# PATTERNS AND DETERMINANTS OF HUMAN-CARNIVORE CONFLICTS IN THE TROPICAL LOWLANDS OF GUATEMALA

By

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To God, who made a perfect world for us to live in and has never abandoned us.

To my parents, Maria and Neftali (deceased), for all their sacrifices and support.

To Nancy and Danny, for bringing so much joy into my world and always reminding me of what truly matters in life.

To the Peten: magical, mysterious land of beauty and life.

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Human-carnivore conflicts have been identified as a major cause of large carnivore population declines and can have negative economic impacts on local people. Although Human-carnivore conflicts (HCC's) have been studied intensively around the world, very little information on HCC's in Mesoamerica is available.

I applied a survey questionnaire to cattle ranchers to examine patterns of livestock depredation and estimate total economic loss due to large predators in the tropical lowlands of Guatemala. Furthermore, I compared ranches with and without attacks using logistic regression and Aikaike's Information Criterion (AIC) to determine whether ranch characteristics (e.g., size, and number of cattle), livestock husbandry practices, and landscape structure in and around ranches explained the probability of occurrence of HCC's. Understanding patterns of livestock depredation and the influence of livestock husbandry practices and landscape features on HCC's is important for site-specific conflict mitigation strategies and identification of areas and ranches most prone to HCC's.

The jaguar was the carnivore most accused of livestock attacks, followed by the puma and coyote in much smaller percentages; the type of livestock most attacked was cattle, followed by

goats, with cattle taken falling between the ages of 2 days and 12 months, while weights of cattle attacked ranged from 11.4 to 431.82 kg. I detected a preference towards male cattle, and, similar to other sites, most attacks occurred at night, and were more common during the rainy season, reaching a peak during the wettest months. A major difference detected between other sites previously studied in the neotropics (e.g., South America) were possible livestock attacks by coyotes in parts of the study site. Economic losses from carnivore attacks on livestock were minimal, yet, because small cattle ranches are predominant in the area, the economic impact of each loss may be perceived as significant by the ranches impacted by these losses.

Finally, landscape variables (e.g., forest cover area, distance to forest cover, and distance to rivers) were the best predictors of HCC's. Even though ranches did not employ practices considered beneficial to reducing carnivore attacks on livestock, ranch characteristics and livestock husbandry practices were not important predictors of livestock attacks in this study because they were similar among most ranches.

# CHAPTER 1
# INTRODUCTION

## Conservation Issue

Human-carnivore conflicts (HCC) in the neotropics arise when large carnivores such as jaguars (*Panthera onca*), and pumas (*Puma concolor*) attack livestock. Conflicts with humans have been identified as the most important cause of adult mortality in large carnivore populations and could lead to their local extinction, even within protected areas (Woodroffe and Ginsberg, 1998). In most cases, livestock depredation involves an economic loss for cattle ranchers and the culling of the carnivore believed responsible for the attacks (Crawshaw, 2004; Zimmerman et al., 2005).

Nevertheless, the impacts caused by carnivores on livestock is often overestimated. For instance, researchers have found that jaguars are usually responsible for a small percentage of cattle losses (Hoogesteijn et al., 1993; Mazolli et al., 2002; Polisar et al., 2003; Michalski et al., 2006; Cascelli, 2008; Palmeira et al., 2008); similarly Graham et al. (2004) determined that large predators are responsible for only 2 to 3% of all domestic animal mortality.

However, because of a lack of strict control and supervision of livestock, mortality incidents due to other causes are often attributed to large predators because their presence coincides with these losses (Gosline, 2004; Graham et al., 2004). Furthermore, when carnivores such as jaguars are hunted down, they are either killed or wounded; the latter exacerbates the problem when wounded individuals are forced to look for easy prey, such as livestock (Rabinowitz, 1986; Hoogesteijn et al., 1993; Polisar et al., 2003).

Consequently, efforts to identify and implement human-carnivore conflict mitigation strategies are urgent, especially on reserve borders and buffer zones where contact between humans and carnivores is more likely (Woodroffe and Ginsberg, 1998; Sunquist, 2002;

Crawshaw, 2004). However, before taking such actions, it is important to examine spatial and temporal patterns of such conflicts in order to propose viable and effective site-specific interventions (Treves et al., 2006).

## Determinants of Human-Carnivore Conflicts

Human-carnivore conflicts may be influenced by prey depletion, landscape structure, and livestock husbandry practices. HCC´s generally occur in areas with a large forest-human interface, where human settlements are found adjacent to protected areas or large tracts of forest. Nyhus and Tilson (2004) found that human-tiger conflicts occurred more often in forests with intermediate levels of disturbance (e.g., multiple use forests) than in protected areas. The notion that livestock depredation by carnivores is more common in areas with low prey abundances dates as far back as Theodore Roosevelt (Rabinowitz, 2005) and has been discussed and studied in detail since then (Hoogesteijn, et al., 1993; Treves, et al., 2004; Sillero-Zubiri and Laurenson, 2001; Polisar et al., 2003; Bagchi and Mishra 2006). Nevertheless, some studies suggest the opposite trend, a positive relationship between depredation rates and wild prey availability, due to higher predator densities in response to an increase in prey densities (Stahl et al., 2002).

With regards to landscape structure, livestock depredation incidents by jaguars and pumas have been found to be positively correlated with forest area and distance to human settlements, but negatively correlated with proximity to forest cover and water sources (Saenz and Carrillo, 2002; Michalski et al., 2006; Cascelli and Murray, 2007; Palmeira et al., 2008). Other studies on HCC's report a negative association of livestock depredation by carnivores and density of human roads and settlements (Treves et al., 2004).

In most tropical forests, rudimentary and non-technical livestock management practices are considered one of the principal factors leading to depredation incidents (Quigley and Crawshaw, 1992; Hoogesteijn et al., 1993; Polisar et al., 2003; Rabinowitz, 2005). Livestock in the neotropics is not adequately managed because most ranches are small and operate at very low costs (Saenz and Carrillo, 2002).

Examples of rudimentary husbandry practices that increase the probability of livestock depredation incidents include keeping free ranging and unattended cattle and other livestock near prime carnivore habitat (e.g., adequate forest cover and water sources). Additionally, adult males may be the only type of cattle that exhibit defensive behaviors against predators (Sunquist and Sunquist, 1989), yet because most cattle ranches keep a higher proportion of females and calves, they inadvertently maintain higher numbers of more vulnerable cattle classes. Also, ranchers are not accustomed to regulating calving seasons; as a result, the most vulnerable cattle age class is available for depredation year round. Keeping livestock surrounded by low quality fencing and enclosures that can easily be penetrated by carnivores is also a principal factor favoring depredation incidents (Rabinowitz, 1986; Hoogesteijn et al., 1993; Hoogesteijn, 2001; Saenz and Carrillo, 2002; Polisar et al., 2003; Sognamillo et al., 2003; Conforti and Cascelli, 2003; Crawshaw, 2004; Graham et al., 2004; Zimmerman et al., 2005; Michalski et al., 2006).

Furthermore, studies examining livestock depredation by jaguars and pumas have detected a positive correlation between carnivore attacks and bovine herd size (Michalski et al., 2006), and have found higher depredation rates during the peak calving seasons (Sognamillo et al., 2003; Polisar et al., 2003; Michalski et al., 2006; Palmeira et al., 2008).

## Human-Carnivore Conflicts in Mesoamerica

Most research on HCC's in the neotropics has been conducted in South America (Quigley and Crawshaw, 1992; Hoogesteijn 2001; Polisar et al., 2003; Conforti and Cascelli, 2003; Crawshaw, 2004; Graham et al., 2004; Zimmerman et al., 2005; Michalski et al., 2006); in contrast, very few studies have examined HCC's in Mesoamerica (Rabinowitz, 1986; Saenz and Carrillo, 2002). As a result, little is known about HCC's in Mesoamerica and it is not clear whether livestock depredation is similar to other areas or if husbandry practices and landscape features affect probability of occurrence of human-carnivore conflicts in the same manner throughout their entire distribution.

The northern half of the Peten District, in Guatemala, along with adjacent protected areas in Belize and Mexico, forms part of the largest continuous forest in Mesoamerica (Grunberg, 2000). Despite this, forest fragmentation in this district is increasing due to current migration trends (Grunberg, 2000; Hayes et al., 2002). Although cattle ranching is one of the principal forms of livelihood (Grunberg, 2000) and is very common in this area (Instituto Nacional de Estadistica, 2003), it has not been studied in detail. There is no information on whether ranches and their livestock husbandry practices are similar throughout, or if they vary according to size and capacity, and if the ranches apply measures designed to protect their livestock from wild carnivores. Therefore, it is not clear if a difference in landscape structure due to fragmentation, and livestock husbandry practices of ranches could be a principal factor affecting the occurrence of conflicts with carnivores in the area.

I applied a survey questionnaire to cattle ranchers in the Peten District. My objectives were to quantify and examine livestock depredation incidents by carnivores and test the hypothesis that the occurrence of HCC’s in the study area was influenced by landscape variables, ranch characteristics, and livestock husbandry practices. To examine depredation incidents I determined type, age, weight and sex of livestock most frequently attacked, as well as the temporal patterns of the attacks and the total and average monetary loss due to depredation. Finally, I compared landscape variables, ranch characteristics, and husbandry practices between ranches with and without carnivore attacks on livestock to identify the best predictors of HCC occurrence.

CHAPTER 2
METHODS

## Study Area

This study was carried out in the Peten District, Guatemala, the largest and northernmost district of Guatemala. It covers an area of 36,000 square kilometers (Hayes et al., 2002) with a population of 366,735 people (Instituto Nacional de Estadistica, 2003).

Altitudes in Peten range from 100 to 300 meters above mean sea level (Grunberg, 2000), annual precipitation varies from 1,300 to 2,500 mm. (McNabb and Polisar, 2002), and mean temperatures range from 22º C to 34 ºC (Novack, 2003). The vegetation in Peten consists primarily of high canopy tropical lowland forests, seasonally flooded lowland forests with a dense understory of shrubs and small trees, wetlands along rivers and lakes, and flat savannah-like grasslands (Grunberg, 2000). Within the Peten District, we find several protected areas that are surrounded by human communities whose principal livelihood is cattle ranching (Figure 2.1). A survey carried out in 2003 estimated that the number of cattle ranches in the Peten District was between 5 and 7 thousand (Instituto Nacional de Estadistica, 2003).

The largest protected area of Guatemala, the Maya Biosphere Reserve (MBR) is situated in the northern half of the Peten District. The MBR covers an area of over 2.1 million hectares (McNabb and Polisar, 2002) and is located within the broadleaf sub-tropical forest of the Atlantic lowlands, known as the Selva Maya (Maya Forest). The Maya Forest represents the largest area of subtropical forest in Mesoamerica, extending over 3 million hectares in Belize, Guatemala, and Mexico (Consejo Nacional de Areas Protegidas, 2001).

Contained within the MBR is a combination of land use designations designed to provide for ecological protection and sustained human development. Protected areas of the MBR cover a noncontiguous area of 767,000 ha. The MBR also encompasses a multiple use zone of 848,440 ha; the multiple use zone is an area divided into a series of community managed forest concessions, where the sustainable extraction of timber and non-timber natural resources is permitted to local communities living within this zone. There is also a buffer zone of 497,500 ha, which is a 15 km wide strip of land situated along the southern edge of the MBR where land use is limited to activities compatible with the biodiversity objectives of the MBR (Consejo Nacional de Areas Protegidas, 2001).

Another important series of protected areas is the Southern Protected Areas Complex of Peten. This complex is comprised of 11 protected areas which cover an area of 180,881 ha, plus a series of buffer zones surrounding each protected area, which total 270,011 ha. (AHT/PROSELVA, 2000).

**Reports of Livestock Depredation by Carnivores**

To record on livestock attacks, I surveyed cattle ranchers; I focused on attacks within the past 5 years (2003 to 2007). In addition, I gathered information on livestock husbandry practices in ranches with and without reports of carnivore attacks. Through office visits and workshops, I first surveyed Wildlife Service government officials and NGO personnel to identify ranches that had reported livestock depredation by carnivores. I then surveyed these ranches. After surveying these ranches, I applied the same questionnaire in as many adjacent ranches as possible. I increased my sample size by using a "snowball technique", in which I asked the surveyed cattle ranchers to provide information about other attacks of which they might be aware in the area (or other areas within the Peten District). I tried to survey an equal number of ranches with reports of attacks and ranches without attacks.

At each ranch surveyed, I documented the ranch geographically through a GPS unit and followed the same process of inquiry. I asked if there had been any depredation incidents within the time frame of interest and, when an incident was reported, I asked a suite of questions about each incident that would allow for the evaluation of the report's reliability and characterize the attack. Only first-hand reports of attacks were accepted and the reliability of each attack was assessed based on the following indications of an attack (Hoogesteijn et al., 1993; Hoogesteijn et al., 2002):

- Signs of struggle: blood on animal or surroundings or trampled vegetation.
- Visible wounds on animal: claw and bite marks, location of wounds (back of neck, skull or on throat), or animal found with neck twisted, and certain parts of animal consumed.
- Description of site where animal was found: animal being dragged away from ranch, or hidden beneath leaves.

For analyses, all second-hand and unreliable reports were discarded. In addition, all attacks were pooled regardless of the carnivore (jaguar, puma, or coyote) believed responsible for the attack, because it is difficult to distinguish between attacks by these predators (Palmeira et al. 2008).

## Patterns of Livestock Depredation

For each reported attack, I determined the carnivore believed responsible for the attack, type of livestock attacked (e.g., cattle, goat, horse, pig, and dog), and time of day, month, and year of incident, when known. Hour of day was categorized as night (6:00 p.m to 6:00 a.m), morning (6:00 a.m to 12:00 p.m), and afternoon (12:00 p.m to 6:00 p.m), because in many cases the exact hour was not known. Furthermore, monthly data were categorized as occurring in the wet (June to January) or dry season (February to May) to test for seasonality.

Chi-square ($X^2$) Goodness of Fit Tests were used to test the hypotheses that species of attacker (e.g., jaguar, puma or coyote), type of animal attacked (e.g., cattle, goats, horses, pigs, and dogs), time of day, and seasonality of attacks were equal in number for all categories; Fisher's Exact tests were used when frequencies of responses were small (Zar, 1999).

I performed Spearman Rank Correlations ($r_s$) to examine associations between frequency of attacks per year and annual total precipitation (mm) and between frequency of attacks per month and monthly rainfall. Rainfall data were obtained through CEMEC (Center for Ecological Evaluation and Monitoring), which is the Geographic Information Systems department of the National Council of Protected Areas (CONAP) in Guatemala.

I also performed similar and more detailed analyses for cattle only, because cattle is the most abundant and important type of livestock in the area. Therefore, I recorded sex, age (in months), and weight (kilograms) of each animal attacked. Cattle weights were categorized into 9 different weight classes (11.4 to 450 kg.).

Chi-square ($X^2$) Goodness of Fit Tests were used to test the hypothesis that attacks occurred on both sexes equally. Spearman rank correlations ($r_s$) were used to test the relationship between number of attacks and age, and weight of animals attacked. Analyses for temporal patterns (e.g., hour and seasonality) of attacks on cattle were similar to those carried out for all attacks.

A total and average annual monetary loss during the study period was obtained for all attacks pooled and for cattle separately by asking ranchers to estimate cost of animal attacked and converting their estimates to US dollars at an exchange rate of local currency of Q7.60 for US$1.00.

All analyses were performed in SAS 9.1® (SAS Institute, 2003). Statistical significance was measured at $P < 0.05$ for all analyses.

## Livestock Husbandry Practices

I recorded if ranches applied livestock husbandry practices that researchers (Hoogesteijn et al., 1993; Hoogesteijn, 2001; Polisar et al., 2003) have recommended to reduce probability of livestock depredation incidents by large felids. These husbandry practices are:

1. Secure enclosures. I measured height of fences where most cattle were kept, number of rows of fences, average spacing between rows and height of last fence row. This last measure was based on the observation that the last fence row presents a relatively larger separation from the ground than the other fence rows do between each other. All fences were made of the same material, wooden posts and barbed wire, therefore type of fence or materials were not evaluated. Only one ranch had electric fencing, and this practice was not used in all the pastures of this ranch.

2. Intensity of guarding. This was measured by the presence of guard dogs, number of people in ranch and number of hours cattle are watched per day.

3. Presence of maternity pastures at a distance from forest cover and mixing adult males in with calves and females. Both these practices help protect the most vulnerable age class of cattle (i.e., calves). Because adult males are larger and may defend themselves against predators (Sunquist and Sunquist, 1989), it is assumed their presence near calves would help protect them.

I also evaluated ranch characteristics, and type of livestock control and care for each ranch surveyed. I assumed that larger ranches with higher number of livestock that applied a suite of livestock husbandry practices recommended by researchers (Quigley and Crawshaw, 1992; Hoogesteijn et al., 1993; Hoogesteijn, 2001; Polisar et al., 2003) would provide better care and protection for their cattle.

Descriptive characteristics evaluated included ranch size, number of cattle, and number of pastures in ranch. The following practices were also examined for each ranch: frequency of cattle rotation between pastures, frequency of veterinary care and whether ranches kept updated cattle records, and regulated calving seasons (this practice would imply a more technical control of breeding and the economic capacity for artificial insemination).

The ranchers were given complete freedom as to which questions to answer; this limits the number of responses and data available per variable.

## Landscape Metrics

The landscape attributes at and around each ranch (Table 2.1) were measured using Arc Toolbox® in ARCGIS 9.0®; all GIS layers where provided by CEMEC. I used vector layers for human settlements, rivers, bodies of water (i.e., lakes, lagoons, etc.), roads, and a raster layer for forest cover obtained from Land Sat images for the year 2003.

I created a layer of the GPS coordinates of all the cattle ranches surveyed (with and without attacks). To calculate distance from each ranch to settlements, rivers, roads, and bodies of water, I joined the cattle ranch layer to the corresponding layer of which I wanted to obtain the metric. This function joins each ranch point to the nearest attribute in the layer being analyzed and calculates distance to that feature.

To calculate forest cover and distance to forest, I used Spatial Analyst®. I created a 5 km buffer around each ranch point and used the “tabulate area” function to estimate forest cover in each 5 km buffer. To estimate distance to forest cover, I used the Euclidean distance function.

## Variable Selection, Model Building and Evaluation

I performed a logistic regression analysis on *a priori* models based on three categories (application of husbandry practices designed to prevent large carnivore attacks, ranch characteristics and type of livestock control and care, and landscape variables) of explanatory or predictor variables and used Aikaike´s Information Criterion (AIC) to compare models and identify the model or models that received the most support for explaining occurrence of livestock depredation by carnivores in cattle ranches. All analyses were carried out in SAS 9.1® (SAS Institute, 2003).

Although prey depletion is regarded as an important factor influencing livestock depredation, I did not consider it in my research because several studies (Polisar et al., 1998; Baur, 1998; Carrillo et al., 2000; Novack et al., 2005) have found a marked decrease in prey abundances around human settlements due to subsistence hunting. Furthermore, Soto (2006) reports a perceived decrease of carnivore prey species around cattle ranches by local people in the Peten District. Because the ranches included in this study are all near human settlements

(Figure 3-1), I assumed similar prey richness and abundances around them due to intense hunting pressure and therefore, little or no effect of this variable on livestock depredation by carnivores.

The models evaluated were the following:

1. Global model (combination of all ranch characteristics, livestock husbandry practices, and landscape variables)
2. Ranch characteristics and type of livestock control and care combined with husbandry practices that protect against predators.
3. All husbandry practices related directly to protection of cattle from carnivore attacks (i.e., secure enclosures, intensity of guarding, etc.).
4. Ranch characteristics and husbandry practices indirectly related to livestock protection from predators, but explaining ranch type and level of cattle care and control (i.e., ranch size, number of cattle, veterinary care provided, updated cattle records, etc.).
5. All landscape variables.

I removed the variable presence of guard dogs from the analyses because only one ranch reported the use of guard dogs, and these guard dogs were not present during the study period.

Models with many parameters are usually not well supported, unless sample size or effect size are large or if the residual variance is small (Anderson, 2001). Therefore, I first conducted a Principal Components Analysis (PCA) following McGarigal et al. (2000) on all continuous variables as a variable reduction technique. The PCA allowed me to reduce correlated variables and retain variables that contribute more to the variation within my dataset.

I used a criterion of $r \geq 0.5$ to determine if there was a significant correlation between covariates (Table 2.2). Five pairs of explanatory variables were highly correlated ($r^2 \geq 0.5$) (Table 2.2). As a result I eliminated one variable from each pair based on my criteria of which variable would contribute more to the analyses.

I then analyzed the component loadings from each of the first five components selected by the scree plot. From this analysis, I retained 5 continuous variables. Three of the final variables selected were landscape metrics and the remainder related to husbandry practices (Table 2.3). To these, I added the 3 categorical variables which could not be analyzed by a PCA (McGarigal et al., 2000). Consequently, I used 8 explanatory variables (2 continuous and 3 categorical husbandry practice variables, and 3 landscape variables) to construct the final models (Table 2.4).

I used Proc Logistic (SAS Institute, 2003) to evaluate the models using presence or absence of attacks in each ranch as my dependent variable for the 5 different models.

I used a Hosmer-Lemeshow Goodness of Fit test to examine the model fit ($\alpha \leq 0.05$) for each model proposed (Hosmer and Lemeshow, 2000). Models were then compared using Aikaike's Information Criterion (AIC) (Burnham and Anderson, 2002). I transformed the AIC estimate obtained for each model into a second-order quasi-likelihood AIC ($QAIC_c$) following Burnham and Anderson (2002) because of a small sample size and possible over dispersion of the categorical variables.

Over dispersion occurred because the categorical variables contained sparse data. In other words each variable had mostly outcomes of one type (Agresti, 2007). Variables with sparse data can be identified by their 95% confidence intervals, which are either very large or infinite (i.e., CI = <0.001; >999.999). All categorical variables were identified as containing sparse data (Table 2.5, Figure 2.2). I also tested for over dispersion by dividing the deviance of the global model (55.92) by its degrees of freedom (41) using PROC GENMOD (SAS Institute, 2003). The value obtained from this analysis (1.36) gave me further reason to suspect over dispersion of these variables.

Finally, I estimated the $QAIC_c$ differences ($\Delta_i$) and the Aikaike weights ($w_i$) according to Burnham and Anderson (2002) to determine the best supported models:

$$\Delta_i = QAICi - QAIC_{min} \tag{2-1}$$

$$w_i = \frac{\exp(-\frac{1}{2}\Delta_i)}{\sum_{r=1}^{R}\exp(-\frac{1}{2}\Delta_r)} \tag{2-2}$$

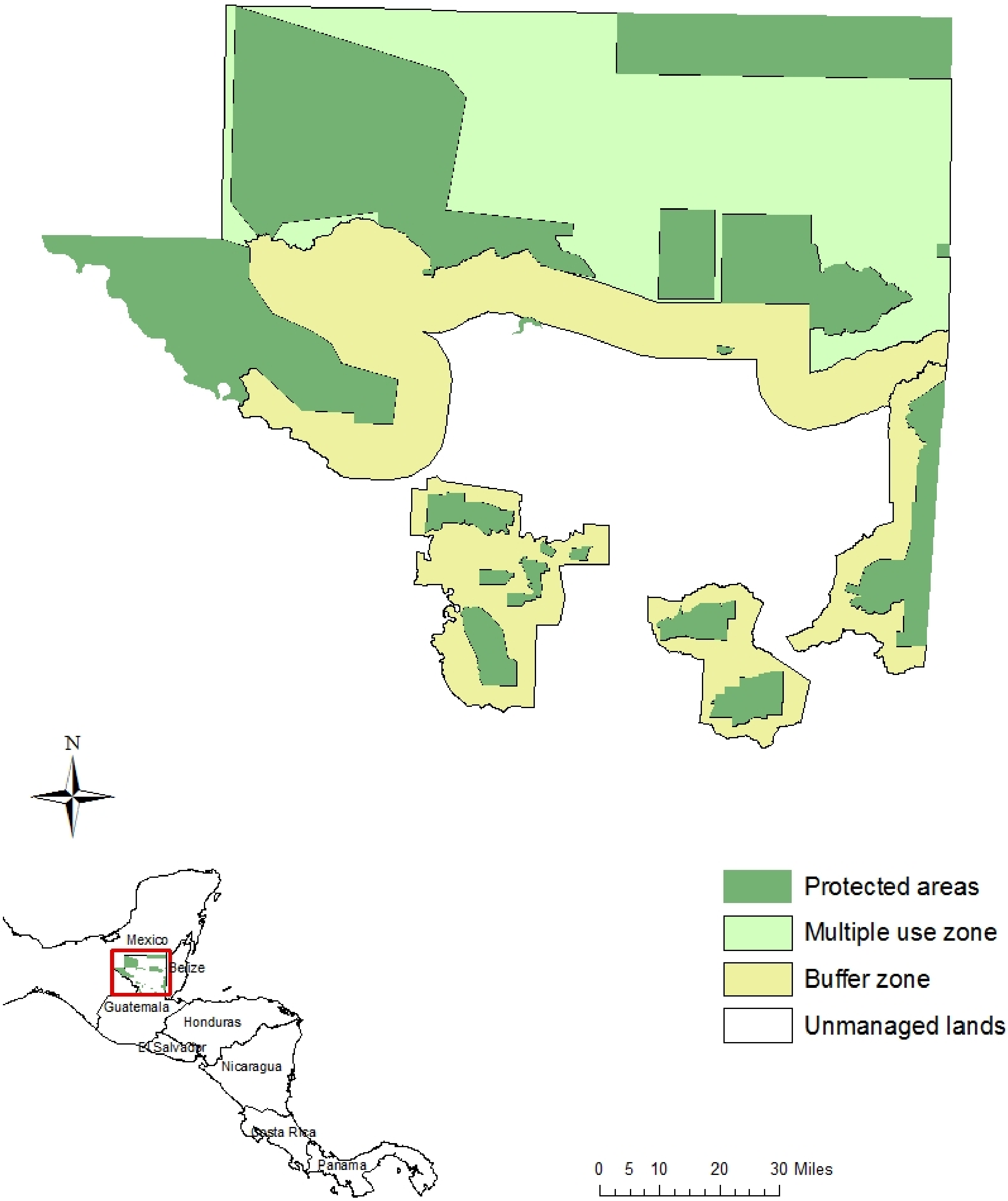


Figure 2-1. Map of the Peten District, 2007.

Table 2-1. Landscape characteristics and livestock husbandry practices obtained for each ranch in the Peten District, Guatemala, 2007.

| Variable | Description | Codes/values | Variable type | Name |
|---|---|---|---|---|
| 1 | Attacks in ranch | 0=No / 1=Yes | Categorical | ATT |
| 2 | Size of ranch | hectares | Continuous | SR |
| 3 | No. of cattle per ranch | Number | Continuous | HCAT |
| 4 | Fence height | Meters | Continuous | FH |
| 5 | No. of fence rows | Number | Continuous | FR |
| 6 | Average spacing between rows | Centimeters | Continuous | FSR |
| 7 | Height of last row in fence | Centimeters | Continuous | FSLR |
| 8 | No. of caretakers in ranch | Number | Continuous | PP |
| 9 | No. of hours per day livestock is watched | Hours per day | Continuous | HD |
| 10 | Guard dogs present in ranch | 0=No / 1=Yes | Categorical | DG |
| 11 | No. of pastures per ranch | Number | Continuous | PST |
| 12 | Frequency of cattle rotation | Days | Continuous | FCR |
| 13 | How often do you update your cattle records? | Months | Continuous | URC |
| 14 | How often do your cattle receive veterinarian care? | Months | Continuous | FVC |
| 15 | Do you regulate calving season? | 0=No / 1=Yes | Categorical | RCS |
| 16 | Do you have maternity pastures? | 0=No / 1=Yes | Categorical | MP |
| 17 | Are males mixed in with females and calves? | 0=No / 1=Yes | Categorical | MFC |
| 18 | Forest cover in 5 $km^2$ buffer around ranch | Squared meters | Continuous | FC |
| 19 | Distance to forest cover | Meters | Continuous | DFC |
| 20 | Distance to rivers | Meters | Continuous | DR |
| 21 | Distance to bodies of water | Meters | Continuous | DBW |
| 22 | Distance to human settlements | Meters | Continuous | DHS |
| 23 | Distance to roads | Meters | Continuous | DRD |

Table 2-2. Results of the Principal Components Analysis Correlation Matrix, Peten, Guatemala, 2007.

| Correlated explanatory variables | Correlation coefficient | Variable eliminated |
|---|---|---|
| FR + FSR | -0.77753 | FSR |
| HCAT + PST | 0.68296 | PST |
| FSR + FSLR | -0.59328 | FSLR |
| HCAT + FCR | 0.68296 | FCR |
| DR + DRD | 0.83281 | DRD |

Only pairs of variables with a significant correlation ($r^2 \geq 0.5$) are shown. From each pair of correlated variables, one was kept for the final logistic regression analysis. Refer to table 2-1 for variable names.

Table 2-3. Results of the Principal Components Analysis for continuous landscape and livestock husbandry practice variables measured at each ranch in Peten, Guatemala, 2007.

| Component and variance explained by each factor | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| | 3.4851 | 2.9779 | 2.1597 | 1.601 | 1.3278 |
| Variable | Component Loading | | | | |
| SR | -0.304 | 0.2198 | 0.147 | 0.079 | 0.63058 |
| HCAT | -0.2473 | 0.7944 | 0.1238 | 0.1115 | -0.1655 |
| FC | 0.7424 | 0.0387 | 0.0478 | -0.1918 | 0.1032 |
| DFC | -0.2375 | 0.1283 | 0.1728 | 0.6829 | -0.3725 |
| DR | 0.4753 | 0.5749 | 0.5502 | 0.1322 | -0.0206 |

Only variables selected from the factor pattern output for the first five factors retained from the PCA are shown. The variable with the highest component loading was retained from each factor. Refer to table 2-1 for variable names.

Table 2-4. Candidate models evaluated through logistic regression, Peten, Guatemala, 2007.

| Model Number | Model description | Variables included in model |
|---|---|---|
| 1 | Global model | SR HCAT RCS MP MFC FC DFC DR |
| 2 | All livestock husbandry practices | SR HCAT RCS MP MFC |
| 3 | Livestock husbandry practices directly related to protection of livestock from carnivores | MP MFC |
| 4 | Livestock husbandry practices indirectly related to depredation incidents (ranch characteristics and type of livestock control and care) | SR HCAT RCS |
| 5 | Landscape variables | FC DFC DR |

Refer to table 2-1 for variable names.

Table 2-5. Ninety-five percent Wald confidence limits of the odds ratios obtained for the global model, Peten, Guatemala.

| Variable | Confidence limits | |
|---|---|---|
| SR | 0.998 | 1.002 |
| HCAT | 0.996 | 1.017 |
| RCS* | 0.093 | 114.554 |
| MP* | <0.001 | >999.999 |
| MFC* | 0.003 | 34.401 |
| FC | 0.997 | 1 |
| DFC | 1 | 1.001 |
| DR | 1 | 1.001 |

*Large confidence limits indicate over dispersion of categorical variables. Refer to table 2-1 for variable names.

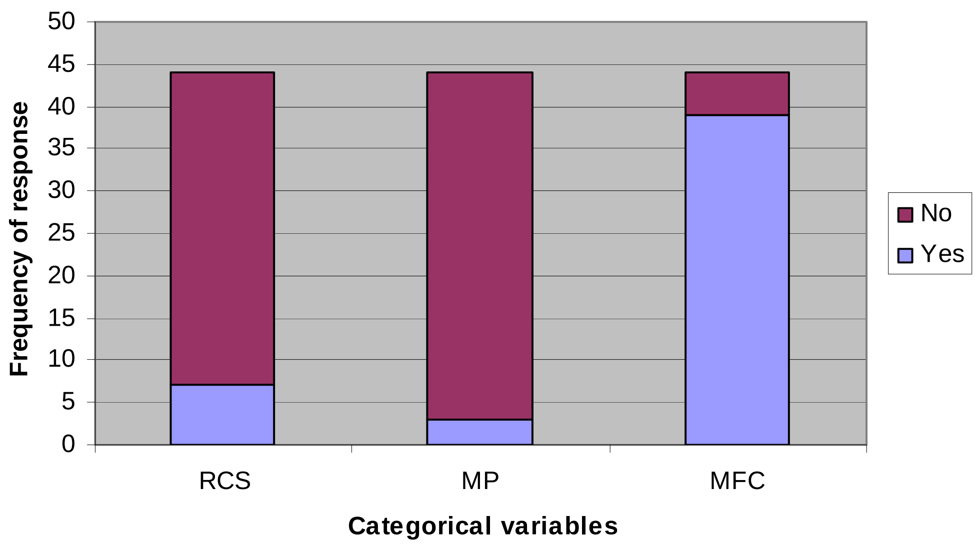


Figure 2-2. Frequency of responses for categorical variables obtained from each ranch surveyed in the Peten District, Guatemala (2007). Graph shows high outcomes of one response type for all variables. Table 2-1 gives variable names.

# CHAPTER 3
# RESULTS

I surveyed a total of 83 ranches throughout the Peten District (Figure 3.1). Of these, 32 ranches reported 104 reliable livestock depredation incidents within the time frame of interest.

Size of ranches varied (mean ± SE = 175.9 ± 41.62 ha, range = 11.2 – 2,688 ha, mode = 44.8 ha, *n* = 70) with a high percentage of small ranches (11.2 to 500 ha) and very few medium-sized (500 to 1,000 ha) and large (>1,000 ha) ranches (Figure 3.2). The mean number of cattle per ranch was 120.51 ± 17.57 (± SE), range = 5 – 750 cattle per ranch, and mode = 100 (*n* = 69).

## Patterns of Livestock Depredation by Carnivores

The jaguar was the carnivore accused of most attacks on livestock (78.85% of all attacks, P < 0.0001, *n* = 104), while the puma and coyote (*Canis latrans*) were accused of 15.38% and 5.77% of the attacks, respectively (Figure 3.3). Cattle was the type of livestock most attacked, followed by goats (Figure 3.3). Furthermore, most cattle were attacked by jaguars, while jaguars and pumas attacked an equal amount of goats and coyotes only attacked goats. (Figure 3.5)

Most attacks occurred at night (P < 0.0001, *n* = 100) and during the wet season (P = 0.0004, *n* = 99). Attacks were correlated to monthly rainfall ($r_s$ = 0.590; P = 0.044) (Figure 3.4) but not to yearly rainfall ($r_s$= -0.30; P = 0.624) (Figure 3.5).

For cattle, most attacks occurred at night (P < 0.0001, *n* = 55) and during the rainy season (P = 0.0003, *n* = 57). Attacks were not correlated to average monthly rainfall ($r_s$ =0.527, P = 0.079,) nor to average annual rainfall ($r_s$ = 0.10, P = 0.873). Attacks were negatively correlated to weight classes ($r_s$ = -0.815, P = 0.0074, 135.06 ± 11.5 kg, range = 11.4 – 431.82 kg., *n* = 56) but not to age ($r_s$ = 0.114, P = 0.698, 6.59 ± 0.597 months, range = 0.067 (1 day) – 12 months, *n* = 46) (Figures 3.6 and 3.7, respectively). Most attacks were concentrated on cattle between the weights of 11.36 and 227.27 kg, with a high number of attacks occurring on cattle in the weight classes of 11.36 to 50 kg and 151 to 200 kg (28.57% and 23.21% respectively). The age class most killed was 9 to 10 months (45.65%), followed by 1 day to 4 months old (30.43%), and finally 5 to 8 months (19.57%). Sex of cattle attacked was significant for males ($P = 0.0009$, $n = 44$).

The total economical loss due to livestock depredation by large carnivores during the study period was estimated at $17,401, with an annual average estimated loss of $3,480 ± $1,526. Whereas for cattle, total reported loss was $14,736, while annual average loss was $2,947 ± $1,491. A total of 0.70% of all cattle reported in the study site was lost to carnivores in the five year span of the study.

**Determinants of Human-Carnivore Conflicts**

I used 44 ranches in the final analyses of suitable models due to incomplete data for livestock husbandry practices. Eighteen of these 44 ranches analyzed had reports of attacks.

The only supported model was made up of landscape variables; the Akaike weight ($w_i = 0.997$, Table 3.4) for this model was almost complete; furthermore, the model fit was accepted ($P = 0.9484$). This suggests that landscape variables (amount of forest cover around ranch, distance to forest cover, and distance to rivers) are the only predictors of depredation incidents, whereas ranch characteristics and livestock husbandry practices are not useful for predicting occurrence of human-carnivore conflicts in the study area.

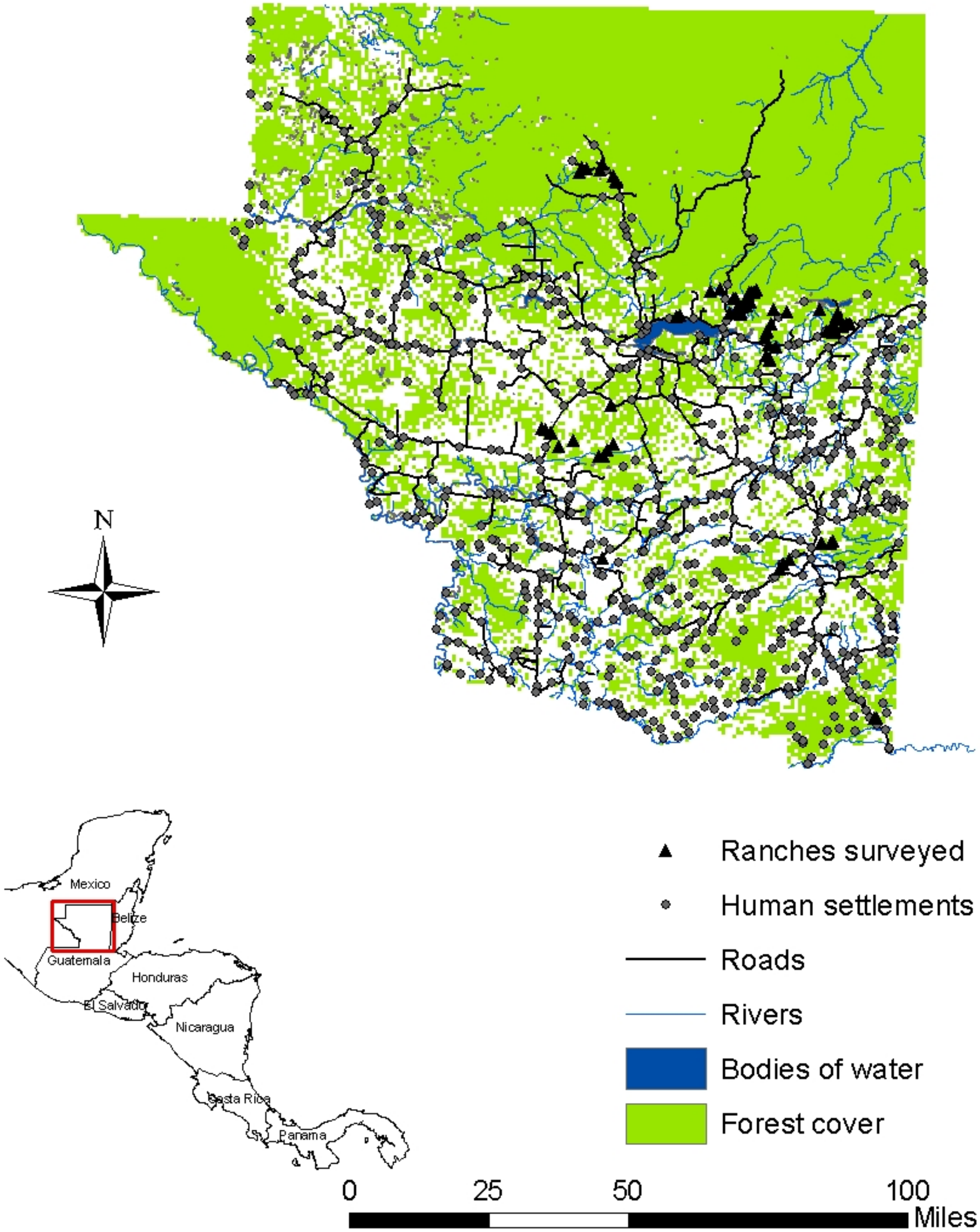


Figure 3-1. Map of study area showing ranches surveyed and landscape metrics measured in the Peten District, Guatemala, 2007.

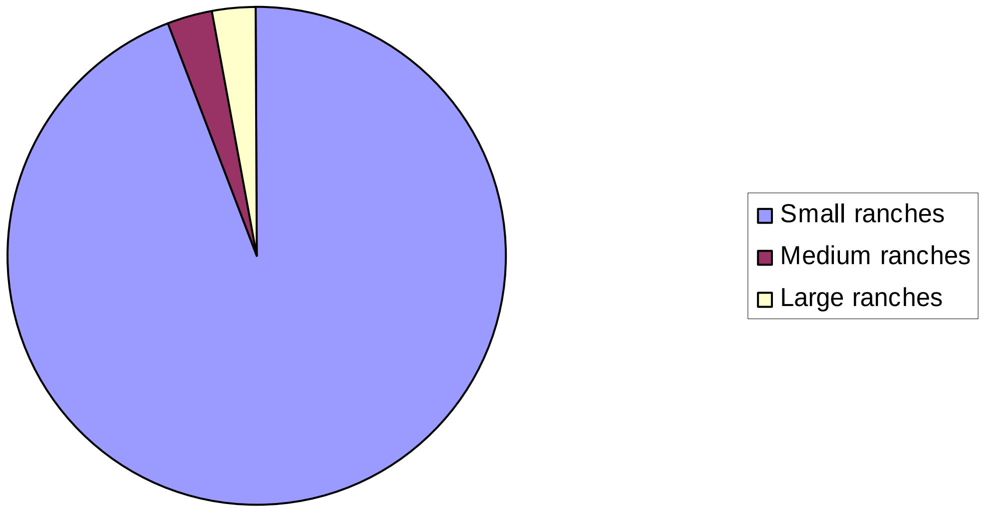


Figure 3-2. Sizes of cattle ranches surveyed in Peten, Guatemala, 2007. Where small ranches: 11.2 to 500 ha; medium ranches: 500 to 1,000 ha; and large ranches: >1,000 ha. Sizes were obtained directly from ranch owner or administrator.

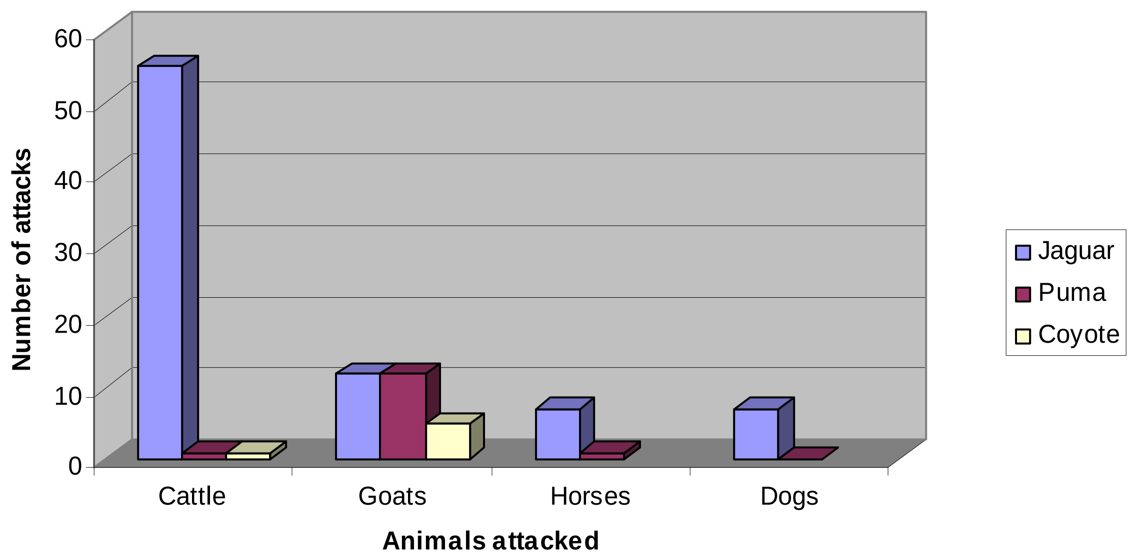


Figure 3-3. Livestock depredation incidents by jaguars, pumas and coyotes in Peten, Guatemala from 2003 to 2007.

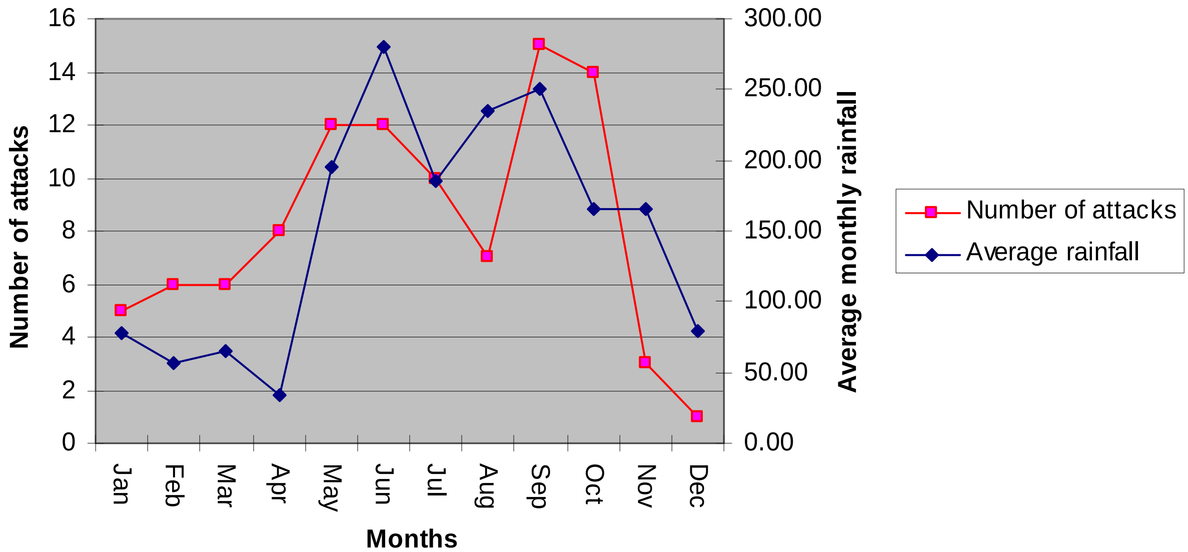


Figure 3-4. Livestock depredation incidents by carnivores per month and monthly rainfall (mm). Rainfall data obtained from CEMEC in the Peten District, Guatemala, 2003 - 2007.

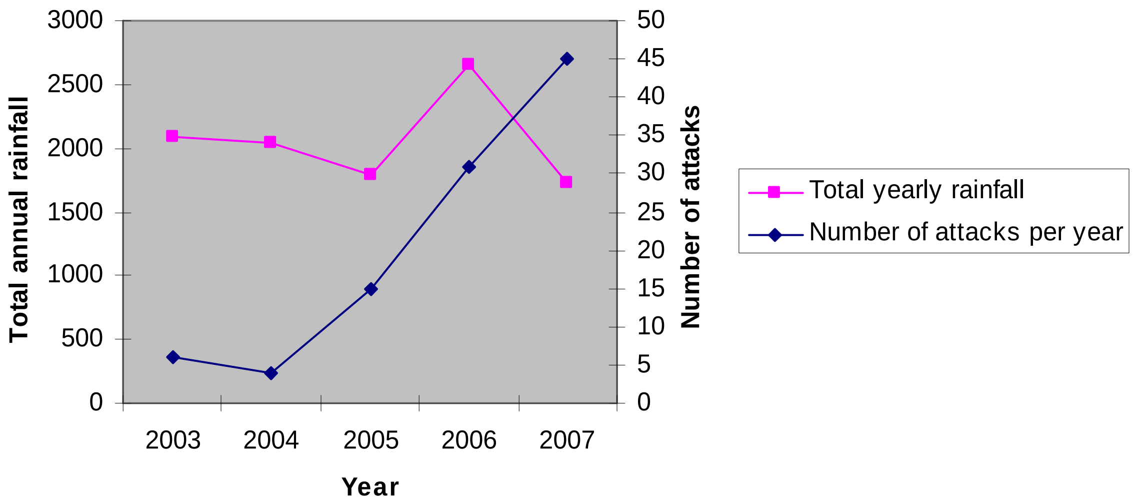


Figure 3-5. Livestock depredation incidents by carnivores per year and total annual rainfall (mm) in the Peten District, Guatemala from 2003 to 2007. Rainfall data obtained from CEMEC.

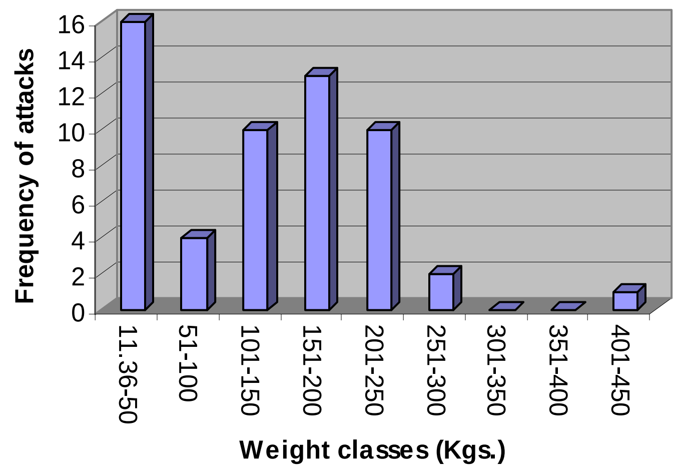


Figure 3-6. Cattle depredation incidents by weight classes of animals attacked in the Peten District, Guatemala from 2003 to 2007.

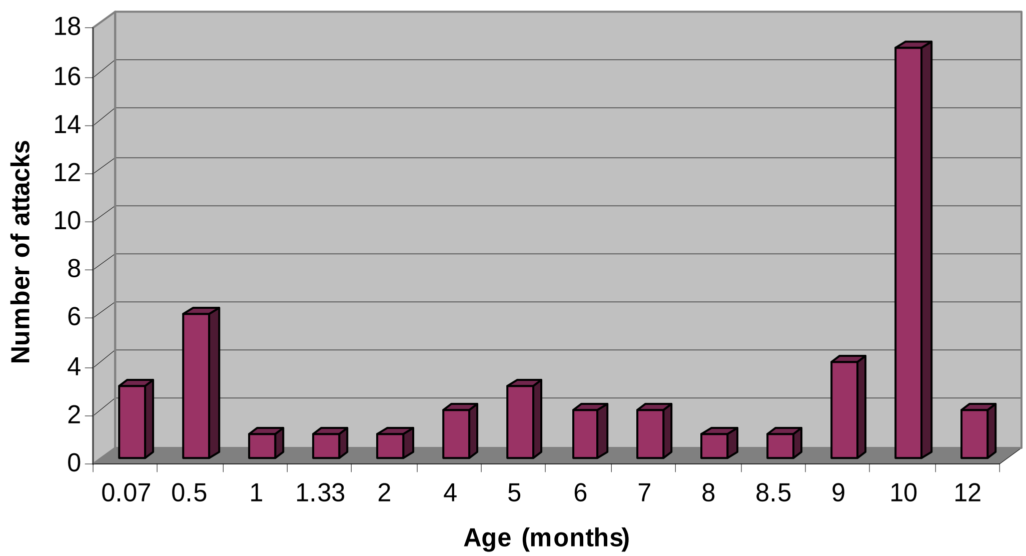


Figure 3-7. Cattle depredation incidents according to age (months) of animals attacked in the Peten District, Guatemala from 2003-2007.

Table 3-4. Comparison of five candidate models in the Peten District, Guatemala, 2007.

| Model | K | Hosmer-Lemoshow model fit | $QAIC_c$ | $\Delta_i$ | $w_i$ |
|---|---|---|---|---|---|
| 5 | 6 | 0.9484 | 73.62 | 0 | 0.997 |
| 1 | 11 | 0.836 | 85.22 | 11.59 | 0.003 |
| 4 | 6 | 0.9074 | 104.07 | 30.44 | $2.5 \times 10^{-7}$ |
| 2 | 8 | 0.7362 | 111.24 | 37.62 | $6.7 \times 10^{-9}$ |
| 3 | 5 | 1 | 111.89 | 38.26 | $4.9 \times 10^{-9}$ |

K = number of parameters in model (includes an intercept term = $\beta_0$, and the variance term = $\sigma^2$). The P value for the Hosmer-Lemoshow Goodness-of-Fit Test is evaluated at $P < 0.05$. $QAIC_c$ = the AIC estimate corrected for small sample size and over dispersion. $\Delta_i$= the difference for the $QAIC_c$ values for the most supported model and the given model. $w_i$ = Akaike weight for each model. Refer to Table 2-4 for model descriptions.

CHAPTER 4
DISCUSSION

## Patterns of Livestock Depredation

As in most other areas, cattle loss due to carnivores was small (0.7% of all cattle reported in ranches), and may be negligible compared to losses due to other causes (Hoogesteijn et al., 1993; Mazolli et al., 2002; Polisar et al., 2003; Michalski et al., 2006; Cascelli and Murray, 2007; Cascelli, 2008; Palmeira et al., 2008). Nevertheless, when a cattle rancher owns a small number of head of cattle or other livestock, any loss is significant (Saenz and Carrillo, 2002), forcing the ranchers to take retaliation measures and exacerbating a negative attitude towards carnivores. Therefore, even though the overall effect of carnivores on livestock appears minimal, it should be considered a problem that can lead to negative impacts on both local people and carnivore populations in areas with small cattle ranches, such as the Peten District.

The jaguar was blamed for a high percentage of the attacks in this study (78.85%), followed by the puma and coyote; nevertheless, this should be interpreted with caution, because culprit of attack was not systematically identified in most cases and local knowledge and perception of these carnivores may have influenced these results. Although coyote presence has not been verified in the area, there are anecdotal accounts of its expansion into Peten, which may imply an increase in conflicts with this carnivore. Furthermore, attacks could also be the act of feral or domestic dogs (Sillero and Laurenson, 2001). Consequently, it is important to educate ranchers in predator damage identification and to establish unequivocally which carnivore species are truly responsible for the attacks in order to propose species-specific mitigation strategies and understand the true impact of jaguars on livestock.

Cattle were reported as the type of livestock most attacked, although goat farming is only now becoming popular in the area (pers. obs.) and a small number of ranches owned goats (n =

5), in contrast to cattle being present in all the ranches; therefore, patterns of type of livestock attacked may reflect availability. Mazolli et al. (2002) found a higher rate of depredation on goats and sheep than on cattle by pumas. Goats are an easy prey item that may provide suitable energy intake for carnivores, at least for pumas, as they have been known to take smaller prey than jaguars (Scognamillo et al., 2003; Palmeira et al., 2008; Cascelli, 2008). The coyote is also known for taking smaller livestock such as sheep and goats (Knowlton et al., 1999). As a result, where goats are present and not adequately protected, they may be targeted by carnivores more frequently, hence an increase in goat farming in the region may lead to an increase in HCC's.

All carnivore attacks on cattle were concentrated on animals that weighed between 11.4 to 431.82 kg., although 94.64% of all attacks occurred on cattle that weighed between 11.4 and 227 kg. Cattle attacked were between the ages of 2 days to 1 year old, with a peak at 10 months old (37% for this age class). These results are consistent with studies that have found higher depredation rates on younger age classes of cattle and smaller livestock (Hoogesteijn et al., 1993; Polisar et al., 2003; Michalski et al., 2006; Palmeira et al., 2008). For example, Palmeira et al. (2008) found higher depredation rates on newborn cattle and very few attacks on cattle older than 8 months old. Similarly, Michalski et al. (2006) found a higher percentage of attacks on cattle between 0 to 5 months old. Nevertheless, both studies report a small number of attacks on cattle older than 12 months, whereas, the highest age class attacked I report is 12 months (only two attacks on this age class). Jaguars and pumas may take larger cattle in these study sites, because these felids have been found to be larger in South America (McNab, 1971; Iriarte et al., 1990) than in Central America. These results imply that some livestock depredation patterns will vary according to site. Nevertheless, these results should also be interpreted with caution because ranchers do not keep records of mortality incidents and the weights and ages reported depend on ranchers' memory and estimates. This may explain the discrepancy between the analyses of weight and age classes attacked (a negative correlation between weight classes and number of attacks and no correlation between age classes and number of attacks).

Furthermore, I also detected a significantly higher number of attacks on male calves. Palmeira et al. (2008) also found this pattern and consider this a possible effect of the male calves being more independent from their mothers.

With regards to temporal patterns of attacks, most attacks in my study site occurred at night and during the rainy season. Researchers speculate that attacks may be higher during wetter months because weather conditions are adverse for human activity (Mazolli et al., 2002), limiting the amount of time humans are present near their cattle. Furthermore, carnivores may be harder to detect during high rainfall periods by both humans and livestock. In addition, jaguars and pumas have been found to be more active during wetter months when temperatures are lower and prey are not concentrated around permanent water sources (Scognamillo et al., 2003). Consequently, the increase in depredation incidents during the rainy season may be due to higher activity patterns of carnivores, a more dispersed distribution of prey and lower detection probabilities of carnivores by humans and livestock.

An increase in livestock depredation incidents during wetter months has been reported in other studies (Saenz and Carrillo, 2002; Mazolli et al., 2002). Palmeira et al. (2008) also found a higher depredation rate during the wetter months, yet they relate this to the majority of calf births occurring during this period. Michalski et al. (2006) found the opposite, an increase in attacks during drier months, mostly related to calving months. Other studies have also found a correlation between depredation and calving peaks (Sognamillo et al., 2003; Polisar et al., 2003). Since most ranches in our study site do not regulate birth seasons, making calves available almost all year round for carnivores, it is not likely that attack peaks are related to calving season, suggesting that they may be more related to weather conditions and seasonal differences in carnivore ecology. Nevertheless, birth rates should be monitored in conjunction with livestock depredation, as well as seasonal variations in carnivore ecology, and calf and prey abundance and distribution to determine which factors may contribute more to the observed pattern of more attacks during the wetter months.

## Determinants of Human-Carnivore Conflicts

Results from this study indicate that landscape variables were the only predictors of livestock depredation incidents and I did not detect an influence of ranch characteristics and livestock husbandry practices on HCC's. The landscape variables measured that had an effect on occurrence of depredation incidents were amount of forest cover surrounding each ranch, and distance to forest cover and rivers. As a result, these variables could be used to construct predictive models to identify sites and ranches most prone to depredation incidents.

These findings are consistent with other studies (Michalski et al., 2006; Cascelli and Murray, 2007; Palmeira et al., 2008) that have also identified landscape variables such as proximity to forests and water sources and forest area surrounding ranches as major predictors for conflicts with carnivores. These variables were found to be important predictors because they also describe prime carnivore habitat and sites where there is a high probability of carnivore presence.

Although my study found that livestock husbandry practices do not predict occurrence of HCC´s, they should not be discarded as important determinants of livestock depredation by carnivores. Low variance and under dispersion of ranch variables indicated that most ranches were similar and applied the same husbandry practices. Consequently, these variables were not important predictors of livestock depredation, not because they do not influence HCC´s, but because low variability influenced the outcome of the statistical analyses. These results imply that small ranches that apply the same management regimes to their livestock, which may predispose livestock to depredation by carnivores, predominate in the areas surveyed.

More important is the conclusion that most ranches did not implement practices recommended by researchers to prevent carnivore attacks, although livestock depredation has been recorded. This may occur because ranchers do not have the knowledge or capacity to modify their practices, or because of a negative attitude towards carnivores and conservation. Several authors report that local people are reluctant to modify their husbandry practices to prevent livestock depredation (Oli et al., 1994; Weber and Rabinowitz, 1996; Mazolli et al., 2002). Additionally, livestock depredation is not a regularly recurring problem, which does not warrant a significant investment to modify their traditional practices. Consequently, eliminating the animal believed responsible for the attacks may be a more effective and economic measure in the rancher's opinion.

Finally, I make the caveat that results of this study should be interpreted with caution due to the small sample size and the predominance of small cattle ranches in the study site. Nevertheless, my results coincide with observations from previous researchers (Quigley and Crawshaw, 1992; Hoogesteijn et al., 1993; Saenz and Carrillo, 2002; Polisar et al., 2003; Rabinowitz, 2005; Michalski et al., 2006) that state that most cattle ranches in the neotropics apply rudimentary livestock husbandry practices that predispose cattle to depredation by carnivores and that landscape variables such as proximity to forest cover are important factors for predicting occurrence of human-carnivore conflicts.

## Conservation and Management Implications

Examining livestock depredation patterns and the influence of landscape structure and livestock husbandry practices on HCC's will help us propose conflict mitigation strategies for the area. Determining livestock most vulnerable to carnivore attacks and seasonality of attacks, among other depredation patterns, will guide the implementation of conflict prevention measures. Furthermore, by understanding which factors predict occurrence of livestock depredation by carnivores, we can identify in which sites and ranches to concentrate conflict mitigation strategies.

HCC's in the neotropics have been intensively studied in South America and mostly limited to conflicts with jaguars and pumas. Few studies that examine spatial and temporal patterns of HCC's in Mesoamerica exist. Information for this area is needed because of socio economical and ecological differences with sites previously studied. As an example of this, values for ranch size and number of cattle per ranch in this study were much smaller than ranches studied in Brazil and Venezuela (Polisar et al., 2003; Michalski et al., 2006; Palmeira et al., 2008). As a result, livestock husbandry practices may vary, with some South American ranchers having the capacity to implement recommended practices such as artificial insemination to control birth periods (Palmeira et al., 2008) and introducing water buffaloes into their herds (Hoogesteijn and Hoogesteijn, 2007), whereas it is highly unlikely that in Central America this is the case.

This study gives us a first detailed insight into human-carnivore conflicts in Mesoamerica. Similarities and differences were found with studies from SA; the differences found imply that conflict-mitigation strategies recommended for sites previously studied need to be altered in order to be effective in Mesoamerica.

The trend of smaller ranches with low technical capacity was noted by Saenz and Carrillo (2002) for Costa Rica, so this should be considered an expected result. Therefore, large, well managed ranches are an exception for most parts of Central America. This suggests that the capacity of ranches to improve their operations and implement practices that will prevent livestock depredation is very limited and should be considered when proposing management modifications. Furthermore, I found that very few ranches implement practices that may prevent carnivore attacks. A considerable challenge will be to work with a large number of small cattle ranchers in each site, as opposed to working with a few, large ranches with better economic capacity.

My results indicate that human-carnivore conflict mitigation strategies should be implemented in ranches near forest cover and water sources. Livestock protection efforts in these ranches should concentrate on cattle younger than 1 year that weigh less than 431.82 kg., especially during the wetter months. This can be done through regulating birth seasons when possible and the practice of maternity pastures located at a distance from forest cover, near human presence and with better designed fences (Mazolli et al., 2002; Palmeira et al., 2008).

Finally, an important difference found between livestock depredation in Mesoamerica and South America is the possibility of conflicts with coyotes. Because the large forest tract of the Darien in Panama may be acting as a barrier for coyotes (Hidalgo-Mihart et al., 2004), this carnivore has not invaded South America, where most research on neotropical human-carnivore conflicts have been carried out. Most studies from South America deal with depredation caused by jaguars and pumas and not with coyotes. Therefore, the presence of conflicts with jaguars, pumas and coyotes occurs only in Mexico and Central America where the distributions of these three carnivores overlap. Coyotes are very intense livestock predators (Knowlton et al., 1999; Sillero-Zubiri and Laurenson, 2001) and the control and prevention of coyote depredation on livestock requires species-specific measures (Knowlton et al., 1999). These measures have not been included in researchers' recommendations to mitigate human-carnivore conflicts in the neotropics; therefore, it is crucial to find depredation control methods that would be effective for preventing livestock attacks by jaguars, pumas and coyotes.

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# BIOGRAPHICAL SKETCH

Jose was born in the small town of Chimaltenango, approximately 54 kms from Guatemala City. When he was 8 years old, he and his family moved to Boston, Massachusetts, where he lived and attended elementary school for 5 years. Shortly after graduating high school in Guatemala, he began to teach English, an occupation that he practiced for 15 years. Having been raised most of his life in the city; it was only during a trip to the ruins of Tikal in Peten that he realized how rich and abundant the natural resources of his country were. He was fascinated with the idea that he was walking through a jungle where such majestic animals as jaguars roamed. This trip was pivotal in his decision to pursue a degree in wildlife biology. The next year he enrolled in the San Carlos University of Guatemala, where he obtained his bachelor's degree in biology. This is where he met his beautiful wife, Nancy, with whom he has a wonderful boy named Danny. Jose began working in wildlife research projects with the Wildlife Conservation Society, Program for Guatemala in Peten in 2001. Since then he has worked in research and outreach projects involving endangered neotropical vertebrates. The focus of his work has been on jaguars and subsistence hunting species, examining the effects of hunting on their abundance through line-transect sampling and camera trapping censuses and analyzing human-jaguar conflicts. Jose plans to follow on with his doctoral degree in the Wildlife Ecology Department, and study neotropical carnivore ecology in Guatemala in more detail, and in the future he plans to return to his home country to apply and share the knowledge and experience he has obtained throughout his graduate studies with the local conservation community.