# Jaguar monitoring in the Chiquibul Forest, Belize

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***Summary:*** *La Selva Maya constitutes the largest intact rainforest in Central America and a core area on which to base jaguar conservation. Jaguar range has been reduced by over 50 percent due to habitat destruction and hunting. Wary, elusive, and difficult to study, little is known of their population status, making jaguar conservation problematic. This study employs infrared, remotely-triggered cameras combined with mark-recapture statistics to estimate jaguar density in the Chiquibul Forest Reserve of Belize within La Selva Maya. Over a two month camera trapping period with 486 trap nights, 7 individual jaguars were photographed. The effective area surveyed was 117 km$^2$ with an abundance estimate of 8 individuals, resulting in a density of 7.48 jaguars per 100 km$^2$. In addition, 27 other species were photographed with the highest trap success exhibited by opossums and peccaries. Camera trapping provides an effective way to monitor jaguars and, over the long term, will yield more information such as survival and recruitment. While the Chiquibul Forest is relatively undisturbed, jaguars may still be at risk due to a proposed dam project and poaching by refugees.*

***Key Words***
*CONSERVATION BIODIVERSITY MAYA FOREST BELIZE*

## Introduction

The Chiquibul Forest of Belize lies within La Selva Maya (The Mayan Forest), a unique geographic region containing the largest remaining intact tropical rainforest in Central America. It forms part of the Mesoamerican Biological Corridor, the largest and most complex sustainable development project to date which seeks to develop a corridor of protected natural habitat the length of Central America from southeast Mexico to Columbia. The governments of La Selva Maya (Belize, Guatemala, and Mexico) have expressed their intent to maintain the integrity of this region and, to this end, have established BIO-MAYA, a database on the status of its plants and animals (Carr & de Stoll, 1999). The Chiquibul Forest contains relatively undisturbed wildlife population. It therefore can yield data from 'healthy' populations which will contribute to the tri-national database as a verifiable way to measure ecosystem health.

Obtaining data on wildlife, and in particular, felids, in tropical rainforests is difficult due to their elusive nature, nocturnal habits, and wide-ranging behaviour. Consequently, we know little of their population structure or ecology despite their endangered status (Nowell & Jackson, 1996). For example, the jaguar (*Panthera onca*) is the largest cat in the Americas and the least studied of all large wild cats (Valdez, 2000). Jaguars have been extirpated from 54 percent of their historic range and their current distribution is broken up into smaller habitat fragments of varying sizes (Sanderson *et al.*, 2002). Without basic information from healthy populations on demographic parameters such as population size, density, sex ratio, and survival, it is impossible to provide management suggestions for the conservation of such species.

A study of jaguars in Belize was conducted 20 years ago in the Cockscomb Basin (Rabinowitz & Nottingham, 1986), an area east of the Chiquibul Forest on the opposite side of the Maya Mountain Divide. Four male jaguars and one female were radio collared resulting in home range estimates of 28-40km$^2$ for males and 10km$^2$ for the female. However, no overall density or population size estimates were given (Rabinowitz & Nottingham, 1986). While this study determined that male jaguar territories overlap each other and those of females, more information is needed to determine how many animals can overlap and occupy a given area of rainforest and, thereby, provide insight into the area requirements for a population of jaguars.

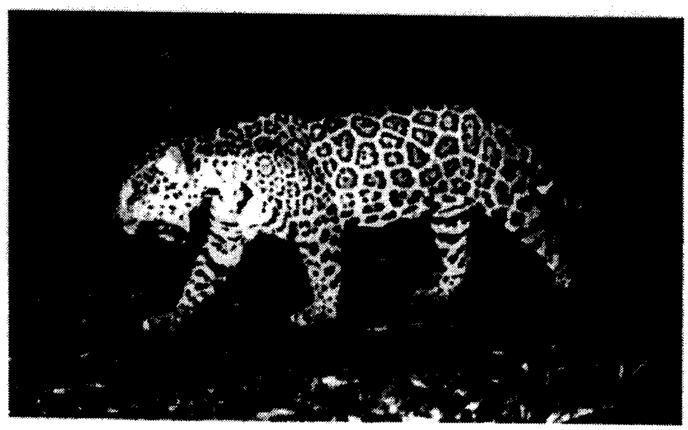
Knowing the space requirements for healthy populations of rainforest cats has important ramifications for biodiversity protection. Felids, especially large ones with large space requirements, function as 'umbrella species' such that protecting their habitat will result in protection of numerous other species residing within the cats' ranges (Noss, 1990; Gittleman *et al.*, 2001). Several studies have shown that umbrella species can be effective guardians of other species in the same area (Launer & Murphy, 1994; Martikainen *et al.*, 1998; Swengel & Swengal, 1999). Tropical rainforests in general, and the Chiquibul in particular (Caro *et al.*, 2001), are known to have extremely high biodiversity and hence jaguar protection will likely lead to extensive biodiversity protection.

Until recently, obtaining detailed information on tropical cats required capture, immobilization, radio collaring, and monitoring, all of which are intrusive, expensive, labour intensive, often dangerous, and result in only very small sample sizes. New methods using infrared remote camera technology can now provide a less intrusive and less expensive method for monitoring wild animals. 'Camera trapping' has been used extensively to survey for tigers (Karanth, 1995; Karanth & Nichols, 1998; Lynam *et al.* 2001; Carbone *et al.*, 2001). These studies have shown that remotely tripped cameras can provide substantial data on tiger biology and tiger prey species. Recently, camera traps have been employed for jaguars following the tiger model (Silver *et al.*, 2004). Because jaguars have coat patterns that remain distinct throughout their lives (Figure 1), it is possible to establish a capture history from remote camera photographs for individual animals and follow them through time. Recent developments have improved the analysis of this type of data which consists of relatively small sample sizes and low capture probabilities (White *et al.*, 1982). The number of jaguars can be estimated using closed

*Photograph A*

*FIGURE 1: Jaguars, like all spotted cats, are individually distinguishable by their coat patterns. Animals labeled A and B on this page are the same individual in different photographs while C and D (on the following page) are different individuals.*

*Photograph B*

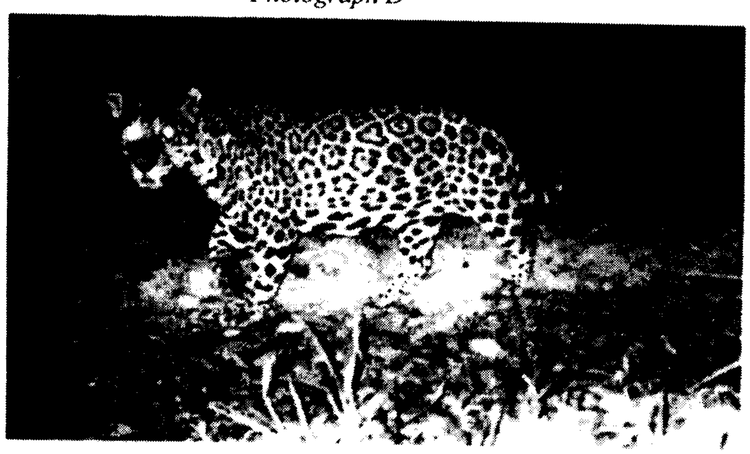


capture mark-recapture models and the resulting population size is then divided by the effective area surveyed to produce an estimate of density of animals. This study uses infrared cameras in a unique and innovative fashion to provide much needed baseline information on the status of jaguars from a non-hunted, relatively healthy population living in the unique intact rainforest of La Selva Maya.

*Photograph C*

*FIGURE 1: Jaguars, like all spotted cats, are individually distinguishable by their coat patterns. Animals labeled A and B (on the previou page) are the same individual in different photographs, while C and D on this page are different individuals.*

*Photograph D*



## Study Site

The Chiquibul Forest Reserve, located on the western side of the Maya Mountain Divide, is nested within the protected Chiquibul National Park. The reserve is approximately 1,775 km$^2$ and is at roughly 500m elevation. This study was conducted out of Las Cuevas Research Station, a facility jointly administered by the Belize Forest Department and the British Natural History Museum (Figure 2). The vegetation in the Chiquibul is a mosaic

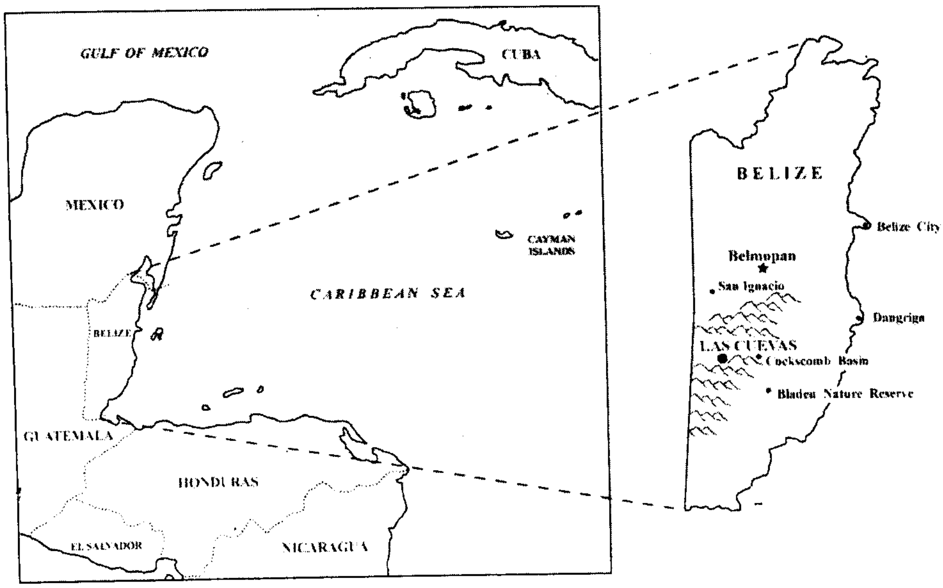



*FIGURE 2: Location of Las Cuevas Research Station in relation to Belize and the wider region*

of deciduous semi-evergreen, deciduous seasonal forest, and stands of pine (*Pinus sp.*) in the northern sector (Wright *et al.*, 1959). The stands of pine generally grow on granites that were intruded through limestone, making for abrupt vegetation changes from broad-leaf rainforest to pine forest with little transitional habitat.

Some blocks of the Chiquibul Forest Reserve have been, and still are, selectively logged for commercially important species such as mahogany (*Swietenia macrophylla*); cedar (*Cedrela odorata*) and pine (*Pinus carribea*) on a 40-year rotational basis. While canopy heights are typically 20-30m, a large part of the Chiquibul Forest Reserve suffered loss of trees in Hurricane Hattie in 1961 resulting in a forest lacking in mature trees (Wolffsohn, 1967). The Las Cuevas Research Station is the only permanent settlement in the forest. Rainfall averages about 1,500mm/year with the rainy season from June to January. Technically, this forest qualifies as a moist forest because it receives less than 2,000mm of precipitation per year and has seasonal rainfall, however, these types of forests are widely referred to as rainforests throughout the literature (Kricher,1997).

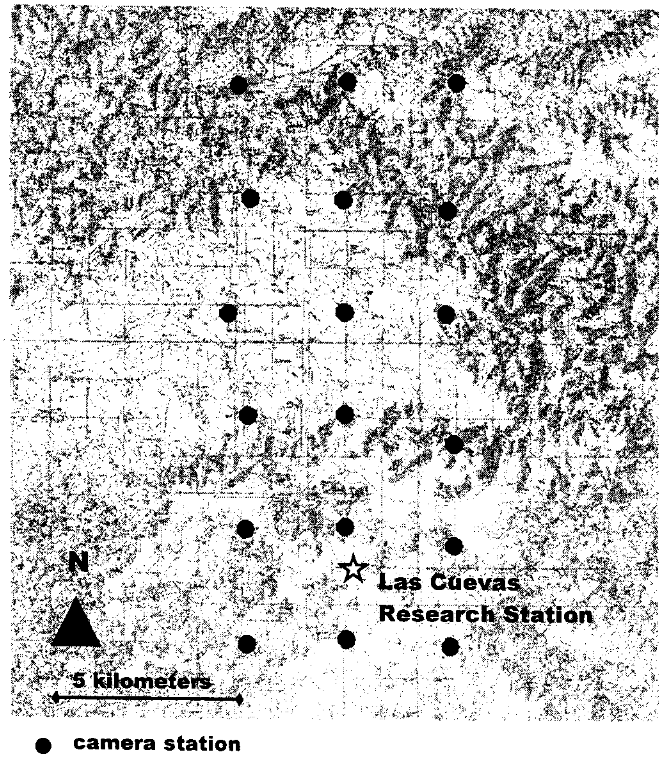



*FIGURE 3: Topographical map showing placement of the 18 cameras stations in the Chiquibul Forest Reserve. Las Cuevas Research Station is in highlighted in dark gray. The southern (bottom) 9 camera stations were established first and operated Jan. 12th - Feb. 10th and the northern (top) 9 stations were operated directly after that from Feb. 15th - March 20th.*

## Methods

In January 2002, camera stations were established in broadleaf rainforest in a fixed grid, similar to the methodology followed in a small mammal mark-recapture study. Each station consisted of two cameras mounted on opposing sides of a trail to photograph both sides of the animal for a positive identification. Cameras were spaced at 3km intervals so that every 9km$^2$ contained a camera station. This spacing is based on the smallest home range size (10km$^2$) estimated for a female jaguar (Rabinowitz & Nottingham, 1986). Hence no jaguar should escape capture with this spacing (i.e. there should be no holes in the grid).

With a limited number of cameras, a 3x3 grid (i.e. 9 camera stations with 18 cameras) was set up at 3km intervals covering 81km$^2$ and run for one month. The grid was then moved directly north and a second 3x3 grid established and run for a second month. This resulted in 18 stations total covering a combined 162km$^2$ (Figure 3). A combination of Camtrakker (passive cameras systems triggered by heat and motion) and Trailmaster

*TABLE 1: Summary statistics from camera trapping for jaguars in Chiquibul Forest Reserve*

| | |
|---|---|
| Dates (2002) | Jan 12 to Mar 20 |
| Days | 54 |
| Camera Stations | 18 |
| Trap Nights | 486 |
| Total captures+recaptures | 17 |
| Individuals | 7 |
| Individuals recaptured | 4 |
| Males | 4 |
| Females | 1 |
| Unknown | 2 |

*NOTES:*

*1. Two adjacent grids each with nine stations were run for 27 days each for a total of 54 days. The second grid was run directly after the first with a short break in between while cameras were moved from grid 1 to grid 2.*

*2. While 18 stations were established, 3 were eliminated in the final analysis due to double camera failures in the field.*

(active camera systems triggered by motion alone) camera traps were used. The cameras were placed approximately 30-60cm high on roads, trails, and game trails where jaguars were expected to pass. When no trails were available, roughly 15-20km of study trails were opened specifically for camera trapping in the more remote areas of the reserve. Cameras functioned continuously for two 27-day trapping periods with rolls of 36-print, 400 ASA 35-mm film. Conducting the study within this 2 month time period was necessary to satisfy the assumption of demographic population closure required for closed population estimation models (Karanth & Nichols, 1998). Each station recorded the date and time of day for each photograph. Each camera station was checked approximately every 14 days.

After the film was developed, individual jaguars were identified by variations in their coat patterns (Kelly, 2001). Mark-recapture data such as this from low-density carnivore populations require statistical methods designed for estimating population parameters when sample sizes are small. Statistical models designed to incorporate individual capture histories (e.g. heterogeneous capture probability) were used in the assessment of population density (White *et al.*, 1982). The number of captures and recaptures were analyzed using the software program CAPTURE (Otis *et al.*, 1978; White *et al.*, 1982; Rexstad & Burnham, 1991). This program uses a number of different models to generate abundance estimates for the sampled area based on the number of individual animals captured and the frequency of recaptures. To estimate densities for the study site, the abundance calculated above was divided by the effective sample area. The effective sample area consisted of the area the cameras covered plus a buffer surrounding that area based on half the mean maximum distance moved (MMDM) by each jaguar among multiple captures during the census period (Wilson & Anderson, 1985).

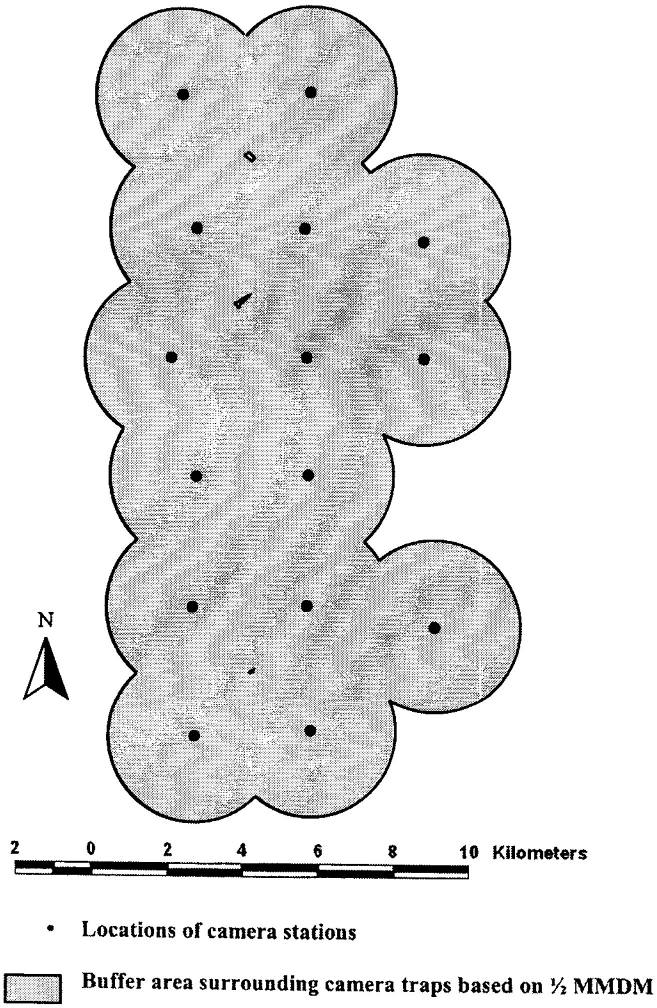



*FIGURE 4: Chiquibul Forest jaguar camera trapping survey area. A buffer surrounding the camera stations of 1.55km was established based on half of the mean maximum distance moved (½ MMDM) by jaguars among camera traps. Camera stations with double camera failures were removed from the analysis and hence have not been buffered. The remaining 15 camera stations plus the buffer resulted in an effective survey area of 107 $km^2$.*

While cameras photograph prey species, individual prey animals are difficult to distinguish and hence absolute prey densities are difficult to obtain. However, capture rate can give an estimate of relative abundances on grids (Lynam *et al.*, 2001). Capture rate for each species was calculated as the number of captures divided by the total number of trap-nights a camera was in the field (i.e. photographs per 100 trap nights).

*TABLE 2: List of potential models for estimating abundance from camera trapping data fom program CAPTURE*

| Model/ estimator | Model selection | Abundance estimate | SE | 95% confidence interval | Density indiv/100km$^2$ |
|---|---|---|---|---|---|
| M(o) | 1.00 | 8 | ± 1.47 | 8 to 15 | 7.48 ± 1.37 |
| M(t) | 0.0 | 7 | ±0.69 | 7 to 11 | 6.54 ± 0.65 |
| **M(h)** | **0.94** | **8** | **± 2.51** | **8 to 19** | **7.48 ± 2.34** |
| M(th) | 0.33 | 9 | ± 2.95 | 8 to 23 | 8.41 ± 2.76 |
| M(tb) | 0.44 | 7 | ± 0.00 | 7 to 7 | 6.54 ± 0.0 |

*NOTES*

*1. The survey area was 107km$^2$ based on buffering each camera trap with a cicle of radius equal to half the MMDM which was 1.55km*

*2. Closure test: z= -1.029; p+0.152*

*3. M(o) is the null model, M(t) incorporates time variation in capture probability, M(h) incorporates individual heterogeneity in capture probabilities, M(b) incorporates a behavioural response after initial capture. Any combination of the two denotes an interaction between the two factors. The M(h) model is likely the most appropriate estimator for this study.*

*SOURCES: (Otis et al., 1978; White et al., 1982; Rexstad & Burnham, 1991)*

## Results

Despite three camera stations with double camera failures in the field, 7 individual jaguars were captured in 17 photographs in 486 trap nights (Table 1). Four jaguars were male, one was a female, and 2 were of undetermined sex. The mean of the maximum distances moved was 3.1km (n = 4) and hence half of that distance (1.55km) was used as a buffer surrounding the remaining functioning camera traps resulting in an effective area surveyed of 107km$^2$ (Table 1; Figure 4).

The abundance estimates produced by program CAPTURE varied from 7 to 9 animals per 100 km$^2$ depending on the particular mark-recapture model chosen (Table 2). Models included in the analysis were: time variation in capture probabilities M(t), individual heterogeneity in capture probability M(h), behavioural responses after initial capture M(b), or combinations of these factors (Table 2). The most appropriate model was the jackknife population estimator, M(h), which included heterogeneous capture probabilities by individual jaguars (Table 2). This model had the highest selection criteria behind the null model (Otis *et al.*, 1978; Rexstad & Burnham, 1991) and is also considered to be biologically realistic (Karanth & Nichols, 1998). The resulting density estimate for jaguars in the Chiquibul Forest Reserve is 7.48 ± 2.74 individuals per 100km$^2$.

In addition, cameras photographed 27 other species besides jaguars (Table 3). Opossums (*Didelphis marsupialis and D. virginianus.*) had the overall highest trap success at 7.65 photos per 100 trap nights, followed by white lipped peccaries (*Dicotyles pecari*) at a 6.12 capture rate. Of the carnivores, jaguars and ocelots (*Leopardus pardalis*)

*TABLE 3: Percent capture success (# of photos/ 100 trap nights) for all species camera-trapped in 18 station grid*

| Species | | % capture success all 18 stations |
|---|---|---|
| **CARNIVORES** | | |
| Jaguar | *Panthera onca* | 3.50 |
| Puma | *Puma concolor* | 1.14 |
| Ocelot | *Leopardus pardalis* | 2.11 |
| Margay | *elis wiedii* | 0.15 |
| Tayra | *Eira barbara* | 0.21 |
| Skunk | *Conepatus semistriatus* | 0.35 |
| Coati | *Nasau narica* | 0.70 |
| Gray Fox | *Urocyon cinereoargenteus* | 1.08 |
| **HERBIVORES** | | |
| Tapir | *Tapirus bairdii* | 1.22 |
| Brocket deer | *Mazama americana* | 0.55 |
| White-tailed deer | *Odocoileus virginianus* | 0.00 |
| Collared peccary | *Tayassu tajacu* | 0.75 |
| White-lipped peccary | *Dicotyles pecari* | 6.12 |
| Depp's Squirel | *Sciurus deppi* | 0.31 |
| Paca | *Agouti paca* | 0.88 |
| Agouti | *Dasyprocta punctata* | 0.00 |
| Mouse | *Heteromys sp.* | 0.57 |
| **BIRDS** | | |
| Ocelated turkey | *Meleagris ocellata* | 0.77 |
| Chachalaca | *Ortalis vetula* | 0.15 |
| Tinamou | *Crypturellus boucardi* | 0.58 |
| Curassow | *Crax r.rubra* | 2.07 |
| Guan | *Columbina sp.* | 0.00 |
| **OTHERS** | | |
| Armadillo | *Dasypus novemcinctus* | 1.22 |
| Opossum | *Didelphis sp.* | 7.65 |
| Tamandua | *Tamandua mexicana* | 0.15 |

had the highest trap success (3.50 and 2.11 respectively) followed by pumas (*Puma concolor*) and gray foxes (*Urocyon cinereoargenteus*) at 1.14 and 1.08 respectively. Numerous ground birds such as curassow (*Crax r. rubra*), tinamou (*Crypturellus boucardi*), and ocelated turkey (*Meleagris ocellata*) also were photographed (Table 3).

Preliminary results also showed that jaguars were photographed more often on roads and established trails while prey animals, especially small ones, were captured more often on newly cut trails. Tapir (*Tapirus bairdii*) were photographed more often at stations close to rivers or streams.

## Discussion

In 1999, 35 jaguar experts from 12 nations gathered for a workshop and were asked to weigh 6 factors (area size, connectivity, habitat quality, hunting pressure on jaguar and their prey, and population status) according to their importance for long-term jaguar survival (Sanderson *et al.*, 2002). This lead to the identification of numerous jaguar conservation units [JCUs] which represent core populations on which conservation should be based. La Selva Maya was identified as one of these JCUs and was therefore prioritized as a site to include in a comprehensive jaguar conservation programme (Sanderson *et al.*, 2002). This prioritization highlights the importance of establishing a long-term jaguar monitoring project in the Chiquibul Forest Reserve.

This study presents data on the density of jaguars from the first jaguar population survey conducted in the Chiquibul Forest Reserve of La Selva Maya. The technique used provides a statistically robust analysis that can be used in tropical rainforest ecosystems to determine jaguar densities within a short period of time. This also confirms previous research with tigers and demonstrates the viability of using remotely triggered cameras for estimating densities of individually recognizable species that have been traditionally difficult to study because of cryptic habitats, large home ranges, and low population densities.

Repeated sampling using this camera trapping technique in the same area (e.g. robust design, Kendall *et al.*, 1995) will provide more baseline information such as recruitment and survival estimates for the jaguar population. The long term study planned in the Chiquibul Forest will facilitate population monitoring over time. In addition, expansion into the pine forest areas within the Chiquibul will provide more information on how habitat differences affect population size and status. Concurrent to this study, several scientists throughout the jaguar's range were also employing camera trapping and density estimates for jaguars from multiple sites and habitat types are beginning to emerge (Silver *et al.*, 2004) and will provide better estimates of global jaguar populations as well as provide solid scientific data to justify support for existing protected areas such as the Chiquibul Forest Reserve. For the handful of studies that have recently estimated jaguar densities, the estimate for the Chiquibul Forest is the second highest behind only Cockscomb Basin Jaguar Sanctuary (although standard errors overlap). The high density in the Chiquibul is likely representative of a healthy jaguar population.

Currently, there are several limitations to this technique. This method relies on recognizable individuals to estimate population size (Kelly, 2001). Therefore the technique is limited to animals with distinct coat patterns. It is appropriate for all spotted cats and will be applied to ocelots in the Chiquibul in the near future. But the technique is less effective for unmarked animals such as most jaguar prey animals. Relative densities of these animals are useful when an area is repeatedly systematically surveyed. Hence studies should be designed with repeated surveys planned.

Camera traps currently cost several hundred dollars each and hence surveying a jaguar population represents a substantial financial investment. Using fewer cameras in a systematic rotation, as in this study, can ameliorate equipment costs, but results in substantially more effort in labour especially in areas such as the Chiquibul where topography is challenging. Cameras are also subject to theft and vandalism and this study lost several cameras to theft. Trained field assistants must be available throughout the sampling period to monitor all camera trap sites so that film can be collected and changed as necessary, and any damaged, tampered with, or malfunctioning cameras can be removed and replaced.

There is room for improvement of this technique especially to increase the capture probabilities. While the density estimate here was roughly 7.5 animals per 100km$^2$, it should be noted that most animals captured on film were males on main roads and trails. The opportunistic camera trapping conducted in 2001 during pilot studies has resulted in a total of 10 males, 3 females, and 3 unknown sex animals identified during 2001-2002. It is unlikely that there is male-biased sex ratio, but rather, females are more difficult to photograph than males. This may indicate that the current population densities are minimum estimates. Additionally, most captures occur on roads and established trails implying that newly cut trails are not an effective way to capture animals on film. It may take several months before new trails are regularly used by jaguars. Further refinement of the camera trapping will only increase the value of this technique for local and global jaguar conservation strategies.

## Conservation concerns

While the Chiquibul Forest Reserve is legally protected, two threats could affect the long-term survival of the jaguar in this area. First, the proposed Chalillo dam site is located roughly 15km from Las Cuevas Research Station but will likely back up the waters of the Macal River all the way to the Monkey Tail Branch, which flows only a few kilometers from this study site. Given that jaguars range far and wide, it is likely that jaguar habitat use patterns will be adversely affected. Additionally, the new roads proposed in this area are large and will likely be detrimental to jaguar especially since roads will provide access to previously remote areas of the reserve.

Second, La Selva Maya is shared between Belize, Guatemala, and Mexico, yet there is little coordinated border control. Landless farmers routinely cross the border from Guatemala to Belize primarily in search of and to harvest Xate (*Chamaedorea* sp.) which is sold on the world market for the flower and shampoo industries (UNESCO, 2000). This results in 'collateral damage': wildlife or bushmeat is hunted to provide sustenance to the Xateros while they harvest. Substantial numbers of animals, such as peccary (both *D. pecari* and *Tayassu tajacu*), brocket deer (*Mazama americana*), and armadillo (*Dasypus novemcinctus*) (which also are the favoured prey animals of jaguars) are killed, and this type of bushmeat hunting has been shown to reduce wildlife populations (Bennett & Robinson, 2001; Rao & McGowan, 2002). If allowed to continue, it could lead to the empty forest syndrome (Redford, 1992). While La Selva Maya is currently the largest intact tropical forest in Central America, the standing forest alone does not guarantee survival of the wildlife therein.

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