545 of 669 (81.5%, covering 52.92

ha) forest patches in 2004 within the river buffer met this criteria (Table 3). For patches greater than or equal to 1.21 ha in size, 16 of 17 (94.1%, covering 2183.94 ha) patches within the river buffer in 1989 and 62 of 64 (96.9%, covering 1408.14 ha) patches within the river buffer in 2004 met this criteria (Table 3). A Chi-square test confirmed that forest patches greater than or equal to 1.21 ha in size within the river buffer did not differ significantly ($P = 0.59$, $df = 1$) across dates.

The 2004 Clumpy values for both forest and non-forest patches decreased slightly as compared to the 1989 Clumpy values (Forest = 0.6599 [1989], 0.6499 [2004]; Non-forest = 0.6602 [1989], 0.6455 [2004]). Values for both forest and non-forest patches indicate these classes are fairly aggregated within the CBS landscape (Table 4). Clumpy values within the river buffer were also similar for both forest and non-forest classes across both time periods (Table 4).

Black Howler Monkey Survey Information

Past survey information shows CBS black howler monkey populations and densities have increased (Table 1) from an estimated 1130 individuals in 1985 to an estimated 5162 individuals in 2004; this increase compares to the high end estimate of 3000–5000 individuals of the 2003 survey results of Brockett (2003). The last survey to show black howler monkey densities, conducted in 1999, estimated densities as high as 178 individuals per sq. km (Horwich *et al.* 2001b), the highest ever recorded in the literature for black howler monkeys.

DISCUSSION

Relative forest cover declined in both the CBS (33%) and the 500 m river buffer (32%) between 1989 and 2004. This relative decrease within the CBS is actually higher than trends for the Belize district (where the CBS is located) (11%) for these same dates, or northern Belize (16.8%) comprised of Belize, Corozal, and Orange Walk districts (Cherrington *et al.* 2010)

Table 2

Area (ha) and percent land-cover of forested and non-forested landscapes in 1989 and 2004 of the CBS landscape and the 500 m river buffer

Year	CBS landscape	Total area (ha)	Land (%)	Year	500 m river buffer	Total area (ha)	Land (%)
1989	Forest	6167.79	70.87	1989	Forest	2231.37	74.34
1989	Non-forest	2535.75	29.13	1989	Non-forest	770.4	25.66
2004	Forest	4144.05	47.61	2004	Forest	1520.01	50.64
2004	Non-forest	4559.49	52.39	2004	Non-forest	1481.76	49.36

Table 3

Forest patch-level analysis of the CBS landscape and the 500 m river buffer

Landscape	Year	No. of patches \geq 1.21 ha	Total no. of patches	Mean patch area (ha)	Median patch area (ha)	No. of total ENN patches	No. of ENN patches \geq 1.21 ha
CBS	1989	48	628	9.8213	0.09	510	44
CBS	2004	102	1323	3.1323	0.09	1025	96
River	1989	17	267	8.3572	0.09	233	16
River	2004	64	669	2.2721	0.09	545	62

Forest patch-level analysis of the CBS landscape and 500 m river buffer from two different years (1989 and 2004) from the following metrics: number of patches \geq 1.21 ha, total number of patches, mean patch area, median patch area, number of ENN patches for total patches and for patches \geq 1.21 ha.

for these same dates. In addition, from 1989 to 2004 there has been a major increase in the number of forest patches in both the CBS and river buffer. Although the number of forest patches

has increased, the overall median patch size has not changed.

Although only a small proportion of forest patches meet the 1.21 ha or greater size criteria, a majority of the forest patches are highly connected, indicating that dispersal potential has not been jeopardised. Patch continuity was a project goal (Lyon & Horwich 1996) in which a connected skeletal forest network of aerial pathways was to be maintained as continuous corridors, even if the private landowners used most of their forested lands for agriculture. Additionally, both forest and non-forest patches within the CBS landscape and river buffer are fairly aggregated. While aggregation of forest patches is beneficial for black howler monkey movement, the fact that non-forest patches are also aggregated (Table 4) may impact dispersal across these areas and create increased fragmented 'islands' of forest and non-forest habitats.

We used habitat criteria for the black howler monkey to assess current habitat suitability (forest patches greater than or equal to 1.21 ha and less than or equal to 60 m apart). Using this criteria, in 2004 this comprised 44.72% (3892.43 ha) of the CBS landscape and 46.74% (1403 ha) of the 500 m river buffer (Table 5). Considering that a landscape with less than 30% habitat connectivity is considered poor fragment connectivity (Mandujano *et al.* 2006), the CBS has not yet met this threshold. Although black howler monkeys may need forest patches greater than or equal to 1.21 ha for survival processes (foraging, resting, etc.), they can still travel through forest patches smaller than 1.21 ha, as long as they are less than or equal to 60 m apart (e.g., forest corridors). Considering this, forest patches that met the distance requirement of 60 m from other forest patches were 44.86% (3904.61 ha) of the CBS landscape and 49.79% (1494.58 ha) of the 500 m river buffer (Table 5).

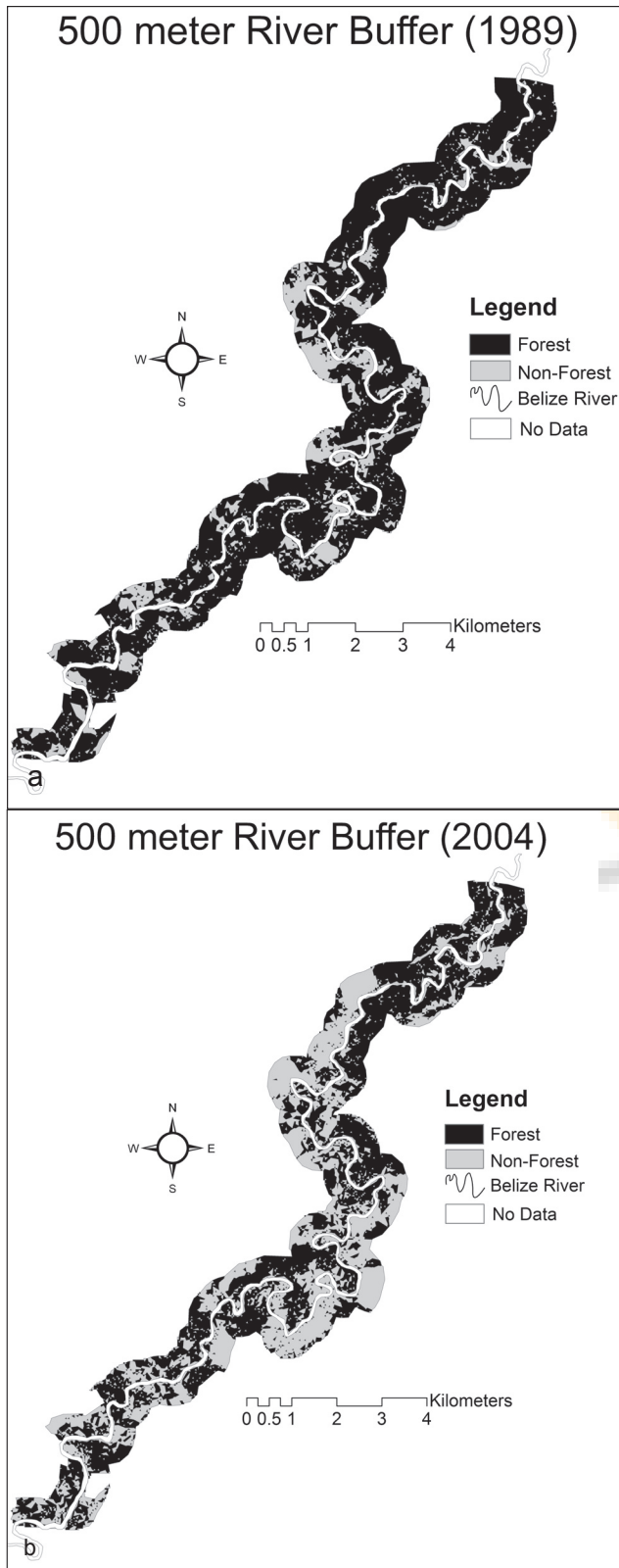


Figure 3
CBS 500 m river buffer landscape in: a) 1989 and b) 2004

Table 4

Class-level analysis of the CBS landscape and the 500 m river buffer

Landscape	Vegetation	Year	Clumpy
CBS	Forest	1989	0.6599
CBS	Non-forest	1989	0.6602
CBS	Forest	2004	0.6499
CBS	Non-forest	2004	0.6455
River	Forest	1989	0.4981
River	Non-forest	1989	0.5338
River	Forest	2004	0.5494
River	Non-forest	2004	0.5540

Class-level analysis of forested and non-forested patches within the CBS landscape and 500 m river buffer from two different years (1989 and 2004) from Clumpy metric

Table 5

Suitable black howler monkey habitat looking at two different criteria: A) forest patches ≤ 60 m from another and B) forest patches ≥ 1.21 ha and forest patches ≤ 60 m from another in 2004 within two different landscapes (entire CBS area and 500 m river buffer within the CBS)

Criteria	Landscape	Year	Landscape (%)
A. Forest patch ≤ 60 m from another	CBS	2004	44.86
	River	2004	49.79
B. Forest patch ≥ 1.21 ha AND forest patch ≤ 60 m from another	CBS	2004	44.72
	River	2004	46.74

Despite increased deforestation and forest fragmentation of the CBS landscape and the 500 m river buffer, obtained survey information shows black howler monkey populations have dramatically increased from an approximate estimate of 1130 individuals in 1985 (Table 1) to an estimate of over 5000 individuals in 2004 (Brockett 2003; Table 1). It should be noted that along with black howler monkey population increases within the CBS, black howler monkey population densities have also dramatically increased over the past 20 years. Past studies within the CBS indicate black howler monkey densities have increased from 31.9 individuals per sq. km in 1985 to as high as 178 individuals per sq. km in 1999 (Horwich *et al.* 2001a, 2001b), overcrowding forest fragments (Silver *et al.* 1998; Ostro *et al.* 1999; Horwich *et al.* 2001b). Additionally, the 2003 howler population survey (Brockett 2003) found increased overlap in troop home ranges, multi-male troops, and the first documented observance of infanticide associated with male takeovers, all of which has been attributed to high population densities (and none of which had been observed in past surveys).

Several factors may explain black howler monkey population increases with increased deforestation and forest fragmentation within the CBS. First, habitat disturbance has less effect on primate species that rely on leaves for their diet (Crockett 1997), with folivores recovering much faster from habitat disturbance than frugivores (Johns & Skorupa 1987). The black howler monkey's description as a 'folivore-frugivore' species (Crockett & Eisenberg 1987) and their dietary flexibility (Milton 1980; Silver *et al.* 1998) probably explains their ability to subsist in a variety of habitats, including forest fragments (Horwich & Johnson 1986; Crockett 1997; Ostro *et al.* 1999; Rivera & Calme 2005). Spider monkeys (*Ateles geoffroyi*), in comparison, are less flexible in food species selection and often cannot survive in fragmented areas (Neville *et al.* 1988).

Secondly, black howler monkey populations can bounce back from disease, hurricanes, and drought where they, and their habitats, are protected (Crockett & Eisenberg 1987; Horwich & Lyon 1987; Crockett 1997), and can exist in disturbed and fragmented forests, and in close proximity to human populations, when there are no hunting pressures (Crockett 1997). Considering that black howler monkeys are not hunted within the CBS and have few predators (Silver *et al.* 1998; Jones & Young 2004), these factors may also contribute to their growing population here. A third reason for the increased black howler monkey population within the CBS may be the composition of the forests that leads to natural rapid reforestation. Of the 102 tree species within the CBS, 66% re-sprout after cutting or burning and thus have a vegetative regeneration capacity; of the 25 most common species, 76% have this property (Lyon & Horwich 1996). New leaves of these regenerating forests have more protein and less toxins which make them more edible by folivores. Additionally, the CBS forest is composed of a mixed successional composition that gives black howler monkeys access to a wide variety of food in a small forest patch (Lyon & Horwich 1996). The high productivity of the secondary vegetation may also help maintain high population densities (Arroyo-Rodríguez & Dias 2010).

Although black howler monkeys appear to be adaptable to habitat fragmentation and have increased in population within the CBS over the past 20 years, in the long run increased forest fragmentation may not ensure their population viability (Bicca-Marques 2003). For example, even though black howler monkeys have been found to travel across cornfields and grasslands in Mexico (Pozo-Montuy & Serio-Silva 2003; Mandujano *et al.* 2004), long-distance terrestrial movement of arboreal primates is relatively uncommon and most likely reflects a scarcity of resources such as food, shelter, and refuge from predators (Olupot & Waser 2001; Baum *et al.* 2004). Decreases in reproductive potential and inbreeding are likely, if fragmentation impacts connectivity and prevents dispersal opportunities between forest fragments (Crockett 1997; Estrada & Coates-Estrada 1996; Clarke *et al.* 2002). Neotropical primates in isolated fragments (inhibiting migration) that experience population declines below a certain threshold are prone to extinction (Coelho *et al.* 1976).

STUDY LIMITATIONS

The distances between forest patches that primate species will travel is not well known or documented within the literature and has only been estimated by a few studies to be ranging from 50 m to 2.6 km—50 m (Onderdock & Chapman 2000), 80 m (Pozo-Montuy & Serio-Silva 2003), 150 m (Mandujano *et al.* 2006), and 2.6 km (Estrada *et al.* 2006). It is possible that this study may have underestimated this distance (60 m) but this was chosen with consideration from these studies' estimates for various primate species, and the short distances we have observed black howler monkeys within the CBS to routinely traverse. Additionally, considering the 30 m pixel size of the satellite image used (Landsat) and Fragstat's method for measuring distance (cell centre to cell centre), the chosen distance needed to link with the 30 m pixel size. Our forest/non-forest classification may also have been limiting for primates who have preferences for specific types of forest vegetation. However, this was the rationale behind including the 500 m river buffer (riparian and seasonally flooded forests within the CBS) in the study focus area. Although this is the preferred forest habitat for black howler monkeys (and the conservation focus within the CBS), they will travel through other forest habitat. Furthermore, the CBS is a protected area, and this study sought to assess conservation in its entirety, including forest cover throughout the village townships.

CONCLUSION

This study is one of the few examining the effects of an ongoing, long-term community conservation effort on both habitat and wildlife to contribute to our knowledge regarding the relationship between forest patterns and habitat, using the black howler monkey as an example. Results show a 33% relative decrease in forest cover within the CBS and the 500 m river buffer between 1989 and 2004, with increased fragmentation of forest habitat. However, connectivity between

forest patches is presently high, indicating that dispersal and colonising potential between most forest patches has not been jeopardised. Reaching a verdict on the effectiveness of conservation within the CBS may be a little more complex than merely saving forests and, therefore saving black howler monkeys within the CBS, as forest fragmentation has not led to a decrease in black howler monkey populations. As an IUCN Category IV protected area, the aim is "...to ensure the maintenance of habitats and/or to meet the requirements of specific species" (IUCN 1994). Therefore, if the conservation objective is the black howler monkey, one could say the CBS appears to be succeeding, at least in the short term. However, if the conservation objective is forest preservation, it appears not to have succeeded. Additionally, having more connected forest patches might not be good news for conservation of black howler monkey habitat, but part of the deforestation process. And if trends continue, at some point deforestation and fragmentation will reach a level where dispersal among patches will not be possible, or population densities will reach their carrying capacity and populations will begin to decline. This may signal that the CBS should not be managed for a single (or narrow) outcome (e.g., black howler monkeys) as the IUCN Category IV protected area designation indicates. Continued monitoring should be conducted within the CBS on both black howler monkey populations and densities, and forest cover change and fragmentation to better advise community management decisions. Future research within the CBS could also complement and build on this study by identifying the occupied and unoccupied patches within the CBS, including their size and distance to other patches, to better assess dispersal and persistence probability of black howler monkeys.

Given this black howler monkey/forest dichotomy, there are two interconnected concerns: 1) using the focal species concept and 2) conservation of private lands. Although the CBS was initiated with the focal species concept, ecosystem and forest protection was always intended. The main problem that was recognised from the start of the CBS was in experimenting with private lands in which landowners expect to use their lands as they please for their livelihood. Thus, any conservation effort on private lands by its very nature has to be rooted in the voluntary commitment of the landowner. Furthermore, any commitment will be temporary and tied to a single owner unless there is a legal mechanism. Since there was a concern that few financial benefits were received from tourism, and the cooperative agreements intended to deter deforestation (see Wyman & Stein 2010), use of a voluntary legal mechanism which would appeal to the common good, yet would not detract much from the rights of landownership would be needed.

Thus, we recommend for the CBS an active campaign to involve landowners in creating better connectivity of forest fragments through permanent easements along property boundaries to protect the lands in perpetuity. Such easements are commonly used in the USA and elsewhere by landowners to give up development rights to ensure the protection of

the forests in perpetuity. The Nature Conservancy and other conservancies or government agencies then monitor that the laws are followed even after the landowner dies or sells the land. A recent Conservation Covenant Act (2009) enacted by the Government of Belize seems to be a similar law that could be used by the CBS for getting landowners to sign easements along their property boundaries to maintain corridor forests between fragments to increase patch continuity. Even then, one must consider a landowner conflict of interest on how much land they can afford to give up and not jeopardise their own livelihoods. That was the idea of the safety net of the conservation pledge in 1985, to leave a minimal skeletal connected forest (Lyon & Horwich 1996: Figure 11-4) which was a mechanism to at least retain connectivity for genetic flow.

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