# JAGUAR HABITAT USE IN A HUMAN DOMINATED LANDSCAPE IN THE YUCATAN PENINSULA, MEXICO

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## Resumen

El acelerado crecimiento de las actividades humanas, ha modificado grandes extensiones de bosque tropical, fragmentándolas y reduciendo el hábitat disponible para la fauna silvestre. Las poblaciones de jaguar han disminuido a lo largo de su distribución debido principalmente a la pérdida del hábitat. La Selva Maya en la Península de Yucatán mantiene la población más numerosa de jaguar en México. La conservación de la especie en esta región requiere del manejo adecuado de su hábitat. El objetivo de este trabajo es determinar los requerimientos de uso de hábitat y los efectos de la perturbación humana (poblados y caminos) sobre el jaguar en la Selva Maya del sur de la Península de Yucatán. Para determinar las preferencias en el uso del hábitat, se analizaron los movimientos de jaguares por tipos de vegetación, uso de suelo, distancia a poblados y caminos en un Sistema de Información Geográfica. Los datos se obtuvieron a partir del seguimiento de jaguares con collares de GPS. Nuestros resultados revelan que los jaguares prefieren marcadamente los ambientes forestales (i.e. selva alta y mediana) en comparación con otros tipos de vegetación con menor cobertura forestal. Usan con mayor frecuencia, las áreas alejadas a más de 6.5 km de los poblados y 4.5 km de las carreteras. Las Áreas Naturales Protegidas (ANP) de la región, mantienen más del 68% de su superficie como hábitat para el jaguar. Fuera de las ANP, hay grandes extensiones de hábitat de jaguar, que pueden ser usadas como corredores biológicos, para mantener la conectividad, los procesos ecológicos, y el potencial de la región para la conservación a largo plazo del jaguar y de la biodiversidad.

Palabras clave: jaguar, requerimientos de hábitat, corredores para fauna, reservas, Selva Maya, Calakmul, Península de Yucatán.

## *Abstract*

*Habitat encroachment by human activities has extensively modified large extensions of tropical rainforest, reducing wildlife habitat availability. Jaguar populations have been steadily declining due to changes in land use and poaching. The largest jaguar population in Mexico is found in the Selva Maya region, in the Yucatan Peninsula. Conservation of jaguar in the Selva Maya requires a careful management of its habitat. So, the aim of this study was to determine jaguar habitat requirements and the effects of human perturbation (e.g. roads and towns) on habitat use. Habitat preferences were analyzed using data on*

*jaguar movements across habitat types, land use, distance to human settlements and roads using a GIS. Data on jaguar movements were obtained with GPS radio-collars. Results indicate that jaguars extensively use forested habitats such as tropical semi green forests. They use more frequently than expected by chance areas located more that 6.5 km from human settlements and 4.5. km from roads. Around 68% of the land in the regional protected areas is the preferred jaguar habitat. Outside protected areas there are still extensive areas with jaguar preferred habitat; those areas are essential to maintain connectivity among reserves, environmental processes, and the long term conservation of jaguars and many other species.*

*Keywords: jaguar, habitat requirements, wildlife corridors, reserves, Selva Maya, Calakmul, Yucatan Peninsula.*

## Introduction

The fast growth of human population has caused severe changes in the dynamics and ecological processes of tropical rainforests in the world (Baillie *et al.*, 2004; Geist and Lambin, 2002). In these regions, programs aimed at developing agriculture and forest exploitation have been promoted to satisfy the demands of the human population (FAO, 1999). This has led to a fast change in land use. Tropical rainforests are transformed into an irregular matrix where human activities dominate the new landscape and have a direct impact on regional biodiversity. This is reflected in an increase in the mortality rate of some species and the disruption of ecological processes (Dirzo and Raven, 2003; Fahrig, 2003; Kinnaird *et al.*, 2003; Reed, 2004). Environmental degradation has increased conflicts between humans and large carnivores, mainly due to habitat loss, a decline in natural prey caused by overhunting, and poor livestock management (Hoogesteijn *et al.*, 2002; Lynam *et al.*, 2006; Sáenz and Carrillo, 2002; Treves and Karanth, 2003).

The creation of protected areas has globally been promoted as a general strategy to reverse the negative effects of habitat loss and fragmentation in carnivore populations and biodiversity in general (Bruner *et al.*, 2001; IUCN, 2006). Unfortunately, protected areas themselves are usually insufficient to maintain viable populations of large carnivores in the long term, due to the large home ranges of carnivores and their ecological requirements in terms of habitat and prey (Noss *et al.*, 1996; Ramakrishnam *et al.*, 1999; Shivik, 2006; Woodroffe and Ginsberg, 1998). In recent years, complementary conservation strategies to protected areas have been proposed with the aim of better managing areas adjacent to protected areas (e.g., Daily *et al.*, 2003).

Jaguars (*Panthera onca*) are one of the species whose distribution and abundance has been modified as a consequence of habitat loss, forest conversion to agriculture and poaching (Ceballos *et al.*, 2006; Nowell and Jackson, 1996). A considerable percentage of the jaguar's historical range has been lost (Sanderson *et al.*, 2002c). In Mesoamerica, the Maya Forest region in Mexico, Guatemala and Belize contains

viable jaguar populations (Chávez and Ceballos, 2006; Sanderson *et al*., 2002a, c). Despite the major environmental change caused by intense human colonization in the area, there are still large stretches of well-preserved forest in communal lands, known as ejidos (Boege, 1995; Chowdhury, 2006; Turner II *et al*., 2001).

The southern Yucatan Peninsula includes several protected areas, the largest of which are Calakmul and Sian Ka'an Biosphere Reserves; however, if deforestation trends in the region are not reverted in the short term, both protected areas and forest areas (e.g., forest ejidos) will become islands unable to maintain jaguar populations and regional diversity (Ceballos *et al*., 2005). If jaguar conservation is to be successful, human-dominated areas will have to be included in regional and national conservation strategies. To do so, it is necessary to identify priority areas for jaguar conservation (Hatten *et al*., 2005; Wikramanayake *et al*., 2004). The objective of this study was to determine jaguars' habitat use and requirements jaguars in an area dominated by human activities and develop a habitat prediction model for the species in southern Yucatan Peninsula to design a regional jaguar conservation strategy. This study complements that of Zarza *et al*. (2005).

## Study area and methods

This study was conducted south of the states of Campeche and Quintana Roo, Mexico, at two spatial scales. The first scale was a focal study area of about 1,100 km$^2$ in Ejido Caoba (18º 14' N, 89º 03' W; Figure 1). The dominant vegetation in the region is tropical rainforest and semi-evergreen forest, and –to a lesser extent– tropical deciduous forest and seasonally flooded forest (Semarnat *et al*., 2001). The main economic activities in the ejido are forest exploitation and crop and livestock farming. Although hunting is not permitted in the forest exploitation area, it is common practice. The ejido is home to 1,322 people, who live in two villages (INEGI, 2005).

The focal study area is located in a region of approximately 78,000 km$^2$, between parallels 19° 30' and 17° 50' N and meridians 90° 25' and 87° 30' W (Figure 1). The second level of the study involved modeling potential jaguar habitat at a regional scale. Although the boundaries of the region do not represent ecological or political boundaries, we decided to cover the area delimited by Calakmul Biosphere Reserve in the west and Sian Ka'an Biosphere Reserve in the east, including both reserves. This region has the largest remaining area of Mexican tropical forest (Martínez and Galindo-Leal, 2002). It is basically flat, with an elevation ranging from 100 to 300 masl, and has sub-humid tropical climate, with a mean annual temperature of 24.6 °C and considerable seasonal changes. The wet season lasts from June to November, and mean annual rainfall is 1,076 mm (Turner II *et al*., 2001). About one third of the region is flooded during the wet season. There are virtually no permanent rivers or streams in the Calakmul region (Semarnat, 2000).

## Capture and telemetry

Jaguars were captured in the dry season –February to May– from 2001 to 2003 (for more details on capture methods, see Ceballos *et al.*, 2002; Chávez, 2006; Chávez *et al.*, this volume).

Individuals captured were fitted with a GPS collar (Televilt, CA); their movements were monitored flying over the study area with a light aircraft. Data were directly downloaded from the collars of jaguars recaptured the following year.

## Landscape variables

To determine habitat use preferences of the jaguar in the region, we analyzed three variables of the landscape on a regional scale-vegetation type and land use, human settlements and roads. Vegetation type and land use were obtained from the 2000-2001 National Forest Inventory at 1:250,000 scale (Semarnat *et al.*, 2001). We clustered the 23 vegetation classes of the inventory into 10: tropical rainforest and semi-evergreen forest, tropical deciduous forest, seasonally flooded forest, secondary vegetation, other habitats, agriculture, grassland, urban areas and bodies of water. Vegetation types present in less than 2% of the study area were included in "other habitats." This classification is based on the one made for the Calakmul region by Martínez and Galindo-Leal (2002).

Data on roads and human settlements were obtained from INEGI (Mexican National Institute of Statistics and Geography) and Conabio (Mexican National Com-

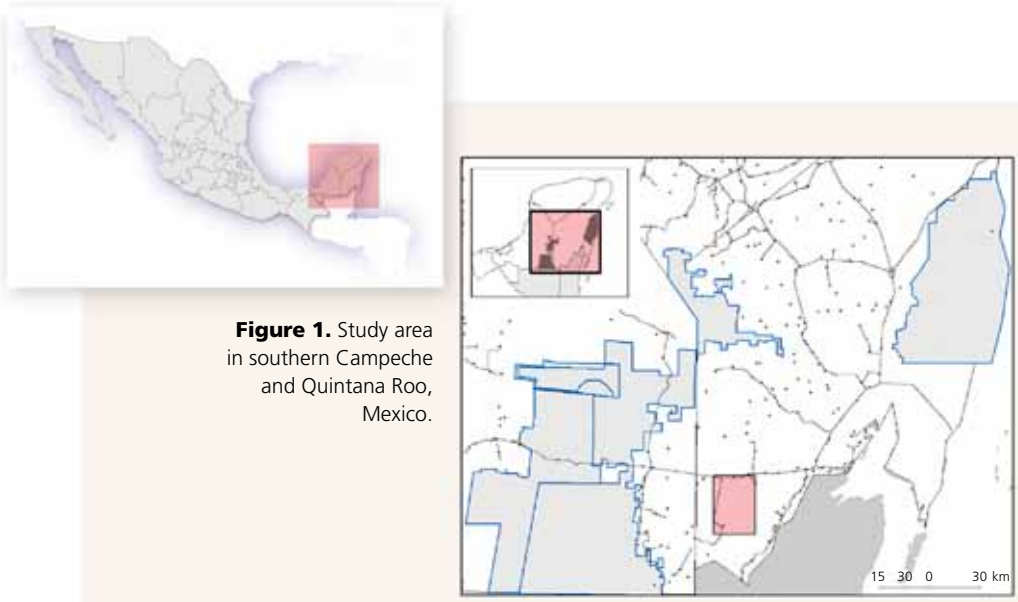


**Figure 1.** Study area in southern Campeche and Quintana Roo, Mexico.

mission for the Knowledge and Use of Biodiversity) in vector format at 1:250,000 scale. We only considered paved roads connecting settlements with a population of over 200 people because updated information is not available and several settlements have been abandoned in the last few years. We ruled out dirt roads, trails and paths because they are used by jaguars and do not limit their movements (C. Chávez, pers. obs.) The region is basically flat, so it was not possible to include thematic variables such as elevation and slope in the model. Hydrologic variables were not used because the region has no permanent rivers.

**Habitat use**

To determine habitat use, we used 620 records or locations of four female jaguars. The error of the records was estimated at 15 m, and we eliminated duplicated records. To avoid self-correlation between the data, we only considered data with a one-day interval at least (Núñez *et al.*, 2002). We randomly selected 50% of the records (n = 310) as modeling points and used them to develop the model and analyze habitat use. The remaining records were used to validate the model and were called "validation points." We used the "modeling points" to analyze the proportion of points observed and expected for each vegetation type and land use, as well as proximity to human settlements and roads using a Geographic Information System (ArcGIS 8.3, Environmental Systems Research Institute, Redlands, California, USA).

All the vegetation types in the focal study area were defined as available habitat. Vegetation types and land uses were classified according to the occurrence of jaguar records relative to that expected by chance. Habitats with a lower occurrence of records than would be expected by chance were defined as low-use habitat, those with an occurrence similar to their availability in the study area were defined as used habitat, and those with an occurrence greater than would be expected based on their availability in the study area were defined as high-use habitat. We used the $X^2$ goodness-of-fit test to determine whether jaguars used habitats according to their availability in the study area (Byers *et al.*, 1984; Neu *et al.*, 1974). We used Bonferroni Z confidence intervals to determine whether the category(-ies) or distance(-s) were significantly used more or less relative to their availability (Byers *et al.*, 1984). All the statistical analyses and tests were determined with a $P < 0.05$.

We identified the different habitat types –low-use, used, and high-use– for each variable based on the jaguars' habitat use preferences. After this, we overlaid the different ArcView 3.2. layers (ESRI, 1999) and obtained a map, which was used to validate the model with the validation points. Finally, we generated a predictive map of potential jaguar habitat by extrapolating the parameters used in Ejido Caoba to southern Campeche and Quintana Roo.

## Results and discussion

### Habitat use

The habitat available in the study area is formed by a matrix of vegetation types and land uses. The dominant vegetation is tropical and semi-evergreen forest (46%), followed by secondary vegetation (22%), grassland (14%), and finally seasonally flooded forest (11%). Jaguars showed marked preferences in habitat use between forest and modified areas. Although jaguar is a large, generalist and highly mobile species that are able to occupy several habitat types in the landscape matrix, it clearly shows habitat preferences. Jaguars used forest habitats more than expected (n = 239; 77%), compared to habitats modified by human activities ($X^2 = 38.3$, $P < 0.05$, Table 1).

The analysis of habitat preferences according to vegetation types and land use showed significant differences between available habitat and the various vegetation types considered ($X^2 = 82.1$, $P < 0.05$). Tropical rainforest and semi-evergreen forest were high-use habitats (58%) and occurred in more records than expected according to their availability (Table 1). Seasonally flooded forest and secondary vegetation were used proportionately to their availability. Cropland and urban areas were low-use habitat (Table 1). Similar results have been observed for other large carnivores such as tigers, pumas, bears and wolves; forest habitats are the best predictors of available habitat for these species (Koehler and Pierce, 2003; Lyons *et al.*, 2003; Miquelle *et al.*, 1999; Mladenoff *et al.*, 1995; Riley and Malecki, 2001).

Human settlements have a major impact on the spatial distribution of jaguar (Table 2). The highest occurrence of jaguars (> 80% of records) was found at a distance > 6.5 km from human settlements ($X^2 = 75.9$, $P < 0.05$). Jaguars also avoided

**Table 1.** Jaguar habitat selection according to vegetation type and land use in the southern part of the Yucatan Peninsula, Mexico

| Landscape variable | Records % (*n* = 310) | Bonferroni confidence intervals |
|---|---|---|
| Natural habitats | 77.1 | S |
| Modified habitats | 22.9 | A |
| $X^2 = 38.3$, gl = 1, $P < 0.05$ | | |
| Vegetation types and land use | | |
| Tropical rainforest and semi-evergreen forest | 58.7 | S |
| Seasonally flooded forest | 18.4 | P |
| Other habitats | 0.0 | A |
| Secondary vegetation | 21.6 | P |
| Grassland | 1.3 | A |
| Cropland | 0.0 | A |
| Urban areas | 0.0 | A |
| $X^2 = 87.1$, gl = 6, $P < 0.05$ | | |

Bonferroni confidence intervals show: A = avoided, P = proportion and S = selected

areas < 1 km from settlements. Studies on other carnivores have shown a similar pattern, that of avoiding or reducing use of areas near human settlements (Kerley *et al.*, 2002; Koehler and Pierce, 2003; Mladenoff and Sickley, 1998). The landscape around human settlements (< 6.5 km) is dominated by cropland, grassland, roads, small patches of mature forest and secondary vegetation. In the region, local people practice traditional or subsistence hunting within a minimum radius of 6 km from their settlements (Escamilla *et al.*, 2000; Jorgenson, 1995). There is considerable overlap between the jaguar's main prey –Central American agouti (*Dasyprocta punctata*), peccary (*Tayassu tajacu*) and armadillo (*Dasypus novemcinctus*)– and the prey hunters are interested in (Amín, 2004; Chávez *et al.*, this volume). Added to habitat fragmentation and modification, this leads to a decrease in the number of prey available for jaguars and a possible increase in interactions with people. The paved road was found to have a lower impact than human settlements on the spatial diestibution of the jaguar. The highest occurrence of jaguars (> 80% of records) was found at a distance > 4.5 km from the road ($X^2 = 209.5$, $P < 0.05$). Areas with the lowest occurrence (< 4%) were those located at a distance < 1.5 km from the road. These results partially support the hypothesis of the direct effect of roads on mortality of carnivores and their prey (Kerley *et al.*, 2002; Mladenoff and Sickley, 1998; Noss

**Table 2.** Effect of the road and human settlements on jaguar's habitat selection in the southern part of the Yucatan Peninsula, Mexico

| | Bonferroni confidence intervals | | | |
|---|---|---|---|---|
| Distance (m) | Road[1] | | Settlements[2] | |
| 500 | 0.6 | A | 0.0 | A |
| 1000 | 1.3 | A | 0.0 | A |
| 1500 | 1.9 | A | 0.3 | P |
| 2000 | 2.9 | P | 0.0 | A |
| 2500 | 1.3 | A | 0.6 | A |
| 3000 | 1.9 | A | 0.3 | A |
| 3500 | 3.5 | P | 1.9 | P |
| 4000 | 2.9 | P | 2.6 | P |
| 4500 | 5.2 | P | 1.6 | A |
| 5000 | 5.2 | P | 3.9 | P |
| 5500 | 4.5 | P | 2.9 | P |
| 6000 | 5.8 | P | 2.9 | P |
| 6500 | 6.5 | P | 5.2 | P |
| 7000 | 5.2 | P | 4.5 | P |
| 7500 | 8.7 | S | 11.0 | S |
| 8000 | 13.5 | S | 11.6 | S |
| 8500 | 9.7 | S | 8.1 | P |
| >9000 | 19.4 | S | 42.6 | S |

[1] $X^2 = 201.6$, gl = 16, $P < 0.05$

[2] $X^2 = 51.8$, gl = 16, $P < 0.05$

Bonferroni Z confidence intervals show: A = avoided, P = proportion and S = selected

*et al.*, 1996). Although the three landscape variables analyzed are related to each other, vegetation type was found to have the greatest weight. Human settlements and roads showed an effect on the jaguar's spatial distribution; the effect of each of these variables was found to be independent and in some cases synergistic.

## Habitat model

We developed a model based on the jaguar's habitat use preferences. High-use habitat has a high probability of occurrence (0.6-1) and includes areas with tropical rainforest and semi-evergreen forest located > 6.5 km from human settlements and > 4.5 km from roads. Used habitat has a medium probability of occurrence (0.2-0.6) and includes vegetation types and land uses that jaguars use depending on their availability, located 2-6.6 km from human settlements and 1-4.5 km from roads. Low-use habitat has the lowest probability of occurrence (0-0.2) and includes the vegetation types and land uses avoided by jaguars, < 2 km from human settlements and 1 km from the road.

The habitat model identified most of the study area as used habitat and high-use habitat for jaguars. There are large areas of these types of habitat in the south, center and east of the study area (Figure 2). Based on probabilities of occurrence, the area including high-use habitat was estimated to cover 35,849 km$^2$ (45.8%), used habitat was estimated to cover 23,076 km$^2$ (9.4%), and low-use habitat was estimated to cover 19,387 km$^2$ (24.8%). The verification of the model showed that 96.5% of jaguars points were located in high-use habitat (56.8%, n = 176) and used habitat (39.4%, n = 123). The same trend was observed in the validation stage; 96% of jaguar records came from the area classified as high-use habitat (57%, n = 177) and used

**Table 3.** Land area and percentage of habitat used by jaguars in the protected areas in the study area in the aouthern Yucatan Peninsula, Mexico

| Protected Area | Surface (ha) | Predicted probability of occurrence ha (%) | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Calakmul Biosphere Reserve | 723,185 | 4,906 | 158,385 | 447,830 |
| | | (1.6) | (25.8) | (72.5) |
| Sian Ka'an Biosphere Reserve | 528,147 | 74,900 | 163,935 | 105,668 |
| | | (21.5) | (47.6) | (30.8) |
| Balam Kú Biological Reserve | 409,200 | 3,521 | 106,513 | 235,290 |
| | | (1.0) | (30.8) | (68.1) |
| Balam Kin Biological Reserve | 110,990 | 285 | 15,285 | 84,036 |
| | | (0.3) | (15.3) | (84.4) |
| Bala'an Ka'ax Flora and Fauna Protection Area | 128,390 | 1,570 | 24,500 | 99,540 |
| | | (1.3) | (19.5) | (79.2) |

habitat (39%, n = 121), as predicted by the model. This means that the model is consistent and highly reliable in predicting potential jaguar habitat in the Maya Forests of southern Campeche and Quintana Roo, Mexico.

About 68% of the surface of the protected areas in the study area (Table 3) is estimated to be high-use habitat, with the exception of Sian Ka'an Biosphere Reserve, which only has 30% of high-use habitat. Although nature reserves are protecting part of the habitat necessary to maintain jaguars in the region, these areas are probably insufficient to guarantee the long-term survival of the species. It is therefore necessary to develop a conservation strategy that considers the forest areas outside protected areas that fulfill the necessary ecological conditions for the survival of the jaguar and regional biodiversity (Daily *et al.*, 2003). Determining habitat use requirements in areas influenced by human activities makes it possible to understand habitat use preferences, analyze how jaguars perceive these new changes and determine where management and conservation efforts should be targeted (Hatten *et al.*, 2005; Ortega-Huerta and Medley, 1999).

In Mexico, any jaguar conservation strategy must be approached from a regional scale, taking protected areas as cornerstones. However, adjacent areas must also be included. This requires solid strategies that take into account the species' biological requirements and main threats as well as the social reality of the region. This can be done by promoting sustainable projects such as ecotourism or apiculture to improve the social welfare of local people by giving an added value to natural resources.

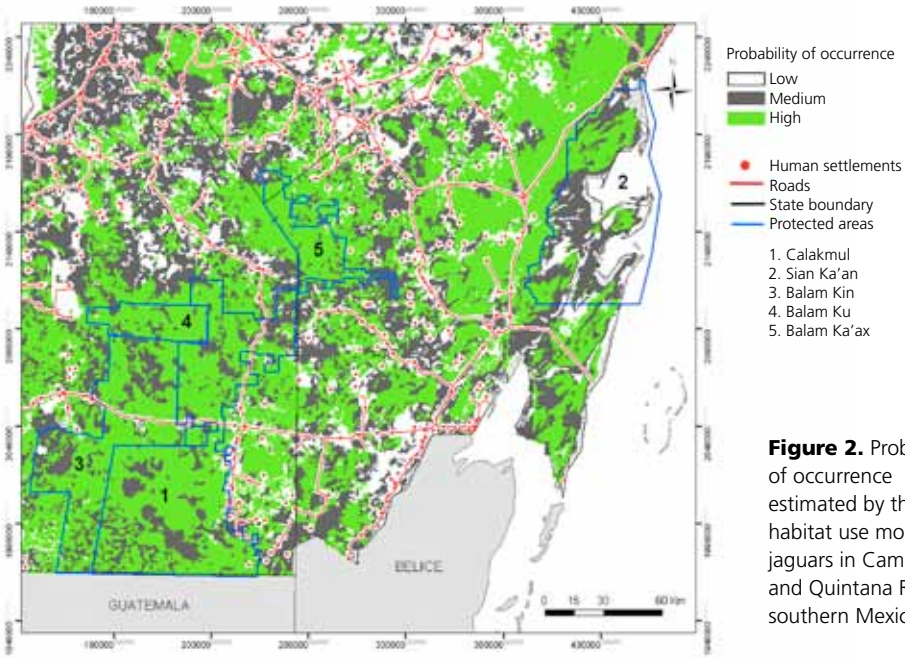


**Figure 2.** Probability of occurrence estimated by the habitat use model for jaguars in Campeche and Quintana Roo, southern Mexico.

## Recommendations

Local and regional development programs must include ecological and biological criteria to make decisions on future projects. Considering the effect of the biological, social and economic interests of the region will lead to better decision making. Including the communities living around the protected areas in the region will lead to better conservation prospects inside the reserves, thus minimizing possible agonistic interactions between large species and humans.

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