JAGUAR POPULATION DENSITY AND SIZE IN THE NORTHEASTERN YUCATAN PENINSULA

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Resumen

El norte de la Península de Yucatán es una de las áreas prioritarias en México para la evaluación de la situación actual del jaguar. Las únicas investigaciones sobre la ecología y la conservación del jaguar en la península se han realizado 400 km al sur de esta provincia biótica, en las selvas más húmedas de Campeche y Belice. Del 2004 al 2006 se llevó a cabo un estudio con trampas-cámara en los humedales costeros de Ría Lagartos, en el noreste de Yucatán, con objeto de evaluar su situación actual, densidad y tamaño poblacional. Las densidades obtenidas fluctuaron entre dos y seis jaguares por cada 100 km^2. Se documentó en la región existen cerca de 4,000 km^2 de hábitat potencial para el jaguar. La población probable varía entre 80 y 240 jaguares. Es decir, la región mantiene una de las poblaciones más importantes del jaguar en México, por lo que es prioritaria para la conservación de la especie. Sin embargo, la región afronta actualmente serios problemas de conectividad con las otras porciones de las selvas mayas del sur principalmente debido a la infraestructura carretera. Las selvas hacia el oriente son ya prácticamente inexistentes por el avance de las fronteras agrícola y ganadera. Por ello, se requiere de una estrategia sólida de conservación para evitar la extinción del jaguar en la región a largo plazo.

Palabras clave: humedales costeros, jaguar, densidad de población, Península de Yucatán, Ría Lagartos, Yum Balam.

Abstract

The northern region of the Yucatan Peninsula is a priority area in Mexico for the evaluation of jaguar's conservation status. The only studies on the ecology and conservation of jaguar in the peninsula have been carried out 400 km south, in Campeche and Belize. This study was carried out with camera-traps in the costal wetlands and tropical dry forest of Ria Lagartos, in the northeastern part of the peninsula from 2004 to 2006. Population densities varied from 2 to 6 jaguars per 100 km^2. We also document that there are around 4 000 km^2 of jaguar habitat in the region. So, the jaguar population size probably varies from 80 to 240. Indeed, this is one of the most important jaguar populations in Mexico, so it is should be considered a priority for conservation. The region has, however, severe environmental problems, and its connectivity with other forests to the south is already impacted by highways: in addition, the forests to the west are practically nonexistent due *to the expansión of agriculture and cattle ranching. That's why a solid strategy is needed in order to maintain this jaguar population in the long term.*

Keywords: Coastal wetlands, jaguar, tropical dry forests, jaguar, Yucatan Peninsula, Ría Lagartos, Yum Balam.

Introduction

Progressive habitat destruction, poaching, diseases and other factors such as road building have caused a gradual decrease in the range of the jaguar (*Panthera onca*) in Mexico and other countries (Medellín *et al.*, 2002; Swan and Teer, 1989). The probability of conserving the species in the long term greatly depends on maintaining the highest number of populations, which should contain the highest number of individuals (Carrillo *et al.*, this volume). An essential strategy for jaguar conservation is therefore to identify priority conservation areas (Ceballos *et al.*, 2006; Sanderson *et al.*, 2002a, b). Conservation of such areas should be given priority by promoting the different possibilities –from the creation of protected areas to payments for ecosystem services– as well as the conservation of the jaguar, its habitat and its prey.

Although the current distribution of jaguars is relatively well known, the status of its populations is unknown in broad regions (e.g., Chávez and Ceballos, 2006; Núñez, this volume). Persistence of jaguars on a local and regional level not only has major ecological implications because of its role in natural communities, but also has social implications, given its cultural importance and its conflicts with livestock farmers.

Recent studies have identified priority regions for jaguar conservation in Mexico (Ceballos *et al.*, 2006; Sanderson *et al.*, 2002c). The largest jaguar population occurs in the south of the Yucatan Peninsula, in the Calakmul region in Campeche and Quintana Roo (Ceballos *et al.*, 2002; Chávez *et al.*, this volume). This population has a high probability of long-term survival, especially if the biological reserves established in the Calakmul region are consolidated and the regional environmental threats such as deforestation and road building are mitigated over the next decades (Conde *et al.*, 2006; Chowdhury, 2007; Vester *et al.*, 2007; Zarza *et al.*, this volume).

The status of jaguars is unknown in other regions of the Yucatan Peninsula. Although the species is present, there is little information about population density and size (Navarro-Serment *et al.*, this volume). The north of the peninsula still has vast stretches of well-preserved habitat, but jaguar's current status is unknown. Hence, the region has been considered a high-priority area to assess the jaguar's current status (Ceballos *et al.*, 2006; Sanderson *et al.*, 2002c). This study provides an analysis of jaguar population density and size in the region of Ría Lagartos. The objective of the study was to determine whether a jaguar population exists in the region and, if so, whether it is likely to survive in the long term.

Study area

The study area is located in the eastern and southeastern parts of the Ría Lagartos Biosphere Reserve and its area of influence. The region is located in the northeastern Yucatan Peninsula, between longitudes 87°30' and 87°40' West and latitudes 21°15' and 21°30' North (Figure 1). About 40% of its surface falls within the biosphere reserve. The rest is in its southeastern area of influence, which includes "El Zapotal" private reserve (23.5 km^2) and land of neighboring ejidos (Faller, 2010b). The biosphere reserve is part of a wetland system that includes two other coastal reserves, Yum Balam Flora and Fauna Protection Area and Bocas de Dzilam State Reserve. Altogether, these protected areas contain about 1400 km^2 of forests and wetlands (PPY, 2005).

The topography of the region is flat or almost flat, with slight slopes. It is part of a limestone platform with no surface streams or rivers. Water filters down, forming a shallow water table formed by caves, underground rivers, sinkholes called cenotes –permanent freshwater bodies– and aguadas –temporary freshwater bodies– (INE, 1999). Although the area is considered as being in the sub-humid tropics, it is in fact in the transition between the sub-humid and humid tropics. This is why some typical animal and plant species of both ecosystems can be found in this region (Challenger, 1998). More than half (68%) of the study area is covered by semi-evergreen forest over 20 years old; about 7% is devoted to crop and livestock farming, and the rest is a combination of seasonally flooded forest (4%), natural savanna (4%), second-

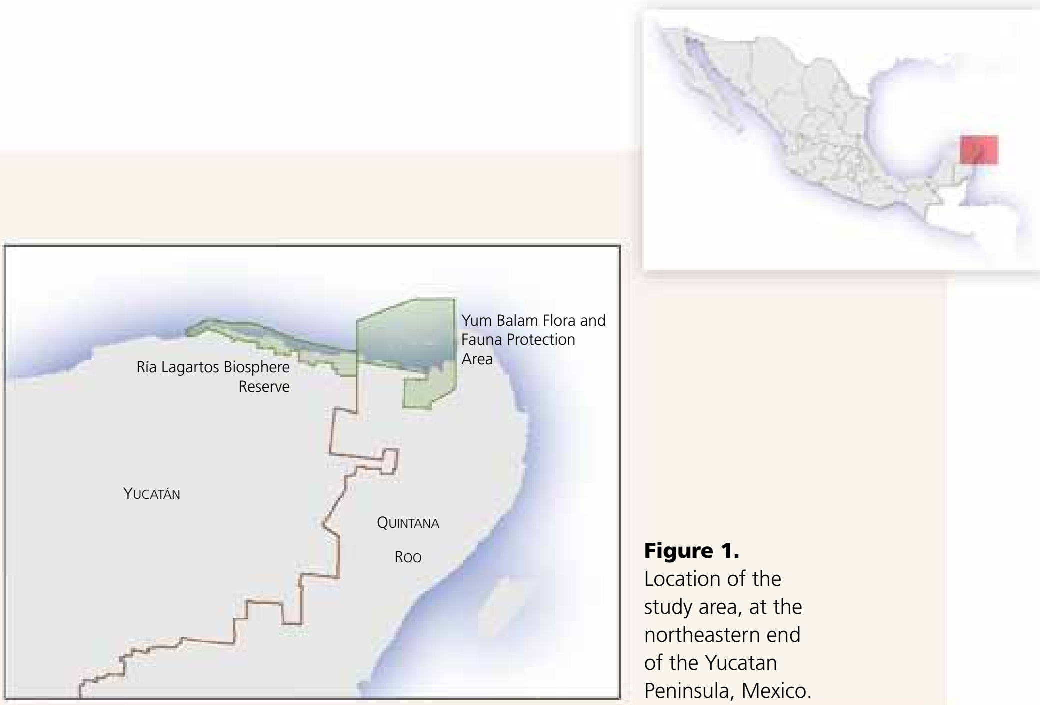

Figure 1. Location of the study area, at the northeastern end of the Yucatan Peninsula, Mexico.

ary vegetation over 15 years old (7%), and part of a system of marshes, mangroves and petenes –emerging islands of forests protected from saline intrusions– (García-Contreras and Vera, 2004).

Average rainfall ranges from 700 mm in the north to 1,100 mm in the south (García-Contreras and Vera, 2004). The rains fall in two distinct seasons; from June to November (70% of total annual rainfall) and from December to May (30% of total rainfall). Monthly mean temperature is around 26°C, with a temperature range of 3°C (INE, 1999). Winds are moderate from November to August, but September and October are considered to be the hurricane season, with winds exceeding 120 km/h. The region has been struck by 9 tropical hurricanes between 1957 and 1996, which amounts to one every 4.3 years on average (INE, 1999).

The study area includes the village of Tesoco Nuevo, with a population of about 300 people, and five small settlements with 30 to 40 people (INEGI, 2000; Urquiza and Ku, 2004). Until about a hundred years ago, the entire north east of the peninsula was practically uninhabited (Reed, 1971), and mainly covered by semi-evergreen forest in a late successional stage (PPY, 2005). Industrial logging began in the 1930s (F. Faller, pers. comm.), and livestock farming started to expand in the 1950s, and grew significantly between 1970 and 1990 (Fraga and Cervera, 2003).

Methods

To assess jaguar presence and density, we used 18 to 27 camera trap stations per year. Camera traps have become an important tool to monitor rare and cryptic terrestrial species in tropical forests (Azuara and Medellín, this volume; Wallace *et al.*, 2003). The unique spot patterns on the coats of jaguars were used to estimate population size with capture-mark-recapture models (Silver *et al.*, 2004). All the cameras were DeerCam® DC-200 except one, which was Camtrakker®. Both models are passive traps, triggered by an animal passing in front of sensors that detect heat and movement (Lynam, 2002). The camera traps were placed in an area of 100 km^2, using stratified random sampling with certain discrimination criteria. A recent (2003) georeferenced satellite image with a resolution of 2 meters was divided into 1 km^2 plots with Arcview® software. This surface represents about 10% of a jaguar's minimum home range in one season, based on data obtained in a region relatively near the study area (Ceballos *et al.*, 2002; Lynam, 2002). The plots were clustered into four groups of 23 to 27 units called sections.

To be selected, the 1 km^2 sampling plots had to meet the following conditions: very open vegetation (grassland, savannas or vegetation in successional stages less than 10 years old) must not cover more than 50% of their surface; they should not have trails regularly used by local people or cultivated plots, because the risk of camera theft increases considerably in these circumstances; the sites had to be accessible, with boundaries not too far (less than 1.5 km) from tracks and trails known or identifiable on the satellite image. All the plots were randomly selected.

In the first fieldwork season of 2004 –from February to July– we selected six plots in sections 1, 2 and 3. We only chose three plots in section 4. In each plot, we placed a camera trap at three or four of the vertices of an inner concentric 330 meter-long side square, called camera trap station. To choose the sites where cameras would be placed, we took into account factors such as the presence of tracks, trails used by wildlife, and the location of water bodies, to maximize the chances of obtaining pictures. The cameras were programmed to be active 24 hours a day. Each section was used for a 4-6 week period. Some camera trap stations were only fitted with three cameras because of technical problems in some cameras.

The second stage of fieldwork in 2004 was aimed at obtaining information to complement the data obtained in the previous stage. It involved installing 10 cameras in different sites of Section 1 that had not been covered in the first stage, mainly paths where felid tracks and other signs are often found. Section 1 is located in "El Zapotal" private reserve.

The design was modified in 2005. We used Arcview® to outline a hexagonal grid with a side length of 3 km on the georeferenced satellite image, and used this grid to install the camera traps. We followed the method suggested by Sanderson (2003), taking into account the minimum home range estimated for the jaguar in the peninsula (Ceballos *et al.*, 2002; Lynam, 2002). In developing the grid, an effort was made to ensure that the vertices and centers of the polygons matched places jaguars were most likely to visit. We selected 15 sites to install camera trap stations. Each station consisted of two camera traps facing each other. The cameras were activated in the second week of May and remained active until July.

In 2006, because of limitations by the passing of two hurricanes, the network of camera trap stations with two cameras per station only covered 8 sites, with distances ranging from 0.9 to 1.6 km between stations. The sites were selected on the basis of data obtained in the two seasons, to maximize capture probability. The camera trapping network was active from May to July.

Data analysis

To interpret the results of the 2004 season, we defined the center of the 1 km^2 plots where the three or four cameras of each station were installed as the "effective camera trapping center." Sampling effort was the number of days that each camera station was in operation. For each of the sampled years, our capture period was 24 hours, regardless of the time lag of one or two days between each of the sampling stations. We define "capture ocasion" as the event of obtaining photographs of the same individual within a period of 24 hours inside the whole web of sampling stations. In this sense, each "capture" or "recapture" stands for the set of images contained in a capture occasion. To estimate population density, we built the capture-recapture histories of jaguars for each of the three years sampled (2004, 2005 and 2006). Data obtained were fed into matrices of zeros (absence) and ones (presence), where each column represents one day of capture effort and each row represents one jaguar. This data arrangement was chosen in order to process the data with the CAPTURE program and obtain an estimate of jaguar population size (Otis *et al.*, 1978; Rexstad and Burnham, 1991). For 2004, we only used the capture-recapture information obtained in Stage 1, using the method followed by Karanth and Nichols (2002) and Silver *et al* (2004).

To estimate the size of the effective sampling area for each year, we calculated the mean maximum distance moved (MMDM) by individual jaguars between cameras for three years, and used half of this distance (½ MMDM) as a radius to trace a circle around the location of each camera trap (Dice 1988; Wilson and Anderson, 1985). The polygon formed by overlaying these circles formed the total sampling area of the camera trap network. The total surface of this effective sampling area was calculated using ArcView® X-Tools and Spatial Analyst. The number of jaguars captured every year was divided by the surface of the effective sampling area to calculate jaguar density. This assessment method has been comprehensively described in other publications (Di Bitetti *et al.*, 2006; Karanth, 1995; Karanth and Nichols, 1998; Nelly, 2003; Maffei *et al.*, 2004; 2005; Silver *et al.*, 2004). Density estimates are the result of combining estimated population size and effective sampling areas. We calculated standard errors in density estimates following Nichols and Karanth (2002).

Results and discussion

According to the results, there is a relative large jaguar population in the study area. We obtained 45 "capture occasions" of 8 individuals in three years of sampling (Table 1; Figures 2, 3). Maximum distances traveled in one year ranged from 1.0 to 10.2 km, with a mean of 4.8 km and a standard deviation of 1.8 km (Figures 4, 5, 6).

The "constant capture probabilities model", M (o) and the "constant capture probabilities model", M (h) of the CAPTURE program were the most appropriate to assess jaguar density in the study area, as they were the best fit models. We used the variable capture probability model for 2004 and 2005, and model M (o) for 2006 data as a more conservative estimate, because there were major inconsistencies in the runs made with model M (h) (Table 2).

Estimated densities were very variable and ranged from 1.82 to 6.18 individuals/100 km^2. The variation in estimation density is probably due to factors related to the sampling methods and natural factors. For example, although there was little variation in the effective sampling area between 2004 and 2005, there was a considerable difference in sampling effort (Table 2). On the other hand, there was little variation in the temporal sampling effort between 2005 and 2006, but a significant difference in the effective sampling area. The density obtained in 2006 (6.18 ind./100 km^2) is probably the result of using a very small effective sampling area, which could fail to accomplish the closed population assumption (L. Maffei, pers. comm.). Thus, the model could not adjust to a closed population. It is also important to note that

Table 1. Capture of jaguars with camera traps in Ría Lagartos, Quintana Roo, between 2004 and 2006

Individual	Year 2004	Year 2005	Year 2006	Total
1. Francisco	8	2	0	10
2. Joann	1	0	0	1
3. Jaguar 2	2	0	5	7
4. Jaguar 3	2	4	0	6
5. Jaguar 4	1	0	0	1
6. Jaguar X	1	5	0	6
7. Jaguar Y	0	0	13	13
8. Jaguar Z	0	0	1	1
Total	**15**	**11**	**19**	**45**

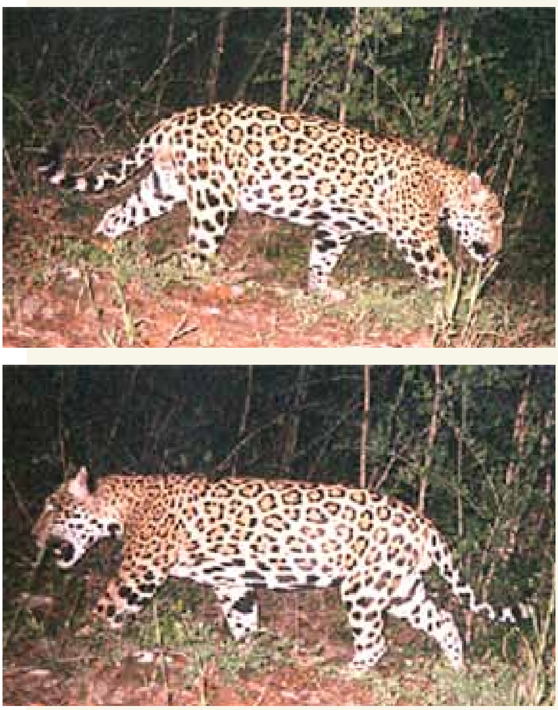

Figure 2. Photographs of both flanks of Jaguar Francisco (2004).

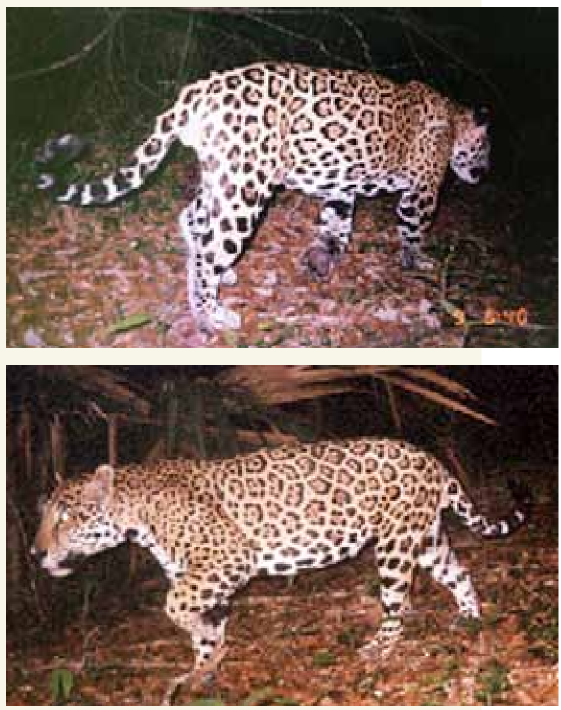

Figure 3. Photographs of both flanks of Jaguar 2 (2004).

Figure 4. Stations and effective sampling area in Ría Lagartos 2004. Coordinates are in UTM (Zone 16).

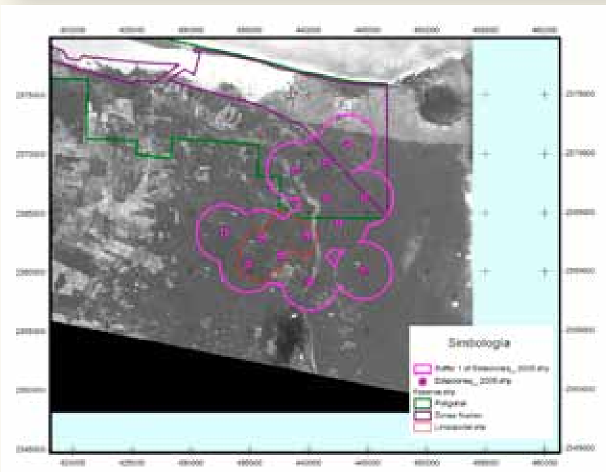

Figure 5. Stations and effective sampling area in Ria Lagartos 2005. Coordinates are in UTM (Zone 16).

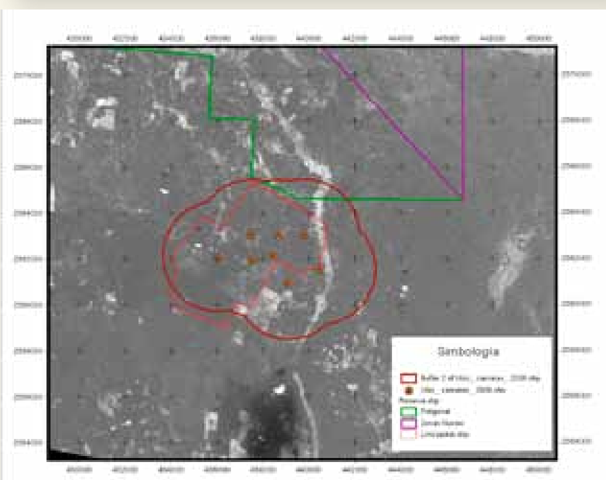

Figure 6. Stations and effective sampling area in Ría Lagartos 2006. Coordinates are in UTM (Zone 16).

the area was struck by a Category 5 hurricane in October 2005. The hurricane caused severe damage to vegetation and flooded the region for several months, which may have caused a general readjustment of jaguar territories towards the periphery of the study area, which was the worst affected. Taking these considerations into account, it is worth underlining that estimated population densities were similar to those obtained for the Calakmul region, in the south of the peninsula (Ceballos *et al.*, 2002; Chávez *et al.*, this volume).

In the northeast of the peninsula, there are 400,000 hectares of forest, including the Ría Lagartos and Yum Balam federal reserves (Figure 7). Before the 2005 hurricanes and the forest fires of May 2006, about 70% of the forests of the region had a good conservation status, and the rest showed moderate to severe levels of disturbance (PPY, 2005). Considering a density of 2 to 6 jaguars/100 km^2, it is possible to make a cautious population estimate of around 80 to 240 individuals in the north east of the Yucatan Peninsula (Table 3). In other words, the region has one of the largest jaguar populations in Mexico and is therefore a high-priority area for jaguar conservation.

However, the region is currently facing serious connectivity problems with the other Maya Forests to the south. The forests to the west have practically disappeared due to the construction of roads, which leads to continuous degradation of ecosystems along their layout. The south of the region is fragmented by a system of roads of various categories. The largest is the freeway between the cities of Mérida and Cancún, particularly the stretch between El Ideal and Cancún; the southeastern corner is occupied by the city of Cancún. The western corner of the matrix is formed by an

Table 2. Results of jaguar camera trapping in Ría Lagartos, Quintana Roo between 2004 and 2006

	2004	2005	2006
Sampling effort	34 days	89 days	97 days
Closed population test	*Z*=-0.357 *p*=0.36	*Z*=-2.569 *p*=0.0051*	*Z*=0.46 *p*=0.68
Model	M(h)	M(h)	M(o)
Estimated capture probability	0.083	0.038	0.055
Estimated population with CAPTURE	6±0.63	3±0.28	3±0.16
Estimated sampling area (km^2)	183	165	48.5
Estimated density (individuals/100 km^2)	3.28±0.34	1.82±0.17	6.18±0.33

* Did not behave as a closed population

M(h)= Jackknife model, variable capture probability

M(o)= Equal capture probability model

imaginary line from the harbor of El Cuyo to the town of El Ideal; the line can be considered as the eastern limit of the farming frontier in Yucatán (Figure 7; Lazcano *et al*., 1995). In spite of this, the region is connected to the almost continuous forests stretching from this area to Calakmul and Sian Ka'an Biosphere Reserves (see also chapters by Chávez *et al*. and Navarro *et al*., this volume).

Therefore, it is essential to make an assessment to determine the necessary conservation, mitigation and restoration measures to halt the loss of connectivity between the forests in the north and south of the peninsula. Corridors with wildlife crossings in roadways need to be created to increase and reestablish habitat connectivity. This will largely determine the possibility of maintaining a viable jaguar population in the long term in the north of the Yucatan Peninsula.

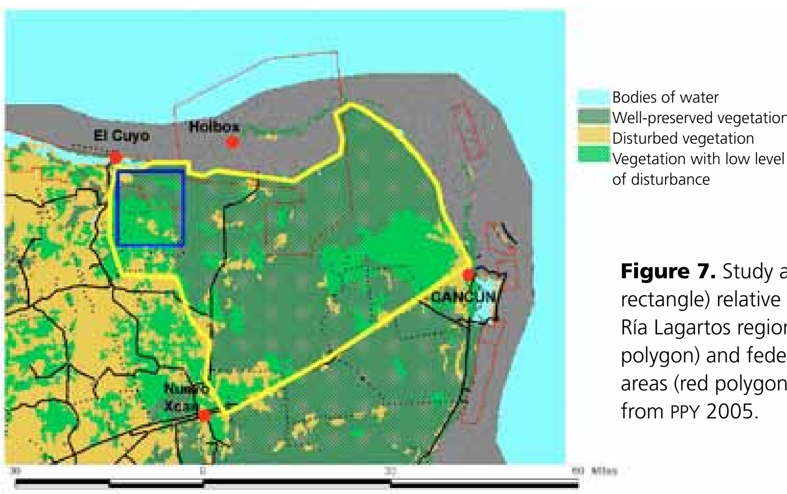

Figure 7. Study area (blue rectangle) relative to the Yalahau-Ría Lagartos region (yellow polygon) and federal protected areas (red polygons). Image taken from PPY 2005.

Table 3. Population size in protected areas in the north east of the Yucatan Peninsula

Reserves	Surface (km²)	Population size 3/100 km²	Population size 6/100 km²
Reserves of the wetlands in the north of the Yucatan Peninsula (RWNY)	1400	42	84
Yalahau-Ría Lagartos region (including RWNY)	4000	120	240

The RWNY are: Ría Lagartos Biosphere Reserve, Yum Balam Flora and Fauna Protection Area and Bocas de Dzilam State Reserve.

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